**ECG-X: Clinical Stakeholder Interview Study**

**TRANSCRIPTS** (Clean, verbatim)

**P01 and P03**

**Interviewer**

Start with the recording now. First question is What's your specialty? And how often do you interpret ECGs? And your daily clinical practice?

**P01**

Currently? Yeah, so I'm an anaesthetic Research Fellow. So at the moment interpretation of ECGs on high care unit is probably once a fortnight... couple of times? Yeah.

**P03**

So I'm a trainee in intensive care and acute medicine. So I look at ECGs a few times a day, probably.

**Interviewer**

Probably the next question can be split up into two pathways, one your subjective pathway the other way, what you've heard from your colleagues, or what's generally known to be tricky in your field? What are the hardest pathologies to spot on an ECG for you? Or what are the ones that tend to get missed the most?

**P01**

The ones I would probably miss the most are more... I'm not very good at these bigeminy or fancy... yeah, things like that. Especially you might miss subtle changes. Could miss a delta wave potentially with... yeah.

**P03**

I think, obviously, ischemic changes are usually, like, fairly hard to miss... but in retrospect, I think sometimes when you look at ECGs, when people have had troponin rises, there were subtle changes there, which on a cursory glance you didn't see initially. So... I think, yeah, like unusual rhythms. And then there's all the scary stuff that you don't see very often that you can miss: things like Brugada syndrome, or Wellens syndrome, or pre-excitation. Yeah, I think that's the stuff that's harder. Yeah.

**Interviewer**

Thank you. When you interpret these searches, what approach do you take? Do you think it's more like a pattern recognition approach, or very mathematical way of getting your rollout and calendar squares? Or do you use automated readouts?

**P01**

I don't use automated readouts. I think I would try to have a methodical approach and go through systematically, but I think on first glance, you have sort of a first glance bias... and I sort of look at it globally, and then if I'm finding it more difficult to interpret, if there's nothing obvious, I will go back to my, you know, "is this is irregular, is it irregular? What's the rate?" and go that way. I don't get a ruler out. I don't count squares.

**P03**

I think I'm very much the same, yeah, like: initial glance, does anything particularly unusual? And then if it's regular, and it looks normal, then I'll usually scan through the ST segments for each lead, just to reassure me, there's nothing ischemic going on. And unless... yeah, I think P01 said as well, if there's something atypical, I'll then slow down and literally go through everything a bit more methodically. I always have a good look at the QTC interval.

**Interviewer**

And when you think of the bigger remit of ECGs, how we put the electrodes on the patient and how the data is recorded and stored and how it's visualised. What do you think are the current shortfalls of ECGs? And how we use them?

**P01**

First of all, there's probably a shortfall in ability to place them correctly, the ECG leads. Some are very good at it, some aren't. Also, there's, I suppose contact issues with ECG leads, depending on whether the patient is sweaty, whether they're hairy... are you able to get them in position to do it... Other things, I think... I think there's a lot of actual lack of confidence in interpreting ECGs. Yeah, they're still something I find quite scary, to be honest, because it's just, I suppose, unfamiliarity -- especially for me, because I don't look at them as often. So yeah, I would say: practical elements, in terms of actual placement of electrodes, ability for them to stick, and pick up things correctly, getting good stable rhythm readout, your patients move... And then the other one is actual interpretation -- probably medical confidence behind that.

**Interviewer**

Cool. Thank you, P03?

**P03**

I think the same to be honest. Nothing more to add really.

**Interviewer**

Are there any features that worked particularly well?

**P01**

On an ECG readout?

**Interviewer**

I'll generally think of Hive now or how they're presented to you.

**P01**

They're on Hive now aren't they?

**Interviewer**

Yeah, it's that it's a good change compared to the paper strips too. Is that a good thing or doesn't really matter,

**P01**

I suppose it's a good thing that they're integrated because you can access older ones much more easily. And also, they don't get lost, you know, having lots of sheets of paper just with a random patient name... on the subject, obviously, patient confidentiality issues as well. So from data sharing and privacy, it's definitely better. I am quite old school; I do like to have a piece of paper in front of me, so I prefer to read things off a document rather than on a screen.

**P03**

Yeah, I think electronic health system is very helpful. Yeah, with it being on hive. Sometimes you still get an issue where the nurses have taken a photo of an ECG and put it in the media section, rather than the ECG machine actually loading in itself, which just creates a bit of confusion, as you can miss an ECG that's happened. But I particularly like on hive, how, again, using the automatic readout, which isn't always accurate, but it does interpret your current ECG in the context of the previous ones -- so, say "compared to an ECG on this day, at this time, there are no new changes" -- or, you know "resolving T wave inversion" or whatever. So I think that's pretty good. I've not found a way of bringing up two ECGs on Hive at the same time, which drives you bonkers. And you get lots of -- particularly foundation doctors I notice -- will take a photo of ECG on their phone, and then look at their phone while they're looking at the other one. Yeah.

**Interviewer**

If I've opened imagine ECG theory, and you would have always just granted what will be your ECG of the future, what the, what she likes to see.

**P03**

In terms of actually like, putting a 12 lead ECG on, it'd be quite cool to have like a laser scanner, so they don't actually have to be applied. You know, so you've not got that contact problem. I know, it's all to do with electrical conductivity, but you are a fairy... so I'll have a laser scanner that basically puts 12 Dots, you know, all the leads, the nine leads on a patient. Yeah, not affected by artefacts. Yeah, and I suppose reliable, reliable interpretation of rhythms and ability to compare to previous -- but that would obviously have to have access to previous ECGs.

**Interviewer**

Brilliant.

**P03**

I think... I think that the automatic readouts, there must be scope for that to get better. With, like, AI and all the, you know, ability to now like, analyse 1000s and 1000s of ECGs, it must be better. And yeah, given how like, you know, so many people feel uncertain when they're looking at ECGs -- particularly junior doctors who probably see the most of them -- more accurate, automatic readouts would be useful.

**Interviewer**

I find it really interesting to ultimately readers, because when I look at them to prompt me to look for things there, and then you get really stressed anything like, what the hell's going on? Why did I not see what the machine sees?

**P03**

A lot of the time it says "abnormal ECG" and you're like... hmm.

**Interviewer**

They're overly sensitive.

**P01**

I think also, then, the only issue with improving automated readouts is that it will take away clinical decision making and that confidence that we potentially already lack, and need to improve through more experience of interpreting them, will be affected -- and probably even get worse.

**Interviewer**

Brilliant. So I'll show you what we're doing. Now with this project basically, because it was all very general what we are doing is we basically, colour ECGs Okay, so this would be a patient with a normal QTc, it's cool colours going from purple to lime green. So we're talking about 350 borderline is a patient, you see prolonged QTc and it goes from yellow into dark red, so really warm colours on another strip, I can just assume in version that looks like this, if we'll have a digital ECG, it starts off with the cool colours and then if the QTc prolonged it just goes into warm colours and without Qt greater fits exactly. So, the more prolonged the QTc, the more red the colours go. Basically, this is preclinical trial stage. Now, this is very new, this is prototyping for STEMIs. So opposite of hyperacute T waves but then it's actually ST elevation going on as well. So that will be just coloured in red because for STEMI we don't use cold or warm colours for that. But the gist of all these things is we try to visualise certain conditions with colour on ECGs okay. So when you look at them on high for example, and you look for LQTS. You will see that the patient ones in red are example That's basically what we're working on. So do you think generally the digital technology can enhance ECGs?

**P01**

Yes, definitely. Absolutely.

**Interviewer**

And when you look at the approaches that I've shown you, this is obviously highlighting specific conditions. So we've got STEMI, we've got our QTc, the other option will be highlighting any abnormalities as in saying something doesn't look right. In regards to that patient demographic? Have a look, we call it that for you. Would you want a condition based approach? Or would you want just any pathologies highlighted in a nice thick sheet that might be not always that patient?

**P01**

It's a difficult one, because I think if... if my gut says specific pathologies... because we've had the problem where it says "abnormal ECG", and you're like, hold on, what am I not seeing here? And that could cause a lot more over investigating of patients if they're all coming up with some form of colour. However, if it's not a particular condition, will it get missed? So, yeah, I'm stuck on that one. I probably say more towards the conditions, but full well knowing that there are some that are still going to be missed.

**Interviewer**

Thank you

**P03**

I would say like, probably the thing that would help patients the most, that will stop things being missed, is spotting the ST elevation and the QT -- so those specific, high risk problems, I think might make the greatest difference. Although, could you not do both and have, like, a button to change the filter on the ECG screen?

**Interviewer**

Yeah. But obviously, the things is. The backbone of this question is the clinical decision making process if you give away clinical decision making, from the doctor in terms of saying, Oh, this is a condition that I've diagnosed now for you, as opposed to, I spotted an abnormality, but you are the one who tells me what the condition is. So that's doing this thing. But obviously, you can change the filter on the button, and then you can do whatever you want. Really, there was

**P03**

I'd probably say spot the abnormality, then, I guess, to highlight people towards a potential condition...

**Interviewer**

The other option will be probably for junior doctors, it will be very helpful if they can click on it, and then they see something highlighted. And then they know that that's what a standard looks like, basically. So yeah, I think what what you said both will be good with different use cases.

**P01**

Yeah, absolutely. Because there's things you don't want to miss -- those big things. But then also, I'd like to think that on the things you don't want to miss, they, they're kind of a bit more obvious. But yeah, in terms of protecting clinical acumen and knowledge, and competency, it's going to have to be a more broader abnormality that you then go and diagnose.

**P03**

Thinking about, like, when I'm the medical reg, the questions I often get asked about for ECGs is like, "what do you think about the ST segments here?" "Do you think they're up or down?" "Or do you think they're okay?" And yeah, that's so... another, even you know, even for me, like, you know, providing advice to someone else, like, having another bit of reassurance that this is probably okay, would be useful in future.

**Interviewer**

Obviously, what we will run another study soon with the STEMI work, and we decided in the end to cluster them into easy, medium and hard to spot STEMIs because they're also subtle differences in leads where it'd be like, that's actually there's an ischemia going on. And then obviously, I would bang on big ones. So it'd be like, yeah, off you go. But yeah, I think it's just another visual aids basically, to confirm a diagnosis. When you compare the colouring approach to the current approach. This is like threshold calculations into automated readers. Well, how did you compare for you?

**P01**

Yeah, I like colour. I'm quite a visual learner. My only devil's advocate like thing would be: what if somebody's, like, green colourblind?

**Interviewer**

Yeah, we've got this. Okay. So very good, because you're the first one, actually interviews that mentioned. Which is great. And reverse. A lot of people with dyslexia, they often say they struggle with reading ECGs, or colour for them will be really helpful as well. And I didn't think of that, but it's true because the leads are not displayed. Anatomically on days, you basically need to map to leads to the heart, but you need to turn them around to actually get everything right. So I've talked to someone who's dyslexic and he was like, really, really struggled especially he's an he's an emergency physician. He said, in high pressure situation. I really, really struggled to get invited by the East Kenya is actually under the need to think of the house and this is really helpful because it's just I see it there. Obviously, it's all computerised. Do you think it's important to have explainable algorithms. So we know exactly from the patient data going in to the output of the computer what's going on based on the rules? Or do you think it could be something like deep learning of blackbox algorithms where we don't really know what the algorithms doing, but the output can be quite accurate? What's your take on that?

**P01**

I'd like to know. So I would want to know what's going on to be able to trust it.

**P03**

I think in this situation, though, the automatic readout at the top is a black box already -- because you've got no idea why it's come up with the conclusion that it has. So actually you almost think the colour... you know, the fact that part of it is highlighted, shows to me that the system or the black box has spotted that bit and can colour it in, and therefore that automatically adds weight to whatever conclusion it draws. So I personally, I don't think I'd be too bothered, I think it'd be quite interesting.

**Interviewer**

Cool. Brilliant. That was it, basically. Have you got any questions for me before I turn off the recording?

**P01**

So what are you what are you doing now with that? I'm just interested.

**Interviewer**

What we do now is the stakeholder engagement basically. So this is for the LQTS work, we've just received a Wellcome Trust grant to get this into clinical translated but for 12 lead ECGs. The STEMI work is just really young at the moment and the stakeholder engagement we'll be doing is basically now informing the system development, if conditions think that colour is generally useful, if we should focus on conditions that we should call first, if we should focus on abnormalities in general that are coloured are the algorithms that we're using for that Explainable AI? They just deep learning approaches that we should use?

**P02**

**Interviewer**

The first question is just about how often do you interpret ECGs in your daily clinical practice? And what is your specialty that you're trained in?

**P02**

Daily. I use ECGs on a daily basis. I am trained in anaesthetics and Intensive Care Medicine.

**Interviewer**

Okay, brilliant. And the next question can be split up into Pathways, one, your subjective one and the other one about more from your colleagues about generally known in your field to be tricky, which are the hardest pathologies to spot on an ECG, or which are the ones that tend to get missed.

**P02**

I think the ones that are a bit tricky to identify are like the more specialised ones, like Wolff-Parkinson-White syndrome, or the AVNRTs, or the AVRTs which are like really, really specific ones. But other than that, I think the basic ECGs everyone should be able to

**Interviewer**

And when you interpret an ECG, what approaches do you take is that more like a pattern recognition approach is very mathematical? Do you use automated readouts?

**P02**

So I think this is based on experience. But ideally, ideally, we should have a pattern. But sometimes, you know, there are a few ECG patterns, like really clear, and you could see at a look "okay, this is what is wrong". But ideally, I think, even for the beginners, or anybody for that matter, they should have an approach. And my approach usually is like, I just start with the rate, the rhythm, is it a sinus or it is not sinus? And then what is the QRS complex? Is there a T wave or not? So like there is a pattern to what I read about.

**Interviewer**

And when you think not just about interpretation, but more how we put electrodes on the patient, how it's presented on the monitor, or in the systems that we use to present ECGs? What do you think are the current shortfalls of ECGs?

**P02**

I think the current shortfall, I think the one that really comes to my mind is it's a bit difficult to identify the post the right ventricular MIs, which are not directly recognisable on the standard ECG pattern. So if you want to see the right sided MIs, then you have to really reverse all the ECG pads, er, leads to see. So I think that is one shortcoming. And I don't know how to improve upon that. But if there comes a technology, that will be really helpful.

**Interviewer**

Okay, and what do you think works particularly well?

**P02**

Particularly well. I think ECG is a really, really important tool, they tell us so many things about the cardiovascular system. So the best thing that I like about them is that it's a very comprehensive and a very simple tool. If you can read ECG, so it really helps.

**Interviewer**

Okay, brilliant. Thank you. And if there could be anything that could be changed in the future, what will be desirable that it will be added to an ECG of how would you envision the ECG have a future?

**P02**

For me, I think what I would want is because I'm always involved in theatres and ICU, the wirings that the cables that these ECG machines have, I particularly feel that they are a hazard, they can pull you over or they can pull something out. So I would want this to have some sort of like an infrared or a Bluetooth technology, where there are no wires involved, that just leads and I could directly see the image and that is what I would want in future. Okay,

**Interviewer**

Brilliant. So I show you what we are working on at the moment, I share my screen with you for that. You should see an ECG now. Yeah, brilliant. So you can see I can make it a bit bigger, I think you can get a more view over here. So on the upper ECG strip, you can see a patient with a normal QT interval. And you can see that the colours go from like a purple to a lime green, which would mean the Qt sees about 350 at the moment. And at the bottom strip, we have a patient with our Qt s. And you can see that they've got a prolonged QT interval therefore, and it's yellow going into deep breaths. So we talked about about 530 to 550, probably on digital strip just looks something like this, I can zoom in here. So you can see that it starts off with cool colours going from purple over to greens, yellows, and then this patient would have a prolonged QT interval and they would go into the red sphere. Other thing that we are working on is STEMI. So you can see that the ST elevation is here coloured in although we have a hyper acuity wave, we can still see that there's ongoing STEMI as well. And what we basically do is we use colour to highlight certain features on on an ECG. So do you genuinely think that digital technology can enhance how we interpret ECGs.

**P02**

Oh, yes, I definitely think it would, definitely. The only issue with this, what I can think of is that we need to bring the physicians on a common platform to say, Okay, fine. If you are seeing this "Yes, it is this". Sometimes like they are, maybe we should leave a little bit of scope for disagreement. Like, for example, if the machine is saying that say this is STEMI, but the cardiologist doesn't agree to it. So maybe we should allow that a little bit of scope to play around with.

**Interviewer**

Brilliant, and there are obviously two ways we can make this happen. So one way is that I've shown you now that we use specific conditions like our Qt s or STEMI, and colour that in the other approach will be that we just visualise and use colour for any pathologies, according to the patient demographic, would you prefer to have a condition based approach but it visualises certain conditions of what you prefer that generally everything that looks or seems to be abnormal on the ECG is coloured?

**P02**

I think the second one [abnormalities], like whatever looks abnormal should be coloured. And then leave it open to interpretation of the reading physician. So like, the machine will tell you okay, fine, this is what I think. But then you decide what you want to do?

**Interviewer**

And do you think that colouring is a specifically helpful technique? Or do you? Or can you think of any other techniques apart from colour?

**P02**

No, I think colouring should be helpful colouring is good, because it gives you a visual clue of what it is. So I think that's fine.

**Interviewer**

And how does the colouring technique compared to other current methods such as automated readouts and threshold calculations?

**P02**

I think automated readouts at least that is what I do, I just don't care what is there on automated readouts, because I just have to see what it is. But if there is a visual aid to it, it will just clear automatic point me directly onto that direction. So at least even if I am trying to ignore it, I will know that okay, the machine is saying something there. So yeah, I think the visual aid of the colouring method is really good. It will help me definitely.

**Interviewer**

Okay, brilliant. And we have got a bit of an analogy, how do you think the ECG is compared to X rays or other medical imaging when you look at it, because obviously, with medical image views, you can zoom in, you can zoom out, you can change, you can turn them around, you can adjust the brightness, do you think that will be something that's been helpful for ECGs? If we have more something that's comparable to a modern image viewer?

**P02**

Yes, that will help at least like, so what I can think of is we can do these sorts of tweaks on the monitors when like, like, if they are continuous ECG monitoring, you can, you can probably like, increase the size or decrease the size and do that sort of stuff. But maybe if we can do that on a single strip where it's like a static image, then that will be helpful. Because you know, the one the one of printers that you get, they don't give you the option to change anything. But if we could incorporate this technology, even to the single print out one, and maybe a little bit helpful.

**Interviewer**

thank you. And obviously, we've got algorithms or a computer doing all these things to you, as a clinician preferred, the algorithms are completely explainable. So you know, when you put the electrodes on the patient, and the signals go into the machine, the algorithm does something that we can perfectly explain because it's rule based. And we know how it comes to the output to, for example, colour that this is a STEMI or LQ. TS, or do you say you've definitely heard of like blackbox algorithms and deep learning, where we don't really know what the machines doing the contours, our output, but the outputs can still be rather accurate. So do they have to be explainable for you? Or do you say, as long as it's accurate doesn't matter?

**P02**

It’s, this is a very difficult question, because I know of tech, I know a few monitors whose technology is propriety so I think this is more of an economic question. Do the companies really want to divulge the information or not? But I think it would be good to know what the exact mechanism is so that we can find out what the what the machine is thinking. But I can totally understand it. The companies think of not divulging the information, because I know of a few technologists, which did not tell us what they're doing. Yeah.

**Interviewer**

And how do you see this from a patient perspective?

**P02**

From the patient's perspective, I think, I think, if I were a patient, and I would, I would definitely think is a good way forward because it is just helping the clinicians improve their technique and it's just going to improve my care. So as a patient, I'm all for it. I think this is a good step forwards.

**Interviewer**

Brilliant. That was basically the end of the interview. Have you got any questions for me?

**P02**

No, I think it's a really innovative way i can i can think I can really understand why where this is coming from and yeah, it's a very nice technology. Brilliant. I think I'll get To see some images in the future, maybe not too far. Yeah.

**Interviewer**

Thanks so much for your time, um, you get a 50 pound Amazon voucher. This will be sent out by finance in the next couple of weeks if that's okay for you. And we have the option for you to stay on as a critical friend, as we say. Would you be? Would you agree that we can contact you in the future again and show you what I've been working on?

**P02**

no problem.

**Interviewer**

Well, that was it from my side.

**P02**

If you need any help from me, or if you need any participation, from my end, I'm more than keen on jumping in helping maybe from an intensive care or an aesthetic point of view. If there's anything that I can contribute. I'll be very happy to do that.

**Interviewer**

Brilliant. That's so kind from you. Thank you. Well, it was lovely meeting you and have a lovely rest of the day. Thank you. Bye bye.

**P04**

**Interviewer**

So the first question will be, what's your clinical specialty? And how often do you read ECGs in your daily clinical practice?

**P04**

So every single patient I assess, at least through the monitor. So, ECG is something that I deal with constantly.

**Interviewer**

Brilliant, thank you. And the next question can be split up into two pathways. One is your subjective way of looking at things. The other one is what might be known in your field, or what your colleagues might say about this, which are the hardest pathologies to spot on ECG for you, or which are the ones that tend to get missed?

**P04**

It's a good question really erm, what tends to get missed?

Probably QT changes, I would say, It's not often, sometimes it takes a bit more effort to actually calculate. So we're always told not to trust the QTc that was calculated on the printed ECGs. So it's recommended to calculate them manually, it takes a bit more effort. And usually, you'd only do that if you saw that there was a QT change that you then sort of actually calculate what the QTc was. So probably QT changes, and then things like subtle electrolyte abnormality changes that you get. So, you know, the peaking of the T waves is a big one that I always had an issue with, I see a lot of my colleagues, a lot of junior colleagues will always be coming up to me saying, you know, the patient's got slightly high potassium, the T wave, does this count as tented T wave to diagnostically treat them with calcium gluconate, for example. So probably say QT changes and sort of those subtle abnormalities that you get with electrolytes, T wave changes, U waves, that sort of thing.

**Interviewer**

Ok thank you. And when you interpret an ECG, what kind of approach do you take? I mean, you've touched upon that you don't rely on threshold calculations that much. So is it more like a pattern recognition approach? So you're very mathematical, you're counting squares and get the ruler out or do you also use automated readouts?

**P04**

I ignore automated read-outs at this point, I've seen things in my career that are wildly inaccurate. So it's, it's a combination of a mathematical approach, and a pattern recognition. I generally will look sort of territorially across the ECG. So the ECG is obviously split into sort of your lateral leads, inferior, your anterior leads, etc. So I'll look through those territories and just look for sort of a pattern recognition type picture, is there anything I can see that’s markedly obvious, you know, huge ST elevation is going to be obvious, as soon as you look at the ECG, then I would sort of go back and sort of follow the mathematical approach to sort of going through it. So I would standard check, check all the details, it's correct for the patient, make sure it's the correct calibration. And then rate, rhythm, axis, P waves, PR, QRS, S T segment, T waves. I might have missed something in there. But maybe I don't know. Sort of all the methologies and durations doing that, I just do that very quickly for each lead, to make sure that I don't miss anything, any abnormalities. So it's the pattern recognition for what I'm expecting to see and then the mathematical approach to sort of pick up and make sure I don't miss anything.

**Interviewer**

Okay, brilliant. And if you think a bit further, not just about how we interpret ECGs, but just the full set or remit of ECGs, basically from putting electrodes on the patient, and how it's presented a monitor so even how we store it computationally, I don't know are you using Hive or have you got different electronic health record.

**P04**

So we've got one system that keeps our monitors all our monitoring so I'm sort of recording we can go back in time on the monitors and have a look at some files of ECGs, erm, they are printed currently and than scanned, some will be scanned on to Evolve. In what we currently, from what I understand we are, everything is pretty much everyone is towards an EPR. And I think EPIC is what we're ending up getting.

**Interviewer**

brilliant. Yeah, that's what we use at MFT as well. But our implementation of EPIC we call it Hive. So yeah, it's the same system basically. So yeah, if you think about the full remit of ECGs, what do you think are the current shortfalls of doing ECG?

**P04**

Minor shortfall inverts it sort of garbage in, garbage out. So you would look at who is doing the ECG to make sure to do the placement correctly, calibrate the machine correctly, label it correctly. So I found machines that have been calculating incorrectly, and sort of 50 millimetres per second and sort of everything looks a bit abnormal. And you have to actually make sure you've done those mathematical steps of checking your calibration. But that's a rarity. Really, most nurses now, you know, most machines come standard calibration, most nurses know how to do it. You know, if you're asking for more specialised things like you're asking for the posterior leads, then you're going to run into some technical difficulties, though, with staff not being familiar with those. So occasionally, I do ask for posterior leads. And those can come out 1000 different ways. And sometimes I have to physically go and do it myself. And then other than that, it's I think it's just primarily education for person interpreting it. You know, we obviously got a lot of time and effort into teaching juniors how to interpret ECGs something often I would discuss on the ward round. I've been teaching the Intensive Care registrars who are coming up to their reg exams, the final FFICM, and looking at sort of variability to interpret ECGs because it's part of their final exam. And it's quite surprising sometimes that people can get to such a high level and yet they got big weak spots in the ECG interpretation. You know, overlooking to interpret the obvious things like ST elevation MI, or people are a bit more, struggle a little bit more with things like the electrolyte abnormalities, like I was mentioning before, like, QTc analysis.

**Interviewer**

okay, brilliant, and what functionalities if there would be a magic ECG fairy, and you could wish for everything you'd want? And what would be a desirable addition? Or what will be a desirable future development of ECGs for you?

**P04**

Probably it’d be some form of checking sources for abnormalities of ECG as it comes out. Is this a sort of ECG, you would expect? Is there an abnormality that would, would make you think that this ECG has been calibrated in correct way or that the leads are in the wrong place or the system saying altogether that this ECGs is impossible because of lead placement, for example. And then better automated interpretation of those ECGs. So, you know, one thing that often seems to be wrong is the QTc, like I was saying, and you know, better discrimination by the software from wherever that point is, there's maximal descent of your T wave in order to calculate QTc accurately, is something that will be very simple, but it will save an awful lot of time and effort, if you could just trust the values on the page, what are the actual intervals and then because of the sort of qualitative analysis saying that this ECG shows evidence of anterior ST elevation MI and things like that, and for those who have been burdened with interpretations that are obviously incorrect, to the point where I generally haven't read those probably a few years now. And it may well be that these technologies gradually creeped up and it's much better now. But it's, it's one of those things that is a feature that has become slightly a controversial, I think because of those issues with the accuracy of it. So not just it being there, but being able to say the accuracy of these is at least on par with the professional exams.

**Interviewer**

Perfect, thank you. So I show you what we are working on at the moment. I'm gonna share my screen with you

Can you see that? Can you see that? Yeah. Okay. So at the top basically, and I mean, it's funny that you've talked a lot about QTc. It's, and it's good that you've mentioned it before me priming you to talk about that because that's exactly what we want basically. So at the top ECG strip, you'd see a patient with a normal QT interval. And you see that the colours go from a light and purple to like a lime green, and we would have about 350 milliseconds in this case, at the bottom strip, we've got a patient with prolonged QT interval. And you could see that the ECG is coloured in a more yellow to dark reds are warm colours. And we'll be talking about 550 probably. So this ECG is taken from a patient with Long QTS, and on electronically coloured in ECG strip that would look something like this. So you can see it starts off with cool colours and as soon as it realises that QTc is actually prolonged, it gets into warmer colours, which you can also see here in a slight dip zoomed in version. And what we're also working on apart from our QTc is the visualisation of STEMI. So you've talked about T waves and people not being so sure and to new doctors coming to you asking about T wave changes. So just looking at it, you might think oh hyperacute T wave, but there's actually ST elevation going on as well. So the colouring here would show you that there's an elevated ST segment in case of this patient. Bottom line, what we're doing, we using colour to visualise certain features on an ECG. In this case, our QTc and STEMI so the first question will be, do you think that digital technology can enhance the way we interpret ECGs?

**P04**

Do I think the digital technology can enhance? That's the question? Yes, certainly.

**Interviewer**

Okay

**P04**

Yeah, I mean, that being a digital recording or electrical mapping to the heart, it, it seems obvious to me that as technology advances that these will get more and more advanced, and the interpretation of them getting more and more advanced, you know, you're taking a digital input, and then recording it and getting humans to analyse it. So it's, it seems like that is the sorts of data that is obvious, that should be able to be taken by computers by AI and analysed sort of more efficiently, more accurately than necessarily some other sorts of data. You know, so I think, yeah, you know, digital technology should be ECGs are probably the easiest way in which to focus on.

**Interviewer**

I turn my volume down, because there's a bit of a delay, I think, obviously, there are two approaches. One is the condition-based approach that I've shown you. So we've got a condition like LQTS, or we've got a STEMI. And this condition then gets coloured in. The other approach will be just colouring in any pathology from an ECG, but then leaving it to the clinician to interpret what's going on. So what do you prefer, as I've shown you a condition based approach or do you prefer to have an algorithm just highlighting anything that might be abnormal with this ECG in regards to specific patient demographic?

So the first approach would be pretty much like we've got the analysis that the system would say, you know, Long QT, or ST elevation myocardial infarction.

**P04**

I don't know. I mean, and it's really difficult to work out between the two as well, because while this sort of technology is still advancing, while it doesn't have, you know, 100% accuracy, you obviously need whoever's interpreting it to be able to pick up those shortfalls. So, you know, the more you have a system that takes over for the clinician, the lazier the clinician becomes. So a system that is just going to give you the answer means that you stop practising interpretation yourself. Whereas if you just flag, there's an issue here and then you have to look at it and interpret that issue. That is sort of assisting the clinician rather than replacing. While that's good to make sure you maintain the competencies of your physicians, and clearly it's still required requires the clinician to be sufficient experienced with ECGs to interpret so it's, I can see it both ways, really, you know, so it's for me what I want the machine to do, you know, what I want is a printout that says what the pathology is, rather than seeing the full ECG, no, I would probably want the second thing really just flagged and then that would help me and work as a safety net for me to make sure I'm not missing things, or do I want the F1s on the ward to have full rein to misinterpret the ECG, probably not probably a bit more, sort of quant quantitative analysis and sort of diagnosis being given to them, is probably safer for patients, but worse for their development. So I'm not sure which way around personally I'd prefer because it's, you know, as you say, if you could, if you come out with 100%, and say, and say to me, this is 100% accurate, this will never fail, it will always pick up every single pathology, and the system will never fail, the software will never crash, doctors will never need to interpret ECGs again. I'd say yeah, fine takes workload of us, and we lose skills, but I mean, that's the nature of medicine, we always lose skills as technology develops. You know, we don't do [?] procedures anymore, we always use ultrasound. So the techniques of using one mark disappeared, that's not a bad thing. That's just the how it made things safer and better. So yes, it can be 100%, right from the start, and then that's probably safer. But there's going to be that intervening period where we're all still going to have to be able to do these things as well. Straight to that outcome, without having the process in the middle of it, like a second technique would have, I think it might be a little bit dangerous in the short term.

**Interviewer**

That’s really interesting. Thank you. Yeah, so it's a trade off between level of experience training and patient outcome isn't. So in terms of what we use, do you think colour is a specifically useful way of highlighting these pathologies and an ECG? Or can you think of anything else that might be useful to highlight it?

**P04**

It is useful certainly for things like QTc example with the intervals, that's really useful, because obviously, it starts colouring in from deviation from the baseline, and then the colour changes. So even if, for example, even if the software is to get slightly confused about where the T ended, and you had to do what we currently do, which is you know, shuffling straight along, get work out the points of maximum descent, and then call that the end of the QT interval. You can look at it and say, well, you know, regardless of where it is, that's going to be well into the red. So regardless of what the absolute value is, there is a long QT. So that's really valuable as a visualisation. The T wave, sort of the ST elevation I'm less certain on. Is the idea with that but it's colouring in the deviation from the baseline. ST segment has elevated Okay. Okay. So that's, I think that's probably a good, I currently off the top of my head, I can't think of a better way of doing it Yeah, I think it's the best way the QT is with that gradient showing you going from normal to abnormal I think, I don't think there's a better way of doing that. And I thought I think if I thought about it for long enough, I still couldn't come up with anything better. But then to me be an alternative for the things that I'm just it's just kind of coming to me it doesn't feel perfect whereas the gradient with the intervals feels perfect.

**Interview**

Brilliant. Thank you. And how do you see the visualisation in comparison to current methods such as automated readouts,

**P04**

Much easier. So you get your tech stuff with ECG, you know, ST elevation in V2,3,4 so it is, it is much easier to recognise as soon as you look at that, and you can say, "oh the QTc is wrong there", you don't have to actually read the report. As someone who continually ignores the report, I couldn't ignore that gradient change, even if I hadn't picked it up myself and be able to, to see it. My only concern would be that in that interim intervening period, where you still rely a little bit on the clinician to make an interpretation, that you're altering the ECG as such. There and obviously drawing attention, so if it was drawing attention to one thing, you'd be necessarily neglecting another area, or it might cull your own interpretation. So I would probably want see two versions of that sort of the unaltered, say, you know, you've also your source lead view, but I would probably want to see sort of a 24 lead version. Or if it was an electronic display, it will tick a box so it's on its default, or those interpretations and they found was like, Well, I'm not if I was to look at it and say, Well, I'm not super too sure about that ST segment, actually, I'm not sure the software's got it right as I'd like to be able to just click a tick box, which takes it all off, I can look at it again and say, Look at Yeah, I actually agree, and then turn it back on. So that you would be able to sort of go back to that classic view and make that interpretation for yourself. But as I said, if you if you could promise this from the start that it was 100% accurate, and there would never be an error is that the problem is gone away. But you certainly still have a good number of clinicians for quite a while grumbling about.

**Interviewer**

Brilliant, thank you. And obviously, all we talk about is driven by a computer that uses algorithms. So for you as a clinician, how important is it to have an explainable algorithm, as in, you know, exactly from when you put the electrodes on the patient, how the signals go into the machine, and then it comes to an output, for example, that the Qt is prolonged. And we can perfectly explain the rules in the algorithm that the computer users step by step how it made this decision, as opposed to having non explainable algorithms. And you've definitely heard about, like blackbox algorithms and deep learning, where you basically get highly accurate outputs, but we don't know really, how the computer made the decision. So how important is it for you to have the explained ability?

**P04**

I mean, as you say, it's a big, it's a big problem we are trying to work out. And there's been lots of issues in different industries, about the explainability of algorithms, you know, particularly sort of things like unexplainable [?] algorithms and different algorithms, you know, I was reading something about an algorithm that was inherently racist, even though it's been told it wasn't meant to be. And the way it was racist as it would names that were traditionally white, it would assign a higher point value to, you know, sorts of people and engaged in that were traditionally white for its for, again, treatment. So you know, that there is always concern about how the algorithm is learning those things. But you know, another example I'm aware of with these unexplainable algorithms, they end up doing something wrong, it's usually garbage in that's caused it. So it's a lack of thought on the floor of it, you know, there was a database of photons of skin biopsies that showed it was supposed to differentiate cancer and non cancerous lesions, and learned that tape measures were cancerous, because a majority of pictures that have cancers have a measuring for reference. And so the algorithm learned that if instead measure there is more likely to be cancerous, so that's where the algorithm did get it wrong. The algorithm learnt exactly what it needed to learn, but it was because someone hadn't put enough thought into: what's the only difference in these pictures and that some lesions were malignancies but, you know, there weren't any tape measures. So I think the algorithm itself doesn't have to be explainable to me if it's accurate, but it requires the people that are training them and sort of putting those inputs into the algorithms to be really careful in this sort of application. If training some sort of deep learning algorithm on ECGs, then the concern would be you know, people who've looked at those ECGs beforehand, as he's scanning them, have they made marks on them Some to you know show where the ST elevation is, you know, I know so many people who will circle an ECG, circle the abnormality. And again, that's going to you know, any marks you have on an ECG, any qualitative analysis that you have at the top of those bars that you know tells you invest in ST elevation, whatever the algorithm is going to learn from those from the values that the ECG has already done. So, it's for me, I wouldn't, I wouldn't be too upset that I couldn't follow it, you know, print it out for me and follow up with my finger. I wouldn't be too concerned personally. But that's probably because I'm quite familiar with sort of deep learning, at least in our research, I do some coding and things like that. So I'm sort of aware of the issues. And I'm aware of how it goes. Because ultimately, you know, pattern recognition is not, is not explainable to a certain extent, you know, quite often you're looking at an ECG, and you'll say, "Wow, this is this." And then someone says, "Why isn't that?" and you have to sort of, you know, sometimes you're able to sort of slightly justify it, but sometimes people will ask me questions that "I don't know why it just is!" There's a degree of our [?] where we interpret ECGs that's not explainable. It's a raw interpretation.

**Interviewer**

Yeah. It's funny that you mentioned it, because it's kind of, because it's kind of if someone asks you to explain the gut feeling is.

**P04**

You know even as a consultant, I've had ECGs like that, where I'll look into ECG, and I'll say, I don't know what's wrong, there's something just wrong here. And then I've used that to basically talk to my colleagues and say, "Is there anything abnormal here? What's going on?" And I've taken it to a consultant cardiologist before now, and we've ended up picking up something and changing the management based on that sort of gut feeling. And as I said, there wasn't really anything that I could describe. It was just something that was abnormal there, that I couldn't necessarily put into words.

**Interviewer**

Brilliant. Yeah. This is just kind of sums it up how deep learning works a bit because it, it also depends how verbose you are. I mean, for a lot of people, I mean, I don't need to tell you about patient history, there are patients that can perfectly well explain the symptoms and what they've got. And there are other patients that just come and say, I don't feel right. I don't feel like okay, well, why? I don't know. So yeah. It's yeah, that's very interesting. That's the end of the interview, basically. Have you got any questions? Any questions? Cool.

**P04**

In terms of so you've already shown me three examples is that because we're seeing sort of the software that you're developing, is that primarily going to be for QT interval and ST segment change or is this sort of a starting block to jump off and look across the whole lot?

**Interviewer**

So that's a starting block. So we started with our QTc. And then we had a look at STEMI. So we work with the emergency department, at the MRI, and then obviously, STEMI is something that they get a lot. And that was just an condition we looked at, we obviously want to come to the stage where we have got general ECG interpretation that can be coloured in, in various forms and ways. And obviously, with new electronic health records, it's going to be more interesting, because we're thinking of the optimal outcome would be I mean, back in the day, you had an x ray on a lightbox and that was it. Now you're probably on a computer and you can zoom in, you can change the brightness, you can turn things around. I mean, you can even do 3d modelling with CT scans now and stuff. So it's massively evolved. And ECGs are rather archived in that way. And that way, because we, I mean, as you say, with paper strips, and I'm definitely back in the days where I trained most of the paper strips which are binned. And they won't even store the recording. So there was a massive loss of data. And it's just all taken up now but the grand vision is to extend it to ECGs basically and do everything that we get with automated readouts, but using different explainable algorithms, logarithms.

**P04**

Hmm you are right we do chest X rays much more than we do. Otherwise, I one of the few people I know that will actually on the Intensive Care if you've gotten arrythmia, tachy arrythmia, I'll quite often go and change the paper speed on the monitor. It's not paper speed, but just sort of stretch it out 50 millimetres per second, just so I can see exactly what's going on between those QRS complexes. And it's really valuable. But it's not something that you that we commonly do, even though it is, it seems we struggle with every ECGs that you can speed them up to diagnose your arrhythmias, but no one ever does that. So as you say, going into more digital with ECG seems like a natural progression really, from how we do everything else.

**Interviewer**

No, no, definitely. And I think there's just, it's just a different way of interpretation. I think that's it and you receive a 50 pound Amazon vouchers a little thing that will be sent out in the next couple of weeks if that's okay, just when the first cycle is over. Would it be right for you to be contacted at a later stage of the project again, if we've got questions or anything, brilliant, thanks so much. Just stop the recording now.

**P05**

**Interviewer**

So the first question is: What's your specialty? And how often do you read ECGs in your daily clinical practice?

**P05**

So specialty's anaesthetics and Intensive Care Medicine. How often? Probably every day in intensive care, possibly every couple of days in anaesthetics.

**Interviewer**

And the next question can be split into two pathways. One is your subjective impression of what I'm going to ask you next. And the other one is what you heard from your colleagues or what's genuinely known to be tricky in your specialty. So which are the hardest pathologies to spot on an ECG, or which are the ones that tend to get missed?

**P05**

So I think, probably trifascicular block is probably a difficult one. Some of the sort of reentry tachycardias are probably difficult as well. And then some of the specialised syndromes, such as Wellens, or sort of, you know, proximal sort of occlusion might be difficult. What else is difficult? Electrolyte abnormalities may be difficult if there's nonspecific, probably, particularly magnesium. Anything else difficult?

**Interviewer**

That's perfectly fine. Thank you. The second part is what's generally known to be difficult in your field or what you've heard from colleagues that they struggle with to interpret.

**P05**

Yeah, so I mean, I teach... I teach on the sort of FRC courses and trifascicular seems to be, you know, a common one, and then for the ICM bits, what I said already, those tend to be the difficult ones. Yeah.

**Interviewer**

Perfect. So when you see an ECG, and you want to interpret it, what approach do you take? Do you think it's more of a pattern recognition approach? Or you're very mathematical? You actually go in on the paper strip, taking a ruler out and count the squares? Or do you use automated readouts or automated interpretation of ECGs?

**P05**

I think it's a mix of both. I think, if the... if it's... if it looks... if an ECG looks to be generally normal, then that I don't go through a full approval. If there are any sort of -- and I think this is pattern recognition, with experience -- if there's any thing that I think might not look normal, then I'll go through a systematic approach. And that would be you know, rate, rhythm, sort of axis, those sorts of things and then going through the P waves, QRS complexes, T waves in order.

**Interviewer**

Yeah. What's your what's your impression of automated read out? So automated interpretation?

**P05**

Very sensitive. Probably too much. So there's probably picks out lots of abnormalities that may not actually be... may actually be normal. Although sometimes they do pick up things that have that I have missed.

**Interviewer**

Okay, so...

**P05**

That's unusual.

**Interviewer**

I know yet it's from, from what I've heard so far, it's more the other way around, that they show something that's not there, rather than that they show something the clinician wouldn't see. If you think about the bigger remit of ECGs, as in how we put electrodes on the patient, how we store the data, and how we record the ECG on a patient, and what our current shortfalls of ECGs in your opinion.

**P05**

So whatever it is -- sort of training and placement...Yeah, so I think I think, firstly, is the education of, sort of, lead placement itself. I mean, you know, we don't really... we depend on nurses to do that in the hospitals we are working in. Very very junior nurses might not be able to do so or might be unsure about the placement, in which case, then it comes back to us... but because we don't really place it very often, then we need to dig in the recesses of our memory to try to remember where the leads are placed in the first place. That's one. The second issue is the equipment. So lots of times the ECG machine... the ECG machine itself, can be quite old. Lots of interference. This particular annoying one where if you plug it in into the, into this sort of mains circuit, it actually shows the 50 hertz alternating current. You know what that means? And people wonder why the ECG looks so weird. And if you take it out and unplug it from mains, that actually solves the problem.

**Interviewer**

So it's basically analysing the hospital's current rather than the patient.

**P05**

I guess availability of the nurses -- or the machines sometimes -- to do it generally tends not to be a problem on ICU, but in anaesthetic practice, you know, if you're already in the anaesthetic room, then it's difficult. If you're in recovery, depends on which recovery... sometimes there isn't available... there are a lack of availability of the actual ECG machine. And then, I guess with the printout itself, sometimes there's lots of interference. That's lots of patient factors, which is very difficult to mitigate for. And then having the sort of physical ECG itself being read by somebody who needs to sign it off. And there's a skill sort of issue there as well.

**Interviewer**

Brilliant, and what does work? Is there anything that works particularly well, by yourself? Oh, yeah, we should definitely keep that thing that works very well.

**P05**

So I think what works well now is uploading onto electronic sort of system. So we've got Hive in MFT. And that means that all the ECG is uploaded pretty much straight away, which means that I don't need to... I don't need to sort of call the cardio... you know, if there's something wrong, I don't need to call the cardiologist and sort of explain, okay, well, there's T wave inversion in this one, and there's that one... I can just say, okay, well, it's on the system, can you take a look at it? And because everybody has access to that, that that's helpful

**Interviewer**

Definitely much easier than the paper strips. Everyone was running around. And then you remarking things and doodling over it. What's the ST elevation? Well, I can't see because you've drawn all over it. So yeah, definitely much better now. If you if it gives you a free pass to dream really big now about ECGs, what developments would be desirable for you in the future? Or how do you envision an ECG of the future?

**P05**

So I know that there are some devices that allow you to extrapolate a 12 lead from less leads, or from only a sort of small, you know, pad or something like that. That would reduce the burden on the education burden on the nursing staff and junior sort of medical staff. But I don't know about the sort of accuracy of that. That's one. Having machines that are more accurate, in terms of the automated reading... but that has a caveat as well, that, that might reduce the sort of experience and the learning for people. Better machines that don't interfere with an AC current definitely helps. I mean, you know, clearly nowadays AI would be a good way to go with both the education side of things, but also picking up new sort of findings that I might not know about. Obviously, the caveat with that is the anatomical variations that happen and AI not really being able to keep up with that at this point of time, but may develop in the future.

**Interviewer**

Thank you. Yeah.

**P05**

And then I guess, how do you... you know... this is dreaming big: everybody should have like an AI sort of machine learning sort of thing. But how do you balance that with the training needs and educational needs? I don't know yet. Perhaps not so much with ECG but you could consider you know, in the field of echo or I do lots of point of care ultrasound and you could consider that as an automated... as automation... as a case then you can see the sort of, you know, when we see ECG findings, we need to correlate with usually an echo or an angiogram finding. But if you can see that or you can pick that up on an automated echo, for example or something like that, then... you know... I know that there are developments in that as well.

**Interviewer**

Yeah. Fabulous. Thank you. So I just want to share my screen now with you and tell you a bit what we are doing at the moment. Can you see an ECG now? Yep, brilliant. So when you look at this ECG, you have got the upper strip, you've got a patient with a normal QT interval. And you see that the colours range from like purple to a lime green. So we are talking about 350 milliseconds of the QT interval at the moment with this patient in the in the upper part. And the lower part, you can see that the colours go from a yellow to a dark red. So this would be a patient with a prolonged QT interval. And we'd be speaking about 550. Something about this as it's taken from a patient with Long QT syndrome. On an electronic strip, this would look something like this as zoom in for you. It goes from purple and recall colours and the longer the Qt C basically is the darker and warmer the colours get. So you would see instantly when you look at this visualisation, but this patient has a Qt s in this case. This is pre clinical trial stitch now, so, this is the most developed algorithm we have got what we trial now with prototyping is all the visualising STEMIs. So, this would be an ECG of a patient with a STEMI you might be tricked into the hypercube T wave there, but there's actually a STEMI going on as well. So, this will be the forms of visualisations that we are working on So, bottom line we use colour to highlight certain conditions on on ECGs. I can't stop sharing now. So, I'm back with you again. Generally, do you think that digital technology can enhance the way you interpret ECGs? Yeah, yep. And do you think, obviously, with the visualisations that I've shown you the approach was to highlight certain conditions with colour one being STEMI. The other one L QT. S, do you think that's an approach for you to work very well? Or what do you prefer to have an algorithm or application that colours any abnormalities or pathologies on an ECG? So it Prime's you visually to look at this area on the waveform, but it's down to you to interpret it. So condition based or generally, abnormalities based.

**P05**

I think for the more experienced clinicians, the... not the abnormality based, the other one... could prime you to look at the patterns. For training purposes, it might be nice to have, you know, this is this abnormality colour coded. How would that... I guess it depends... does it depend on how many various sort of abnormalities you're trying to focus on? Would that give too much cognitive overload? For somebody looking at an ECG... and does that then draw too much attention to specific things while making the clinician sort of ignore things that are not highlighted by the colour? That's, I guess, one of my concerns, or one of my questions. And the other one would be: how long would it take for, you know, comparisons? So if you have, let's say... I don't know... five abnormalities that you might pick up -- individually, how long does that take to do that, versus somebody reading it at various levels? And does that help to integrate the information into a unifying diagnosis?

**Interviewer**

That was very interesting, because I completely understand the abnormalities based approach. If the patient comes with, let's say, potentially five issues on ECG, you've just got a huge colour burst, and everything's just colour all of a sudden. So what I take away from this is that there should be some form of filter that you could probably use in terms of I want to look at the ST segment now. So call me that in at the moment. I want to look at Qt see, for example, let's check the QRS complex for me. So I think there should be some way of filtering but what Take minutes, because I appreciate that there might be some cognitive overload. If, if, if, if you've got a difficult patient than it would everything would just be called all of a sudden, and you wouldn't see the waveforms for themselves anymore. The other thing is, it will be real life. So you wouldn't have any delay in taking the ECG and to interpret it. So we wouldn't need to wait for anything in that regards. But I think we've having electronic screens now where we can read ECG is not a paper strip, I think it would be quite beneficial to be able to set certain filters, and then remove colours completely and add according to what you would want to see. How do you think of Do you think that colouring itself is specifically useful? Or can you think of other forms to highlight optimality isn't ECGs?

**P05**

I mean, you've given two examples: ST elevations, and QTCs. I think QTC is probably quite useful, actually, because if one doesn't remember what a normal QTC is, then that's probably quite helpful. For ST elevation... would it be helpful... Would it have... Would it have...

**Interviewer**

It would not use the colour spectrum. So because there's obviously this is why I've just shown red, because as soon as it matches the clinical criteria for a STEMI it will show it up with colour because obviously, a STEMI is a STEMI is a STEMI. There is I mean, yes, according to patient demographics that are some standards where we think oh my god, that's really really bad. Complete occlusion or whatever. Or you obviously have got a spectrum of standards, but the clinically bonds it's a STEMI it's a STEMI. So we wouldn't use cold colours to warm colours.

**P05**

No, it'll just be... I mean, that makes sense. I guess with, you know, things like left bundle branch block, then I guess needs to be some mitigation for that. And I guess there will be clever algorithms you can write. That will be... that will be nice. And that will probably be able to write Sgarbossa criteria, which would be really nice.

**Interviewer**

That's as long as you can define it. For the computer. I mean, obviously, with deep learning approaches, you can just train it on tonnes of of capacity cities and then you get that. But this will be one of my questions further down the line. Um, how do you see visualisations in comparison to the current methods we've got such as the automated readouts?

**P05**

I think they, I think they're much better actually. Because they're open to interpretation. They're not... they're not... they're not written down as "this is the diagnosis." Whereas the printouts would be, you know, "R wave or whatever in this lead." Okay, fine, but in context? So if that's just highlighted, that leaves the interpretation to the clinician, which also probably makes, you know, from a neuro behavioural psychology point of view makes the clinician feel a bit better about him or herself?

**Interviewer**

Yeah, no, definitely. Because this is what kind of these automated readouts I personally think to sometimes prime you to look for something that's not there. And then especially for junior doctors, you can get really stressed because you don't see it, and the patient even hasn't got it. But you, you get primed by the readout to find a STEMI or a branch, or whatever that isn't there. Which can be really stressful. I think, especially for junior doctors and less experienced interpreting ECGs. You, you probably refer patients to diagnostic investigations that they probably don't need, because they don't have it, or any other such things. But it's really interesting. Obviously, it's all a computer doing this. Do you think it's important to have explainable algorithms, as we know exactly from again, do you think it's important to have explainable algorithms as in terms of we know, from the time where the data gets taken from the patient to computer has a set of rules mainly set by experts, and we know exactly how the computer comes to the decision that this is a STEMI. This is our Qt s for example. So it's perfectly explainable to a human being, or do you think with like deep learning approaches, and you might have heard of like black box algorithm And while we probably don't know what they're doing exactly, but they can have a quite accurate output. So what's your take on this?

**P05**

It's a really interesting question. I mean... I think... I think you probably can use a little bit of both. I don't think they're mutually exclusive. I think there are certain rules that can be used by... they can be explained... and it will be helpful for training education purposes, those sorts of things. But there are probably also instances where we can push the boundaries and use the blackbox algorithms to increase, perhaps, the sensitivity, or the earlier recognition of particular syndromes that might be difficult to categorise into an explained algorithm. I guess the problem comes with all AI blackbox sort of algorithms is: who's responsible? And who takes, you know, medical, legal sort of responsibility for that? And I think that's a big question for AI at this point of time. On the whole, I think that could be you know, that I think they don't need to be mutually exclusive. I think they can work in parallel. Actually going... going back to what you said before, as well, I think I was just thinking, you know, you could, when you set filters, you could almost set it almost like a systematic way to sort of approach ECGs and so you could tick like, you know, okay, P wave, I'm doing a rate, rhythm, axis, all those sorts of things. And that can be a really powerful educational tool as well.

**Interviewer**

that's this, this is actually really interesting. So I'm really glad you say it, because a lot of people see healthcare technology, just on the perspective of the patient. But there's actually lots that can be done in terms of medical education, and roll the Think of AI for patient care ai for patient outcomes, AI for diagnosis, the AI for treatments, but there's actually a whole remit of AI for education out there that a lot of people have, especially I've spoken to a lot of clinicians now. And hardly anyone mentioned education, which is really interesting.

**P05**

So I think that a lot of what we do is not necessarily just because it's good for patients, it's because it's convenient for us.

**Interviewer**

That's one big thing. Yeah. And then then then there's the other thing of more convenient for clinicians or convenient for someone's budget. Yeah, definitely. I think these are these are big impacts. Yeah. So that was it from my side. Thank you so much for for your time. I'll stop the recording now.

**P06**

**Interviewer**

So the interviews quite informal, really, it's just basically a chat about how you use ECGs. And what you think of them and what we could improve or make differently. It's also no assessment because some colleagues asked me if they're going to be assessed or if someone looks over that there is no assessment of ECGs, or whatsoever, it's not going to be a test. The first part is generally about ECG. The second part is more related to our project. And I just start with the first question, which will be how often do you read ECGs? In your specialty?

**P06**

Every day... sort of probably on a... probably maybe 10 a day, I would say.

**Interviewer**

Okay, so a lot. The next question can be split into two pathways, one your subjective pathway, what you perceive, and the other one, your colleagues, or what's generally known to be quite tricky. So the question will be, which are the hardest pathologies to spot on an ECG? Or which little bonds to tend to be missed out? A lot?

**P06**

So yeah, I mean, obviously, you can split it into lots of different things, but I think probably ones we see quite a lot is, like, missed high lateral STEMIs or subtle lateral STEMIs, subtle inferoposterior STEMIs can get missed... and then often, sort of... RV strain will often get misinterpreted as this anterior ischemia. What else will there be? Yeah, I mean... I think some of the tricky ones to interpret... something like, the subtle, like, changes like Brugada, sometimes, like, Brugada type two and type three will often get picked up or sort of interpreted as such, when really, they're just normal variation. And yeah, things like Epsilon waves with ARVC is very difficult to pick up, I think.

**Interviewer**

Okay, brilliant. And when you look at ECGs, and interpret them, are you using more of like a pattern recognition approach? Or you're very mathematical and getting the rollout and counting the squares? Or do you use automated readouts?

**P06**

A lot of it's pattern recognition. But then if I'm, like, concerned about the patients, and if I've missed something, then I might go a bit more methodical. And I do use the computer read outs... I probably look at it last, to be honest? Because often I'll sort of look at it and say, well, it looks alright to me. And then if the interpretation says something different, then I'll look at it in a bit more detail.

**Interviewer**

Okay, brilliant. And when you extend the remit now, not just from how we interpret ECGs, but when you think of electrodes, how they are visualised on the monitors or paper strips, what do you think are the current shortfalls of how we do ECGs?

**P06**

Yeah, I mean, I think... they are quite time consuming to, you know, get a repeat ECG. And often there can be variations of lead placements, you know: you might get an ECG that's done in A&E that's completely different to one that's done on the coronary care unit. And sometimes it's difficult to know if that's lead position, or what? Because, obviously, sort of... when you're on the phone saying "oh, can we get a repeat ECG?" and then when you're actually with the patient... it's clearly time consuming. And so I think it is actually more time consuming and more work for, like, the nursing staff and things than I think we often recognise.

**Interviewer**

Yeah, I've heard that as well. Because I think it's often hard to actually attribute nurse times on how long it takes a job. And then you just keep requesting, requesting, requesting, and they're gonna be like, hang on, we have five requests on backed up there. We can't just do everything. Yeah. So that's, that's one of her before are the things that work particularly well, of how we do ECG. So are you at the are you at MFT Yeah, yeah. So you can also think of Hive now obviously.

**P06**

Yeah, that is good. I think it's -- on Hive specifically -- I think it's quite difficult to compare ECGs because you have to, like, go into one, and close it, and then go into another one. But I use the... I really want to compare it with MUSE... we have the MUSE programme where you can, sort of, put them side by side. So we can use that. Because I think that's... when, you know... when you have printout ECGs and then that's sometimes really easy to compare side by side. But then the downside of that, is that they go missing, they get lost... and yeah. I think it is definitely good having electronic ECGs, definitely -- mainly for that reason, you know... it's very easy for one to go missing or not to have a name on it. It gets found somewhere, you know, in CCU...

**Interviewer**

I mean, it has paper strips, that was just an absolute mayhem, because a lot of them were just patient one or patient two, and then you don't know which one was patient one, and which one was patient two, then you get a different name from the previous patient. And then monster had been signed off for look at I mean, there's such a huge data loss because they made these two, which was thrown in the bin afterwards. And that was it. Yeah. It was just seeing a patient history in terms of ECGs. That was just not possible, because no one stored it. So yeah, that's, that's definitely better with electronic storage. Now, if that will be the magic ECG theory, and she would grant you every wish. What would you want to be cities of the future? What will be desirable for you to have edit to the city of the future?

**P06**

I think often with some [inaudible], you get like a lot of artefacts, so some way to try and reduce artefacts would be very useful. I think the trouble is, is that they are they're complex, aren't they? And they have to be interpreted with the clinical scenario as well. So it's... it's tricky. I think, like continuous 12, lead ECG monitoring, like, in the future would be amazing. But how feasible that would be I have no idea. But you know, that would be amazing. Because then you would... for example, you've got that patient in A&E, who you're a bit concerned about... some ongoing chest pain, but you're not quite sure, and you say, well, let's do an ECG in half an hour, and then it might end up turning into an hour. But if you've got continuous 12 lead monitoring, then you can pick up, like... the STs might start going up, and you could get alerts to that. I think that would be... and that would potentially save a lot of time, and it would probably, if there was a way to automate... it would probably end up saving a lot of man hours as well. But I just don't know if that's feasible.

**Interviewer**

no, I mean, continuous monitoring is definitely things what we are currently looking at the trust is actually getting all the icy, bedside monitoring, stored in on a server, because they are continuously monitored, but no one stalls it. And if you're just not the nurse or the doctor at bedside, and something occurs, you just miss it. Exactly. And that's that's if there's anything in hindsight where we could look back at the continuous monitoring. So that will be a lot of good benefits basically, pop if there will be 12 leads even better, but with 12 leads being a router fafi business at the moment, it's it's hard to fulfil that really. I'm going to share my screen with you. And then I'll show you what we are working on at the moment.

**P06**

Yeah, I found that in ICU as well, as you go to the patient and say, "oh, this happened." "Not that I don't trust you, but can we see?" "No."

**Interviewer**

Can you see that now?

**P06**

Not Yeah. Oh, yeah. There we go. Yeah,

**Interviewer**

So you should see some ECGs now. Yeah, cool. So what you see on the top strip is that we've got a patient with a normal QT interval, you can see that the risk assessment is colour based basically, so you have purple colours going into line green. So the times we'd be looking at would be about 350 milliseconds in terms of that patient. On the bottom strip, we've got a prolonged QT interval. So this is a patient with Long QT syndrome. And we can see that the interval is actually coloured from a light yellow to a dark red, which reporters above the 530 in an electronic resolution of an ECG that looks something like that. So we start off with the cool colours and then get the longer the prolongation is into warmer colours. So in this case, we have a long QT s. We look at reds sumed in this would be looking something like this so colours in the full debrief and just goes on to the end of the of the next heartbeat. What we also doing is so this one LGTS is preclinical trial stage now. So we've done quite a lot of work with that one. on what we're also looking at at the moment, which is prototyping is for STEMI. So we actually call it the ST segment elevation or then depression in there as well. But with the STEMI cases here, I've specifically chosen this because you might look at it and then see, oh, it's just an hyperacute T wave for the moment, but there's no standard, but actually there is ST elevation ongoing, we have that patient as well. So the algorithm will pick that up and actually colour the area under the ST segment in and shows that it's elevated according to patient demographics. So bottom line, we basically using colour to visualise certain conditions on ECGs and make them hopefully easier to spot and interpret. Got to stop my screen sharing now. The first question I've got for you, do you think that digital technology can generally enhance the way we interpret ECGs?

**P06**

Yeah, I mean, I'm quite a visual, sort of, learner. So I think that sort of stuff is quite useful... is quite nice. And so yeah, I would say that's a good idea.

**Interviewer**

So how we tackle the visualisation. So obviously two approaches, what I've shown you now was a condition based approach. So we've got our Qt s, we've got STEMI. And obviously, this is very condition focused. The other option will be obviously according to patient demographics, that we would just highlight any pathologies that are ongoing in ECG, or might be an abnormality in regards to the patient. For use a clinician, would you prefer to have something that's more condition based as you can filter? And see that's an acute Yes, or a STEMI? Or would you prefer to have an algorithm that just colours anything that might look suspicious on an ECG, but it's for you to interpret it later?

**P06**

Good question. Yeah, I mean, I think the trouble is... is that you may end up with a lot of, sort of, false positives, and you'd end up getting a lot of colour, to the point that maybe people start dismissing it, you know, rather than taking it more seriously. But I'm sorry, I don't have a great answer for you there.

**Interviewer**

Yeah. I mean, it's obviously there's obviously patient dependent and how they present. But I think if we if he said the main issues that obviously thresholds and hopefully wouldn't call anything in and I mean, if there's a patient with a STEMI and prolonged QT and a heart block, for example, I mean, then it's, it's, it's a cluster situation anyway. And I think, yeah, that would be if there's a lot of red colour ongoing, I think, then it will be a huge emergency anyway

**P06**

That's true. Yeah, I mean, as long as... as long as it's, you know, pretty sensitive, and reasonably specific, then I think there's no problem with it having... picking up lots of different things... it's just so long as not, like, you know, 50% of the ECGs that are actually probably within normal limits have a lot on -- and then it's almost like the alarm burn out that you get on ICU and stuff, isn't it? That people will start to ignore it a bit?

**Interviewer**

yeah. You just mute for the next hour? And then you mean for the next hour? You know? I've obviously never said that. So that doesn't happen. And generally, when we think of colour, do you think colours are specifically useful tool to highlight these pathologies? Or could you think of anything else that might be useful to use it an ECG?

**P06**

I mean, I think colour ideas are good, personally.

**Interviewer**

How do you compare our visualisation approach to current methods like automated readouts and threshold calculations?

**P06**

Yeah, I quite like it. I think it will take some getting used to because I think everyone's quite used to the automated readout now. But yeah, I mean, I personally quite like it.

**Interviewer**

like it. Yeah. Brilliant. And is there anything in specific to this project that you would make differently going forward? So what do you I mean, it's wrapped up hard, but we've touched upon it anyway, it was more related to the conditions and to the abnormalities. Would you change colour schemes? What do you make anything different in that regard? If you think specifically of what I've shown you

**P06**

I think with that... with that long QT, it's a little bit difficult to know if that's sort of... with the graded colour scheme, are you definitely in that red zone, there? Because yeah... yeah, are you sort of saying... because it's just there's that red at the end of the T wave, is that definitely long QT? Yeah, that sort of will make it a little bit difficult to interpret, I guess. Rather than just, sort of... with the STEMI thing, obviously, it's sort of just got that red and you say you... you're a bit more concerned. It's a bit difficult to know with that graded system.

**Interviewer**

Yeah, because obviously, there's a variability I mean, it colours it as soon as there's a slight prolongation, it goes into orange and red and the longer the prolongation is, it goes deep red. So as soon as you see a warm colour, that's a dark yellow orange, it's actually prolonged already, if it goes into dark reds is like really prolonged. So we talked about, like, 550 to 570 milliseconds. Yeah. Obviously, it's all algorithms at work. How important is it for you to have explainable algorithms, as we put the electrodes on, we get the signals from the patient, we feed it through a computer, and then there's an output as in, that's a STEMI? For example, do you want to have this explainable from A to B, as we know exactly what rules the computer is working on to come to the conclusion? Or do you say another approach, which hopefully, you've definitely heard of it than immediate blackbox algorithms that do something and we can't completely explain, but they can handle very high accuracy and their interpretation as well. So for you personally, what you think you prefer explainable algorithms, or you don't care, as long as the outputs accurate?

**P06**

I probably wouldn't care as long as the output was accurate. Because I don't... yeah, I don't think I would take the time to, sort of, understand it in that much depth, because I imagine it's complex. So I think I would just sort of say... well, you know, if it's been shown to be accurate, then I will trust it, obviously, to a certain point... and take perhaps into account as well. So yeah, I wouldn't be too interested.

**Interviewer**

What do you think from a patient perspective?

**P06**

I think you know, anything that's going to improve diagnostic accuracy -- and, you know, reduce the risk of something getting missed -- should only really be seen as a good thing.

**Interviewer**

Yeah, cool. In terms of the interview, that was it, basically, we're at the end of it. Have you got any questions for me or anything to add?

**P06**

And I don't think so. I mean, I think AI is ultimately going to, you know, increase massively in medicine, isn't it? Yeah. I think as... yeah, I mean, it's brilliant, because obviously, like, when we have SHOs and stuff, who come in with lots of subtleties that you might want to teach them with ECG interpretation, your worry is some of that might get lost? But as I say, if there's something that's going to, you know, improve the accuracy and reduce, like, missed STEMIs and things like that, it's going to be important, but I wonder if it will lead to a lot more phone calls to us. Yeah. I'd say if it's gonna improve [inaudible] for the patient, that's only a good thing.

**Interviewer**

Obviously the work just started and goes for three years and would it be okay for you to be contacted again and followed up or caught? Thank you. And you receive a 50 pound Amazon voucher. In the next couple of weeks when the first engagement cycle is over. You just receive an email with the voucher code and you can use it on Amazon. I stopped the recording now.

**P07**

**Interviewer**

So could you just tell me a bit of your job role? And how often do you read ECGs in your daily clinical practice?

**P07**

Okay, so I'm an ST7 doctor at Blackpool Victoria Hospital and [inaudible] cardiology for about nine years now. So a significant amount of time. And I interpret ECGs on a daily basis. So sort of... multiple times a day, every patient I see gets an ECG. So yeah... so, multiple ECGs in the course of a shift, whether that be you know, in the clinic or on the wards in A&E, you know, in the cath lab... so, you know, in all settings, there's an ECG to interpret.

**Interviewer**

Perfect, thank you. And the next question can be split up into two pathways, one subjectively how you what you perceive to be the most difficult ones. And then also from your colleagues, I was generally known in your field to be hard to spot how to interpret. So the full question will be, which are the hardest pathologies to spot on an ECG? Or which other ones that tend to get missed the most?

**P07**

I suppose an ECG gives you information about rhythm, you know... it depends on the context of the patient in front of you as well, you know. Often in emergency, a lot of patients have emergency presentations like chest pain, or collapse, which is loss of consciousness. So those are, you know, two main cardiac symptoms, which makes you worried that... is this heart attack? Myocardial infarction? Or is it a bradyarrhythmia that's caused the patient to collapse? I suppose [inaudible] ongoing chest pain, or they've collapsed missing a life threatening ECG abnormalities, very uncommon -- because obviously, the ECG gets very [inaudible] doctors... you know, a very junior first year, doctor might miss it, you know, but they always run these emergency cases, past someone with a lot more experience. And in my experience, those don't get missed. They might get missed once in a blue moon -- I've had that experience where, you know, a non cardiologist has missed something they really shouldn't have missed, you know -- but that's uncommon.

**Interviewer**

Okay, thank you.

**P07**

I guess, the most?

**Interviewer**

Good, no, sorry. I think there's a bit of a delay. So I thought we were finished speaking,

**P07**

Go on, I'm finished.

**Interviewer**

And in terms of how you look at ECGs, and how you interpret them, do you think you use more a pattern recognition approach or using a mathematical approach as in counting squares and rulers? Also what we've got automated readouts and threshold calculations. So what's your goal, two methods to look at ECGs.

**P07**

So a bit of everything. So the first thing is the rhythm and the rate, you know, because that gives you a lot of information and informs some of your decision making. You want to know what the rhythm is -- mainly, if it's a normal sinus rhythm, which will be the case in the majority of patients. There's another common rhythm called atrial fibrillation, and then there's more life threatening arrhythmias, then, you know, but those are the three most common types of rhythm you're trying to differentiate. If someone's stable, and they're well, and they've not got really awful symptoms, then it's normally sinus rhythm, or occasionally, it might be atrial fibrillation. And then with that, you want to discern what the rate is... heart rate. And often, I can do that through experience because it's... it's my day job, I guess, that I can just look at an ECG, and I know what is roughly 70-80, 80-90, I can estimate it visually. But there is... you know, the way I teach medical students is the counting method: you know, R-R interval, you look the R wave to [inaudible] 100. So that's one way. The other way is just look at what ECG machine tells you. 95% of the time it's accurate.

**Interviewer**

Okay. And what do you think, in general? So think in broader remit not just the interpretation of ECGs. But you can start with the electrodes, you can think of how electronic patient records are stored. What are the current shortfalls in how ECG is a record that interpreted and stored?

**P07**

The shortfalls are... there's a lot of variation between ECG machines, you know... some of the ECG machines are a bit outdated. There's no log of previous ECGs, because once it's been, you know, been done, you print it... you might label it with the wrong patient details and a trace of that, you know, get printed out. There's no, like, memory on the ECG machine to say, this ECG was done at this time. Once it's been printed, there's no, you know, backup for it. So you could put any patient's details on that piece of paper, and then you're not sure. And in our experience, we've had that before... we've had ECGs for the same patient, and it's obvious that one ECG has been mislabeled. So that does occur sometimes. Another shortfall is that the ECG can misinterpret an ST elevation MI, you know, which is an emergency. So especially in cardiology, you know, circles, it's... it's one of the main emergencies where we need to do something urgently for our patient... so we need to take them to the cath lab and do primary angioplasty on them. Knowing what is an ST elevation MI is really important, because it's a life saving treatment that is indicated if that is the case. So often an ECG will label... an ECG machine will label an ECG as ST elevation, and it isn't ST elevation. And then obviously, the doctor on the other end gets concerned then calls us in the middle of the night, sends us the ECG, and often we say, you know, "this isn't ST elevation, you know, just manage locally, he doesn't need to come across urgently"

**Interviewer**

Perfect. Yeah. And what things work particularly well, if there are any?

**P07**

[inaudible]

**Interviewer**

Yes, stuck now

**P07**

[inaudible] Is that better?

**Interviewer**

You're still not moving. I think it's coming back a bit. Yeah, it's yeah, it's very, it's very laggy.

**P07**

Yeah, either way. Yeah.

**P07**

It seems to be better now. Yeah,

**P07**

I can always accommodate an extra 10-15 minutes if you need [interviewer’s name], it's fine. So yeah, in my experience, the ECGs are good at diagnosing atrial fibrillation, which is a very common arrhythmia. A lot of older patients get it... it's picked up incidentally, a lot of the time as well, you know. Sometimes patients have palpitations, and it's picked up that way. But other times they're completely asymptomatic, and ECGs are good at diagnosing that, you know, and it clearly interprets, and it diagnoses on the top that this is atrial fibrillation. And atrial fibrillation is important because it's a risk factor for having strokes, you know, and that dictates anticoagulation... like warfarin, but there's newer types of anticoagulants now. Warfarin's gone out of fashion, as you might know... but that's important, prognostically... it's important, and ECGs pick up atrial fibrillation a lot of the time.

**Interviewer**

Brilliant. Thank you. So the next question is a bit future forward looking. If there will be anything you could wish for in regards to ECGs. What will what would your ECG of the future look like?

**P07**

As an ECG machine,

**Interviewer**

you can you can think of everything now, whatever you wish for.

**P07**

I would, you know... it would be really revolutionary if there could be a smartwatch or an app on your phone that, you know, picks up [inaudible] .. because we've already got that technology on a lot of that. And there's, like, this cardio device where patients put their fingertips on the device, and it tells them what the rhythm is. But if 12 lead ECG could be done just on an app, a smartphone or a watch, or... yeah, that would be really cool.

**Interviewer**

Okay, thank you. I'm gonna share my screen now with you and tell you what we are working on. Just tell me if that works or not.

**P07**

Where are you based, so you're based in mostly University?

**Interviewer**

University and Manchester University NHS Foundation Trust. So I'm split between the two sites. So what we're working on, you can see in the upper strip here, there's a risk assessment if a patient's got a prolonged QT interval or not. So in the upper area, you can see that the coloring goes from a purple to like a lime green, which would indicate that patients QT interval is normal up to around 350, probably from the colors. But at the bottom, you can see that the colors have changed. And it goes from a yellow into into a dark red, which indicates that the patient's got a prolonged QT interval. On a rhythm strip electronically, this would look something like this, you can see that it's going from purple into red. And if you zoom in, you can you can see the bit closer that this patient in this case would have Long QT syndrome, for example, with this ECG. And another condition we are working on is STEMI. So you can see that the ST elevation is clearly highlighted here in the in the area under the wave. And I've used specifically this one because a lot of people get tricked by the hype, aka T wave and actually don't look at the at the STEMI. So it was quite interested in USAF STEMI is something that that everyone needs to spot, because it's a very accurate situation. So bottom of what we are working on this, we are using a colors, eg visual approaches to make ECGs easier to interpret and just flag certain things that are happening on an ECG. So I'm gonna get back to you now and stop sharing your screen. First of all, generally, do you think I mean, if you've you've touched upon a 12 lead, ECG would be great. If we could do this with a smartphone or an app, do you think that digital technology can generally enhance how we interpret ECGs?

**P07**

I think it can, you know, if... if the apps and the technology is smart enough to recognize, you know, elevation to J point and ST deviation with your schematic, with the color scheme, where it knows that the, you know, ST junction is above the isoelectric line and it uses a color coding system... that would be really useful, I think, you know. The areas you're looking into are quite relevant, you know... QTC prolongation is another potentially life threatening condition which presents insidiously a lot of the time. And if someone can have that diagnosed without actually presenting with an arrhythmia, then then that's great. You know... you know, we often say in cardiology prevention is better than treatment. So with these conditions, if we can pick something up, you know, before it occurs, then it's good, isn't it? Yeah, I think that technology, you know... I'm not really an IT guy, but you know, if... if there is... if there is the option for it to be there, then why not?

**Interviewer**

Thank you. So, obviously, what I've shown you were two specific conditions being ALC, UTS and STEMI. There are two options we have in visualizing ECGs one would be a condition based as I've shown you, so we pick out certain conditions like our key dance and STEMI and visualize these ones. The other option will be according to patient demographics. Now that we just highlight any pathologies in ECG that might be abnormal in regards to certain patient presentation for using the nation, do you think you will prefer to have a condition that's colored? Or would you prefer any pathology? So anything that might not look right, but you are the one interpreting it, what condition it is.

**P07**

I think there's an overlap with... you can't really always diagnose a condition just based on an ECG alone. So I think you still need clinicians... because every ECG, you know, if it's abnormal, it needs to be interpreted in light of the patient's presentation, and the history, you know. Things like abnormalities in the PR interval, okay -- so obviously, you've got different aspects of the QRS and, and the P, Q, R S, you know, T wave -- so that PR interval, you know, can be short, you know, and that often indicates an accessory pathway, but if someone's had no symptoms of palpitations or arrhythmias, then we often just ignore that abnormality. Yeah, equally, if someone's got a bit of PR depression -- which is an indent of the P wave going into the R wave, that can be a sign of pericarditis -- which is inflammation around the heart. But again, if someone's completely asymptomatic, they've got no chest pain, they've had no viral illnesses recently... and if you saw a pure depression on an ECG in a well individual, you would ignore it. So it depends. You can't always diagnose a condition on an ECG without looking at the patient, asking the patient questions, in the context of what the patient is experiencing.

**Interviewer**

Brilliant. Thank you. And in terms of color, do you think color is a specifically useful way of visualizing these abnormalities? Or could you think of a different way?

**P07**

No, I think color is useful, you know, color's useful... or if the ECG can actually give us a measure of intervals, you know -- what the QRS duration is, what the QTc interval is, in milliseconds... what the PR interval is. And then if it gives those values on the side, then any anything outside the normal range, it ends up as red, and that's assigned for [inaudible] review those abnormalities. Because obviously, if you saw a PR interval... an ECG calculated it as 280, you know [inaudible] 280, it's abnormal, and if that came up as red [inaudible] would be for the clinician to ask the patient questions, you know: "are you getting dizzy? Have you ever blacked out?" And that would be a prompt to take that abnormality, but [inaudible]. So yeah, color's useful. I think color's more useful if there's deviation, you know -- PR, depression, ST elevation... where there's an abnormality of a wave from the isoelectric line... ST elevation, it would be useful, 100%. But I think other intervals like QR, QTc interval, QRS interval, PR interval... those might not be so relevant, because it's more of a linear relationship, isn't it? So if machine could give us a value in milliseconds instead, that would be useful.

**Interviewer**

Okay. Thank you. And you have a bit of an analogy at the at the end. So how does the way you look at ECGs compared to other imaging techniques, such as an x ray, for example, or a CT scan or an MRI because we've modern image spheres, obviously, with X ray or CT scan? We can change the brightness, we can zoom in, we can zoom out, we can change the weights on an MRI scan. Do you think this will be features that will be useful for ECG presentation?

**P07**

I think so, yeah, because already we can change the paper speed. So generally, each small square is four milliseconds, 0.04, so we can sometimes change the paper speed 25ms [inaudible] ...we can increase it 50. So, you know, especially when you've got low amplitude waves in [inaudible]... is useful. And that gives you more information in interpreting what the rhythm is what the amplitude of [inaudible] ... yeah.

**Interviewer**

Yeah. Perfect. And then we were at the last question. So obviously, everything I've shown you is done by a computer and algorithms. Yeah, how important is it for you to know how an automatic algorithm to interpret ECGs is working in terms of explainability. So obviously, there's an approach, which is called rule based where we know exactly how the algorithm is taken in the data, what it does in between, and then how it comes to the output that it presents as in a QT interval is prolonged. And this is why it's colored red. However, there are also algorithms and I'm sure you've heard of them, it's blackbox algorithms that we can't explain, really, but they can be very accurate still in their outputs. So do you do you think for you, as a clinician, it's important to have explainable algorithms? Or do you say, as long as the outputs accurate doesn't really matter?

**P07**

As long as the output's accurate, I don't think it really matters, to be honest. Yeah. As long as the output's accurate, and you know, there's... any abnormalities picked up on interpretation are reviewed by a clinician, you know, then I think the output is... as long as it's accurate, yeah.

**Interviewer**

And how do you see this from a patient perspective?

**P07**

What do you mean?

**Interviewer**

Do you think as someone who provides care, do you think you have a duty to explain to the patient how something was, how a decision was made? And if the system can be trusted or not? So it's more from the patient side? If you explained that there's a algorithm and based on this algorithm, you receive treatment X? Do you think we should be transparent with patients? Is that something as long as patients receive the right treatment, then it's fine.

**P07**

I think so. I guess it's difficult for me to comment on that, because the way the NHS is now, every ECG will get run past a clinician, you know... the system hasn't become automated in a way where an ECG isn't looked at, you know... ECGs always get looked at by a clinician. And sometimes maybe the urgency of it being looked at depends on the automation -- so if these if the ECG is interpreted... if the machine has interpreted an ECG as normal, and... that might not get flagged up, you know, but any abnormal interpretation will get flagged up. But ultimately, every ECG, even in a GP practice, in the hospital, ED, outpatient clinics... they all get reviewed, ultimately by a doctor. So I guess that question of being transparent with the patient doesn't really come up in our clinical practice.

**Interviewer**

Thank you. This was the end of the interview. Have you got any questions?

**P07**

No, just, I hope I was useful. Yeah. 100% of what you're doing is, is interesting, you know, there is room for improvement. I feel, you know, because it's, especially in the area of, of ST elevation and interpretation of things like left bundle branch block, you know, the ECGs don't always pick up the accurate emergency presentations, you know, and and another suggestion is that ST elevation comes in, in a couple of different variants, you know, ST elevation, when it's more concave, you know, or convex, rather, is is ischemic, right? So it can be an emergency presentation, like a myocardial infarction, it's in the name, ST elevation myocardial infarction, STEMI, as you know, but then STL ration can also have a different morphology, saddle shaped ST elevation, we call it, which is more concave. And that is pericarditis, which is inflammation around the heart. You know, that's also a form of ST elevation. And it's very much the shape of the ST elevation, we're different. There's a different shape and the ST elevation when it's at MI, emergency life threatening, and when it's pericarditis, inflammation, less life threatening. Well, inflammation around the heart isn't really life threatening, but it's, it's pain. Yeah, you know, so having that distinction. If any ECG machine can be smart enough to differentiate between the two, I think, would be quite useful, you know, and another thing in ST elevation are only in specific leads, often, you know, there's a distribution to them, it's inferior lead to three aVF, or it's anterior leads the one to be five, or if it's more lateral, it'll be like V five, b six, what an AVL generally, because our trees perfused different parts of the heart. And, as you might know, we can gain anatomical information from the ECG as well, you know, in an MI, we often already know, which part of the part is, is having the MRI, you know, which our tree is implicated, you know, because an ECG is a good continuation into the angiogram that we do as an emergency, because already looking at an ST elevation MI, in the inferior leads to three aVF. I know, as an interventional cardiologist, 90% of the time, it's going to be the right coronary artery that's blocked, you know, so that's useful. And an ECG will often tell us that as well, you know, inferior as television, but because it knows that the celebration is in two, three AVF equally, ECG might get it wrong and call an MI, a celebration when it's actually pericarditis, you know, again, but that's because the shape of the elevation is different. And often in pericarditis, the ST elevation is more generalized. You know, it involves all the leads, it doesn't follow a specific territory, you know, because it's not an RPG of an artery. It's not an infarct of your LED circumflex RCA, it's not like a territory that's affected. It's the whole card around the heart. So the ST elevation has a different shape, and it's all over. It's all over an EEG. machines often get that wrong, you know, differentiating pericarditis in STEMI. So that's another area you could focus on.

**Interviewer**

Thank you. We're definitely going to be looking into into these things. Would you be interested in staying on the project as a critical friend as we call it, so when we have got new updates that we send you an email, ask you some questions, if that's okay for you?

**P07**

Yeah, of course.

**Interviewer**

Perfect, thank you. I stop the recording now.

**P08**

**Interviewer**

So the interview is split into two parts, really. Before, I tell you what ECGX is, and what we are doing, I just ask you some general questions about ECGs, and how you're using them in your daily clinical practice. And I then show you some examples that show you what we are working on at the moment. And then we go a bit more into the specifics of ECGX and the work that we are doing. If you need a break in between, just give me a shout. If you've got questions, please just ask them or tell me to stop. And there will be time for a debrief afterwards, if you've got any follow on questions after the interview. The first questions that we start with is: what is your specialty, and how often do you read ECGs in your daily clinical practice?

**P08**

Okay, so, I'm a cardiology registrar and I read ECGs multiple times an hour

**Interviewer**

Okay. And then the next question can be split up into two pathways. One will be your subjectively that you just find to be very tricky. The other one is what you hear from colleagues or what's generally known to be hard to interpret in your field. So the question is, which are the hardest pathologies to spot or which are the ones that tend to get missed?

**P08**

So I think subtle ischemia can be difficult. Some sort of types of tachyarrhythmias tend to be sort of misdiagnosed. In my experience.

**Interviewer**

Okay, have you got anything that your colleagues find hard, things like that, specifically with junior doctors or that are just starting training? Is there anything that they tend to miss?

**P08**

Yeah, I think, I mean, I guess it's because it's recent, just yesterday, someone mistook atrial flutter for sinus rhythm, for example. That's quite common. I think those are the probably the most common things. I think, if you cast on a broader things like LVH tend to be misdiagnosed as sort of non-STEMIs or some sort of inherited cardiomyopathy. These sometimes get mislabeled if, with, you know, ischemic pathologies. You know. I think those are just a few that I can think of off the top of my head.

**Interviewer**

Yeah, brilliant. Thank you. And when you see the ECG, and you start to interpret it, what kind of approach do you take? Do you think it's more of a pattern recognition approach? Are you very mathematical? Are you counting squares and get the ruler out and measure things on the paper strip? Or if you look on a monitor, do you use automated readouts?

**P08**

So I try not to use automated readouts. I, I do have a system. I do tend to if something looks prolonged or short to me, I will count out the squares and I will, you know, for example, QTc, I'll work it out myself rather than depending on the computer. So but most of that, so you know, if if, I guess there is both... I think there's a pattern recognition element, as well as the mathematical elements. If I look at it initially, and it looks to me as a pattern that is okay, then I might not calculate, you know, the QTC on every single ECG, but if I look at it, and on the first look it appears to me to be abnormal, then I will calculate it

**Interviewer**

Perfect. Thank you. And if you think of it wider, not just interpreting ECGs, but from putting the electrodes onto the patient up to reading the ECGs, and how it's displayed and stored: what do you think are the current shortfalls of how we do ECG these days?

**P08**

Yes, very good question. So I think firstly, I don't think there's, again, it's quite common in my practice that you see ECGs with misplaced leads. And, you know, you might see sort of, you might get a referral about an ECG that looks abnormal, but actually it's just the leads that are misplaced. And I don't think there's a... I think there are standardised sort of ways of putting where to put leads, but I don't think it's documented as to where the leads actually have been put. That's the first thing. Second thing I think, in my trust, it is, it is paper. Oddly enough, you know, if you've got a rash you can see a picture of that on a computer, but if you have an ECG, you can't see that. And also paper ECGs tend to get lost and serial ECGs are a useful diagnostic tool. So I think that's something that could be improved. But also, I think, you know, it's ultimately it's just digital data isn't it's -- just voltages across a time axis. So you could store that and actually use that for so many purposes. If you if you could standardise that and store it in a way.

**Interviewer**

Yeah, definitely. That's one of the big issues here. I mean, paper strips get constantly lost, or you don't have the right patient name on it, or you have the last patient's name on it, then people scribble on it, and then it's just lost data, really.

**P08**

Yeah.

**Interviewer**

You don't have to answer this question, but is there anything that works particularly well how we're doing ECGs at the moment?

**P08**

So I think the standard 12 lead format, which again, fairly standard, most hospitals use, you know, when you have the lead 1, 2, 3 on the side, and then avF, aVR, aVL, aVF, and the limb leads, with the rhythm strip at the bottom of lead 2... I think that's a pretty solid configuration. Some trusts and some GP practices don't use that. And I'm sure you know, if you looked at it, if you look at that all the time, you'll probably get used to looking at it. But this format, I think, is very good. What else do we do that's good? I think by by and large, most ECGs are adequate, which I think is a positive of the system, you know, they must be doing something right?

**Interviewer**

Definitely. Yeah. And if I will be the.. I always sum it up as the the magic ECG fairy. If I will come to you and say, I give you the ECG of the future. What do you want me to develop? Or what do you want to change? So basically, how do you imagine ECGs of the future?

**P08**

So in my mind, what would be amazing? What would personally, if I think of myself, what would help my practice loads? If I had access to all the ECGs that patient had ever had? If you could overlay ECGs? You know, just see what there's some things become prolonged or not, or, you know, the ST segment has gone up or down, or what. Comparison is the key, I think, especially in cardiac patients who don't have normal hearts to start off with. I think that's what one thing that I would wish for.

**Interviewer**

Yeah, I mean, it would take away a lot of the acuity of patients when you think, Oh, my gosh, there's something really wrong. But then when you look at a serial ECG, you can say oh no it was like this five years ago already, so I think that's that will be huge change. I'm going to share my screen now with you and show you what we actually doing at ECG X. You should be able to see some ECGs now.

**P08**

It's currently a blank screen.

**Interviewer**

Maybe it takes a while. Yeah. This should be shared with you now.

**P08**

Yeah. Got it now

**Interviewer**

Brilliant.

So what we are doing, as you can see here, we've got on the top strip, we've got a patient with a normal QTC, you see that the colours range from a purple to like a lime green, so we're speaking about 350 milliseconds, probably with this patient. With the bottom strip, you can see that the colours range from like yellow to a dark red. So we'll be speaking about 550 milliseconds on there. So what it does, it shows you that this patient on the bottom strip has got a prolonged QTC. This is an ECG taken with LQTS on the more electronical print, I can show you what it looks like here when I zoom in. So you see that it starts off with counting a normal QTC. And then the the longer the prolongation basically, the warmer and the darker the colours get. So it starts off with a purple, but then it goes into a dark red which will indicate that this patient's got a prolonged QT interval. So, this is at stage T4, which is one stage before preclinical trials. This is an algorithm just working with QtC. So it just looks at the QT interval basically, of the patients. What we're also trialling at the moment is colouring STEMIs: so you see obviously for STEMI it wouldn't make sense to use a colour gradient from warm up from cold to warm because a STEMI is a STEMI. But it deflects a bit from the hyper acute T wave that we've got in here and shows that there actually is an ST elevation going on as well, in regards to that patient. So to sum it up, what we are basically doing is we are using colour to visualise certain parts of the ECG. Do you think generally, the digital technology can enhance the way we look at ECGs?

**P08**

Yes, in short, I think if you... it's basically about clarifying if there was a change and quantifying that change. And I think if you've got a colour map, that's essentially what you do when you compare these two, certainly. And I think you've got a colour map that's striking and different. And that makes it easier.

**Interviewer**

And in terms of the approach that I've shown you, this was obviously a specific condition. So we've got a patient with LQTS. And we've got a patient with STEMI. The other approach would be just put the conditions aside and don't worry about if the patient's got a STEMI, LQTS, branch block or whatever, you just look at the ECG and every abnormality or everything that could be a pathology is highlighted with colour, but it is the clinician who interprets what the condition might be. Would you prefer to have a condition based approach? Where you can click on a filter, basically looking for LQTS, looking for STEM, you're looking for branch blocks you're looking for... you name it... Or what do you prefer that the [...?] and ECG is generally just highlighted by colour, but you look at it and you are the one that makes the decision? What it is?

**Interviewer**

Personally, I would find that too much information, I think, and then you have more decisions to make more decisions to make, potentially, that may or may not be clinically relevant, for example. I think usually when there's an ECG done, there's a reason for it. And I think you already have a filter of like, what conditions you might be thinking before you look at the ECG, and then unless there's obviously any other striking abnormality. For example, I think, if you see someone who's come in with, you know, upper abdominal pain, and I guess one of the differentials might be ischemia. But on the ECG, they've got a Wenkebach type phenomenon, which is an abnormality, but potentially not related, that might distract you away from it. And that might distract you from like assessment of abdominal pain that the patients come in with

**Interviewer**

That makes sense. Yeah. So if you have some filters where you could look for specific conditions, that will be the preference.

**P08**

Yeah, I think so. Personally, that's what I would find useful. But I think I imagine... I think in my practice, by the time I see someone, they've already been seen by a couple of clinicians. So I guess most conditions have been thought of or dealt with. So it is different, I think. I think an a&e person might say differently. I don't know.

**Interviewer**

Yeah, brilliant. And do you think that colouring is specifically useful? To highlight something on an ECG?

**P08**

I can't think of a better way to better and simple way to quantify... to quantify an abnormality.

**Interviewer**

How does... how do our visualisations compare to current contemporary methods? Like automated readouts, for example?

**P08**

So I've I've had experience with a couple of... so in Addenbrooke's, they have a system which... so they use Epic, I think I can you guys use that in Manchester as well?

**Interviewer**

Yeah

**P08**

Yeah. So it does give you... so it does have all the ECGs within, you know, when since Epic started, and it will say, you know, compared to last ECG, QTC is 20 milliseconds more prolonged, for example. I don't think it's terribly accurate, which is the main problem with it, and which is why I tend to ignore it.

**Interviewer**

That's... yeah. I think thats what we all agree.

**P08**

Yeah, if it has, like, a text summary at the top saying this ECG shows, you know... concerning for this, compared to previous, is changed in this way... I would say it's probably 40 to 50% accurate,

**Interviewer**

Which is troublesome, really.

**P08**

Mmm

**Interviewer**

But I think that's the general feeling about automated readouts. Anyway, and I think it's, it's especially tricky, with FY1 or FY2 doctors who don't have much experience in interpreting ECGs... they get, they get primed to see something that's not necessarily there, because they're oversensitive usually in what they state. And, yeah, it's really interesting with the automated readouts really. In terms of... obviously, we've got a computer doing all these things. In terms of explainability in algorithms, do you think everything that's happened with the colouring should be completely explainable as in from the point we got the data from the patient when it goes through the algorithm to the actual output being coloured, we have step by step explainable algorithms where we exactly know what the computer's doing at any point in time. Or do you think we could also use methods like machine learning or deep learning, where we don't really know what the computer is doing? But the output can be either accurate? So what's your take on explainability? And transparency of algorithms?

**P08**

Good question. I think in certain situations that might be useful. So for example... and I think I, I would probably favour the second approach where you do know what the computer's doing, what the computers looking at. But I think if you're front of door and you just want a clinical question answered, you might not. So I think it depends which use case scenario you're going to use it for, I think. If you're just looking to triage or not to miss emergency presentations, then just an answer is fine. But when you're looking for a bit of a deeper assessment of why the computers saying that, you know, QTC is a bit more prolonged or not, which might be a sensitive sign, you know, which might be the first sign of chemotherapy related myocardial damage, for example, you might not be able to pick that up as a pattern recognition that you get on ECG, but if the computer say that, so I think it might be useful in that sense.

**Interviewer**

And how do you see explainability and transparency from a patient perspective? Do we have a liability, for example, to tell the patient how the diagnosis was made? Or can we just say, oh, no, it was some algorithm on a computer?

**P08**

I think I, so if I draw parallels with my practice, so whenever I see a patient and I make a diagnosis, I tell them the reasons for why I think they have X or Y. So on that basis, I would say it should be explained to patients, but again, then you have the additional layer of communication.

**Interviewer**

Yeah, I mean, obviously, a lot of patients are not interested in knowing why the diagnosis was made, or how it was made. But I think we should have the failsafe of actually being able to explain why we diagnose something, I guess. To end the interview, I've got a bit of a... it's not really a thinking game, but it's just an analogy of how would you compare looking at an x ray to looking at an ECG?

**P08**

Yeah, very similar. I look at you know, for example, chest X rays, I look at them in a very similar way to looking at ECGs, I guess, I guess the first thing is a first glance from really from a distance and see if there's any structural abnormalities, or does it look mostly okay? And if it looks mostly okay, then there are a few things that I always look for to make sure I'm not missing, you know -- things like small, pneumothoraces or, you know, rib fractures or humerus fractures is a common one that I look for quite commonly. If I'm purely just looking at investigation, not the patient, obviously. So I would say, they're very similar. I don't know if that answers your question.

**P08**

And obviously, yes, I was looking for how you're prone to looking at things. And the other thing is, do you think it would be helpful for ECGs to have the same image modification capabilities that we've got with medical imaging because obviously, with CT scans, MRI scans, X ray, we can change the brightness now, we can change the weighting, we can we can we can zoom in, in certain things or not. And I mean, I think you've kind of explained this with having paper strips, it's obviously the complete opposite between analogue and digital, but would you actually use certain features from medical imaging on an ECG if you could?

**P08**

So again, I've had experience with this where certain systems you delay... you sort of increase the amplitude or you know, look at the morphology in one way, and I haven't found them terribly useful to be honest. Because if you increase the amplitude there is just gain. It just increases the gain and then you get more noise. So you don't tend to... or even if you slow it down, for example, to look at tachycardia or whatever, you don't tend to get any more information, because the noise is there, the way it's filtered. So I don't know how useful that would be. Unless of course, you have the data from a different source or filter it differently.

**Interviewer**

Brilliant. Thanks so much for all your input. That's the end of my questions are basically Have you got any questions for me?

**P08**

No. Just just very intrigued to see Connect is very interesting. And I think ECGs have been left behind a little bit. Yeah.

**Interviewer**

I stop the recording now.

**P09**

**Interviewer**

So generally, the first question is around how often do you read ECGs in your job? And how do ECGs relate to your daily clinical practice?

**P09**

So I'm using ECGs, every day, multiple times a day. Pretty much every patient I see will have an ECG, because I'm a cardiology registrar, and I specialise in PCI. So it's critical, pretty much.

**Interviewer**

The next question can be split in two paths. One is your subjective on what you find to be the most difficult ones. The other ones is about your colleagues almost generally known in your field to be hard to spot. So which are the hardest pathologies to spot on an ECG?

**P09**

Which are the hardest pathologies... I would say people are confused about QT interval, and that's often inaccurate on automated ECGs. I would say people don't have a clear understanding of cardiac axis. And maybe a third option. What else? I would say. I'm sure people struggle... I suppose, looking for other uncommon things... so maybe whether there's Epsilon waves or maybe a Brugada sign -- I suppose they're common things that people think less about.

**Interviewer**

Okay. Cool. Thank you. When you think of how you interpret the ECG, would you say you're using more a pattern recognition approach or a very mathematical approach that you get the ruler out and count squares, or you've touched upon that automated rules are quite inaccurate often times. Do you rely on automated readouts?

**P09**

So I ignore automated readouts, generally. I find them very unhelpful and inaccurate. I work with a very structured approach, from initial -- you know -- observing time, demographics... and I'll work very structurally through a methodology I have that I've been trained to do. [Inaudible] when you glance at an ECG, but I've tried to refrain from doing that until I've looked structurally through the ECG, and then I'll implement the pattern recognition.

**Interviewer**

Thank you, and genuinely, not just about how you interpret ECGs. But you can think of how they are stored how they recorded so from electrodes to monitors, sprinters, whatever, what do you think are current shortfalls of ECGs? Or what's particularly faffy or doesn't work well?

**P09**

I mean, I've seen... I've seen it change. So I mean, obviously I'm in Wythenshawe, I'm in MRI, so ECGs are automatically uploaded onto the computer, so I think that's really helpful. And I think, obviously, there's also been... they used to get lost as well -- especially when they come in from A&E -- and again, they're now automated and uploaded on patient admission. So that's changed dramatically, because obviously, there'll be people who say, "well, we saw this in the ambulance and this at the time" and then there's no record of that, and then you can't do anything about it if there's complete heart block, or this or that, unless there's documented evidence. So that's changed, and that's been, I think, vital to the way we work now. I think sometimes people have a lack of confidence in positioning of the leads, and I've seen really useful ways of doing that. I mean, it changes obviously, with body habitus, but I've seen, sort of, a set, like... I don't know if it's like a stencil, which fits on a chest where they're almost automatically positioned or guide to where they should be positioned for the chest lead, certainly. I think that's something... like, that's quite useful. What else is sort of useful? Probably... I don't think there's much otherwise that I can think of off the top of my head.

**Interviewer**

Now I've just heard about, like, obviously placement of leads and then a lot of artifacts in ECGs as well, but I just had a chat with someone from our biomedical engineering group because having used ECGs a lot myself, I couldn't believe that we have so many fast paced medical advances, but then you need to still faff about with 10 electrodes for a 12 lead ECG. And then if the patient's hairy, you know, going down that road, it's really faffy basically for how advanced we are. And the consensus was that it's still the best way to do. But I was thinking of like, if he couldn't just spray the patient's body and apply something like a loop or something that's much easier. But apparently, it's very hard to do that. So I completely relate to that lead placement is something that would need to improve.

**P09**

You can design that then fits onto like a belt that goes around someone's torso, just [inaudible] a size shape. But again, it's obviously very patient size and shape dependent.

**Interviewer**

Exactly. Because then you would still obviously need to have the leads in the right place at the end of the day. But I wasn't thinking of the copy algorithm to correct for the error. But I think it's all very much things of the future.

**P09**

The other thing which I think is so primitive -- but you know, you see people who do it -- is just the entanglement of leads, which is so frustrating. And you see people using little syringes you know that they sort of hollow out and put on the end of them. But it's such a simple thing, but no machine I've ever seen has actually come up with something that stops them from being tangled.

**Interviewer**

Yeah, that's true as well. Yeah. I mean, the glue and sticky stuff that are not very well placed and then you just rip them off. And yeah, it's quite a quite a pain really, in comparison to other things. So what I do now I share my screen with you. And I'll show you what we are working on. You should see a PowerPoint now does that work?

**P09**

I can't… yet!

**Interviewer**

Brilliant. Yeah. So what we are working on, we are using algorithms that pseudocolour ECG waves. So you've touched upon the QT interval at the beginning. So this will be the first algorithm that we've basically developed and are working on, which colours your QT interval. See in the upper one here. There are colours going from cold colours to like a lime green, which would indicate that the patient's got a normal QT interval, with the bottom one, going into darker colours from yellowy orange to dark red, which indicates a prolonged QT interval on a strip that can look something like this. So colours in from purple, and then you can see goes into red. So this patient would have long QTc, for example, if it's zoomed in, you can see the colours a bit better here. And the other condition that we are currently working on is STEMI. So you would see that the ST segment is elevated here. This would be coloured in accordingly, which then goes into the hyperacute T wave here. So this is basically what we're working on. We are using colour to highlight some conditions in ECGs. And the first question, would be in general, do you think that digital technologies can enhance how we interpret ECGs?

**P09**

Yeah. I think any anything that can help visually aid -- especially people who have less experience -- will be useful. I think what's important is... is to not... to not distort the ECG that makes it difficult to read the actual wave line. So you know, if you're going to put color in don't color over the line... and it's still got to be quite clear where the line is. I think it's very helpful to have all these things. Any sort of [inaudible]. I think there's something else I forgot to mention, which is atrial fibrillation. I think sometimes people -- and even myself -- could find it difficult sometimes, if it's something fast or it's not clear to see p waves to make that differentiation. Is it atrial fibrillation or not? That's something else...

**Interviewer**

Yeah, I think narrow complex stuff can often be quite hard as this relates to the other question then because we've got the X ray analogy, obviously with modern medical image viewers, maybe an x ray or CT scan or MRI. We obviously allow us to be able to zoom in, zoom out. We can change the brightness, you can change the weights on an MRI scan, how does it compare to ECGs? And do you think that we should approach ECGs more in in in a medical imaging way in terms of that we're actually able to rewind zoom in modified ECG.

**P09**

I've never felt I needed to do that myself. Usually with the naked eye, you can appreciate one or two millimeters of ST elevation. Very occasionally, electronically, you may, because the facility's there, you may use it... but I've never... it's hard to say... I suppose I have it now, so occasionally, maybe I've zoomed in. I don't think that's critical. I don't think there's any real need to change the contours of the lines or any manipulation. No, again, you might repeat an ECG if there's artifact or something that doesn't look quite right, but I can't think of a way that you'd need to manipulate it that would help it to be clear.

**Interviewer**

Okay. Thank you. Yeah. And obviously, what I've shown you now is our LQTS and STEMI. So two conditions. Do you think the future way forward would it be more helpful from you from a clinical perspective, to show any pathologies on an ECG, just everything that's in a certain patient demographic could be unusual that this gets coloured in? Or do you think the way forward is actually highlighting specific conditions? So general pathology approach versus a condition based approach?

**P09**

I think there's always got to be the original ECG, and I think that should always be referred back to rather than just coloring over the first ECG. So I think there should always be a plain copy, and then something that's maybe... something that's AI generated after that. I think it's helpful to highlight any abnormality, you know... if you can say confidently, "there's a normal ECG" -- fine. But I think any abnormality is useful to identify, because sometimes it's not clear exactly what it is, but when you piece together multiple areas of the ECG, where you can clinically correlate it with someone's symptoms, then to give you that... that "something's not right here" I think is helpful.

**Interviewer**

And how do you think, do the coloured visualisation compared to current methods that we've got such as automated readouts or threshold calculations?

**P09**

Yeah, I think again, QT is a tricky one, because the threshold is a spectrum. So highlighting what's abnormal is useful, and what's more abnormal is useful because it helps you calculate... appreciate risk. And again, that varies with heart rate, and age, and sex. So I think it's quite useful to demonstrate that spectrum.

**Interviewer**

Yeah. Okay. Thanks. And obviously, we have algorithms, that can be explainable. So we know from as soon as the patient's got the electrodes on, we know the signals, we know what the signals are going in and how they process to come to a conclusion that this QT interval is prolonged. Now, other methods might be a method of blackbox algorithms. So we can't explain really how they do what they're doing. But we still get accurate results in terms of defining that this is our LQTS, for example, how important for you, is it to have explainability in these algorithms, or not?

**P09**

Just thinking I'm not quite sure I appreciate the question...

**Interviewer**

So we can use algorithms that are completely explainable. So when you asked me, [interviewer’s name], how does the computer make the decision that this QTc is prolonged? Now, I can tell you, okay, there are some rules, the algorithm follows these set of rules. There are other approaches like deep learning or machine learning, where we can train the algorithm on huge loads of data, but we can't really explain what the black box is doing to come to the conclusion that this is 95%, accurate, prolonged QT? Do you think it's important that these things are explainable? Or do you say, as long as it's accurate, I don't care.

**P09**

I suppose, it's hard for me to make that decision, because it's not really something I probably understand mathematically. I think it's got to be quite evidence-based. So you know that... you're looking for abnormal readings that correlate with risk and in on a population level... I suppose I probably don't have too much myself of a personal interest of how it got there.

**Interviewer**

Do you think it's something that patients might want?

**P09**

I don't think so. I don't think it's particularly... I don't think it's so important to patients. But I think it's got to clinically correlate, like I say, with... on a population scale, and risk associated with it. I probably don't have too much of an understanding about the AI and deep learning, you know, world at the moment.

**Interviewer**

Okay. Thank you. Well, that was basically the interview. Have you got any questions or remarks?

**P09**

Not really, not really. I mean, I'm very passionate about ECG training, and interpretation. And I think, especially, I mean, obviously, even as we get more experience, we miss things. And whether it's because of pressure and stress and any help to, you know, help and assist us, I think is always appreciated, I think is really helpful at the earliest stages to help demonstrate things visually different people have different ways of learning, and retaining information. So I think any anything that is helpful, I think it's got to be on a huge scale, if you're going to demonstrate these are effective. And I'm sure you will have your methodology. Yeah. Yeah. In terms of, you know, like the actual you know, what's abnormal and what's normal, but you know, I'm sure you must have 10s of 1000s of strips. Yeah.

**Interviewer**

So we've got we've got, we've got literally got 10s of 1000s of hours of ECGs. And we are currently exporting all of ECGs that are stored in Hive.

**P10**

**Interviewer**

The first part will be very general. So we don't talk about the project in specifics just yet. And then after the break that we don't do much just get into showing you a couple of things of our prototypes and what we do with ECGs. So can you just tell us, your specialty and how often you look at ECGs? If you come across them on a daily basis, and what they mean to you in your clinical daily business, basically? Yeah,

**P10**

So I am currently an ST4 cardiology registrar, and I also have a significant general internal medicine component to my training as well. I'm also... I've also just finished my academic clinical fellowship, ACF, and I'm about to start my PhD in two weeks time. Hopefully doing what yourselves are doing. And in terms of ECGs... so in both general medicine and cardiology multiple times a day... my shift last night... I've lost count of how many ECGs I've seen -- from ones in Resus, for example, acute chest pain, all the way through to juniors, on the wards, or other specialties wanting to run ECGs by me, as well, and a patient's case, for example. Other types of ECGs, technically, that I see, clinic twice a week... sometimes we have patients who've got a 24 hour holter monitor report... up to 72 hours... And the other ways I sort of see ECGs, I guess, or traces would be when I'm doing an echo list, we hook them up to three leads, and then monitor their heartbeat alongside doing the Echo, as well.

**Interviewer**

Thanks. That's great. The next question can be split into two pathways, one for you personally. And the other bit what you come across what colleagues tell you about the next question. So which are, in your opinion, the hardest pathologies to spot on any ECGs or what other ones that tend to get missed or misinterpreted?

**P10**

That's a really good question, actually. I can only go back to, I guess, what I've just recently experienced on my set of nights. I think,... particularly juniors and perhaps ED colleagues, ST changes -- so whether that's elevation or depression, obviously -- given the acuity of the patient cohort they come across -- is something that I should comment on. And also, I guess, because sometimes it's very subtle, you know... one versus two millimetre difference... different lead territories. And the other one, I guess, is always there's a lot of electrical and or movement artefact, which makes things tricky. So that's what they find tricky. What I personally find tricky is looking at -- to be honest -- sinus tachycardia. I think that's quite hard, because it could be sinus tachycardia versus SVT, versus, you know... just a very regularly irregular rhythm. Especially when something's going fast and it's narrow complex, I think that's actually trickier for me more than, sort of, ischemia per se.

**Interviewer**

Thank you, um, in what ways do you look at ECGs? Do you think you approach it more like from a pattern recognition type? So look for certain patterns immediately, when you see a trace? Are you more mathematical? So you're getting the ruler out and doing one millivolt and changes in the amplitude? Or obviously, there are automated readouts and threshold calculations as well. Are you using these? are you opposed to using them? So what's your take on how you how you initially tackle an ECG?

**P10**

I think, acutely, it's been pattern recognition, to be honest with you, just because of demands of the job. And trying to get as much information as I can from whoever's running the ECG by me -- so, clinical presentation. If things are a bit trickier, and it's a bit more nuanced, so if it's a... you know... an EP (electrophysiology) issue and it's more clinic, and things are a bit calmer, then I will do a lot of Googling of Life In The Fast Lane, the ruler, atypical presentations of what I think it could be... and then running it by the boss essentially. So I guess it's very contextual depending on where I am and what time of day or night is, is what I do. And then I'd always try and scroll through I think the NWAS (northwest ambulance service) are very useful when they capture rhythm strips. I think they often get missed. So I always try to compare it to those ones, and then obviously, have a look through for, like, scanned in previous ECGs. But at the moment, it's very heavily pattern recognition just because of on-calls.

**Interviewer**

Cool, thanks. And now thinking a bit further not just about how we interpret ECGs or look at them. If you think about the whole world of ECG, so from 10, electrodes for 12, ECG, for example, the machines that we're using, are there any shortfalls in how they are recorded, interpreted or stored, and we're using hive. So you can also talk about hive, and it's different

**P10**

I'm at a different hospital ward where it's paper notes!

**Interviewer**

Brilliant, because we're just everyone's just ranting or not about hive. So yeah, tell us about the paper notes.

**P10**

So I think the thing that myself and the medical team, when we're on call, come across is: the ECG is always missing. They're just never there, because of the fact that it's paper based. The other thing is... things always having to be [inaudible]. So the machines that I use don't actually have the automated interpretation. So you have to, sort of, manually look and do everything. It's a bit potluck. You'd be lucky if you get a machine that gives you the automated bit... otherwise, you just have to sit there and really think about it -- which has pros and cons. I don't think the machine is always wrong, or incorrect, but when it is automated, I try and sort of look at it with covering the top bit and seeing what's going on -- and then whether it matches or not is a little self-test. I think it can be tricky, because everything's paper based and currently -- especially when people are unwell, you know, and they're in extremis -- they're wiggling around and things like that... the lead placements are sweaty and clammy... there's so much, I think, movement and electrical both... the interference makes it tricky. I think that's a real, like, limitation of it.

**Interviewer**

Cool, I think Yeah. artefacts are like one of the biggest obstacles, aren't they? Because it just messes a lot up and makes it harder. Are there any features with current ECG usage, or contemporary ECGs that work particularly well.

**P10**

So I guess, the measurements -- so like the PR interval, and things -- are pretty spot on, unless it's super complex ECG. I think it's also quite good at picking up paced rhythms as well, because it will often say "paced rhythm no further analysis performed" which I think is spot on. So I actually think those features aren't bad. The other thing is, I guess, just obviously, the classic paper, speed, and everything like that that we're used to here works well for me, just because that's the only type of ECG that I've seen. But again, I've not practised in like North America and other places where things might be a bit different.

**Interviewer**

Thank you. And if there will be a magical ECG fairy, and you would have a wish, and it's just changes ECGs to your liking, or whatever you wish for what will be desirable for future ECG developments.

**P10**

This is probably going to be weird, but I'm... I'm a bit dyslexic and dyspraxic, so I have, like, really difficult spatial awareness sometimes, and it's hard to picture things... sort of closing my mind and figuring out the way the leads are placed. If there was ever, like, in the future, some kind of hologram but like a 3D like, picture, or, like, model... kind of like a 3d, you know, like the CT scans can be like 3D or whatever? It's something like that, and [inaudible] like blue or yellow or red colouring like, you know, which way, like, electrical impulses and things are being recorded, and polarised, and repolarisation -- and just more of a 3D structure to help people who are potentially like me? .

**Interviewer**

You're definitely not the only one. So we had another colleague that who's dyslexic as well, and he mentioned that this will be a huge step forward because he struggles, obviously, the leads don't reflect the order how to capture the anatomical structure of the heart. So he's just struggling to translate the leads to the actual anatomy of the heart is something that he really struggles with as well. So yeah, it's definitely not the only one and we haven't interviewed so many people that is definitely a thing that's hard for people to translate, I think. Brilliant. I show you what we're doing in our project. Now. I share my screen with that. I've got a horrible lisp. I'm really sorry. I've got Invisalign for my third day now and it's just like, I'm very self aware now with my

**P10**

teeth look very good.

**Interviewer**

Well, that's the project we are working on. Can you see the slides? Does that work?

**P10**

Yeah, I'm seeing, like, ECG.

**Interviewer**

Cool. So that's just the basic ECG. And what we're basically doing we are using colour to highlight certain conditions on an ECG. So this will be Long QTS. Now, for example, and in the upper trace, you see that everything's coloured in cooler colours. So going from from like purplish to lime green, which tells us automatically when we look at it, that there's a normal QT interval. With the bottom one, it looks a bit different colours go from like a yellow or orange to like a red. And we can see that this will be on a trace or prolonged QT interval. This can go further, if you just have an electronic trace like that, so you could see even better now, what we're doing here, it tells you instantly through the colours that there's a prolonged QT interval, I have a zoomed in version here. So you see, as long as in purple, and then going over blue greens and yellows. Up to the green, it's fine. Everything is over the lime green, like slight pale green actually tells us that there's a prolonged QT interval with that specific patient. l Qt s is preclinical trial now. So this was the biggest part we've been working on for now, congenital and drug induced QT syndrome. And what we're working on now is and I'm really happy that you said ST segment is a bit tricky. We are working on visualising ST segment elevations for now. So we haven't started with depression. But this is just a prototype, what STEMI visualisation would look like so we've got this subtler ST segment elevation in here. And some people might get triggered with the hyperacute T waves in there and look at that it’s a STEMI, that's in there, actually. So yeah, you get the gist of what we basically do. And so this is we're basically, to sum it up, we're using colour to back again, we're using colour to enhance certain features in ECGs. So generally, do you think this technology could enhance the way we interpret these cities?

**P10**

100% yes. Yeah, for someone like me, who is simple, I think colours like, you know, red, bad, blue / green good, you know, hot and cold... I think that works really well and the ST elevation, the second one you showed me, it really highlights how things can be missed. Yeah, no, I think that's a fantastic idea.

**Interviewer**

Thank you. Very good. Very positive. What were the column with the visualisations that I've showed you? Now, these were obviously I've spoken about specific conditions being our LQTS or a STEMI. There will be another option, which will be just colouring every abnormalities in an ECG, or basically not having a condition specific approach, highlighting abnormal waves and then giving the clinician the keys to the interpretation basically, what do you prefer a more condition focused approach? Or would you be happier to say, as long as it highlights or colourises any pathologies, and I want to be the one that interprets them.

**P10**

I think obviously, given... you know... a lot walks through the doors of ED / your clinic. Oh, that's a tricky one, actually, I can see the pros and cons of both. I guess, for me, I think, highlighting all the different conditions, and then being able to sit down with it and have a look, would be really useful. But I appreciate that sometimes it can just look crazy on the page, if there's, like, a lot of colour, and I can see why it can be quite daunting for colleagues who perhaps aren't, as, you know, well versed in reading ECGs, day to day -- and it might make things even more confusing. I was just going to ask actually: the dashed lines that come with it. Is that included in the interpretation, or is that something you annotated?

**Interviewer**

That's great that you mentioned that this is basically the Qt nomogram line, where the normal QT interval stops and the prolonged QT one starts. So, this is the calculations that we used to define the algorithm, where the QT interval is too long millisecond. So, this will be something that could be added for example, yeah,

**P10**

That dashed line is quite good, because again, it helps make things quite clear cut -- rather than just [inaudible]. The other thing I see day-to-day happening -- just because I work in such an under resourced hospital -- is do you need specific like colour toner and things like that? Because I can imagine that being like an added thing where like nursing staff, for example... well, we've run out of this and this... and yeah, machine's aren't working... like, some of our machines, you can barely get the paper for. Like, it's really bad.

**Interviewer**

So this is this is obviously you're completely right. This is obviously assuming that hospitals have got flashy monitors or iPads, escape(?) terminals. While you can just do your thing on an iPad. Going back to paper traces, we would probably be able to print the dashed line, but not colour anything because those trace printers are usually no colour printers. So this will be another obstacle to add. But I'm hoping that we all get to a point where we don't have paper trace prints anymore and have a more digital version of ECGs. That certainly is something we'd be looking into for short term, it probably wouldn't work on a paper trace. So we could look at dash lines and something but everything we do is obviously assuming that there will be a digital means that app that we could actually upload to hospital systems. Like chi muse, for example, that it's just an integrated. You've already mentioned the heart as a hologram or a CT scan, which can render in 3D. Now, I've got actually got a question too, that it's the X ray analogy, as we call it. Obviously, with X ray CT MRI scans, you can change the weights, you can change the brightness, you can zoom in, you can zoom out, you can overlay things. How do these different forms compared to ECGs? And I think this plays more into thinking of digital rather than paper, because obviously a paper trace can never keep up with modern CT viewer. But all those image modification options that we've got with medical image viewers, what do you think that will be helpful with an ECG as well, aka zooming in and changing amplitudes and stuff to actually better see the waves? And

**P10**

I think zooming in, definitely. The caveat I could see what potentially changing amplitudes is that people might -- this is really, like, simple -- might forget to change settings back, then someone's like, suddenly dashing around being like "oh, my God, they're having an MI" when they're not. I think it was more of a personal preference, just because I'm a bit, sort of, neurodiverse, and that's why I need to have... I need to be able to see it... just because I'm a bit weird, basically. Whereas I know, some colleagues will be like "what, a 3D-like hologram or something of the heart, that's... you know... why do you want that, that makes things complicated" But it was just more for me just to be able to see, like, the structure. Believe it or not, even as a cardiologist -- and I've been, you know, doing non training jobs and then gotten into training -- I still struggle with like, anatomical positioning of the heart. Even when I'm echoing I have, like, a 3D model of the heart, like, on my desk, because sometimes I just really do get confused. I'll put my hands up and admit that, so, for me, it was more just for my own personal, like, reasons why.

**Interviewer**

That's completely understandable. I mean, I just something relatable, it's even not as complex as to human heart. I just recently struggled to find the quadrants of my teeth, because I couldn't find a model to translate it.

**P10**

There used to be an app where you can link to your smart toothbrush, and as you're adjusting pressure and moving around, you can... it's all, like, colour coded, and it's, like, Bluetooth connected, I think. I remember that was quite useful as my old toothbrush.

**Interviewer**

They've got attachments and one fell out and I was like, Okay, that's a canine but which one is it? Is it this one? Not that one. I was totally. Okay. So yes, spatial thinking is

**P10**

Because when we as, like, physicians see things like, say, for an X-ray, it's different to, perhaps, you know, feet-first CT versus CT head, like, they're all different -- and I think that can sometimes be confusing. I

**Interviewer**

do with such things I always imagined I'm standing behind the monitor from the difference that's quite useful. For a lung X ray, for example, obviously, I just saw then behind the monitor and look at the basement from the back. So it makes sense to me again, but this is just how I worked. Yeah, no, I

**P10**

Yeah, no, I think that... that's useful because yeah, like, especially when you're, like -- you know, human factors -- like you're tired, it's like your third or fourth long shift in a row and yeah, stuff like that... definitely

**Interviewer**

Generally going back to the colouring, do you think colours are the right method for boards? Or do you think I mean, we've spoken about colours and the dashed lines now. But do you think generally colours will be a helpful means of visualising stuff on ECGs? And

**P10**

For me personally, yes, I respond quite well to colour, and the reason why I think it's quite good that used, I guess, the standard colour palette is because when we do colour Doppler, for example, in echo, you know, it just makes sense to me as well. So I personally think colour is, you know, the best way to do it. But then again, someone might say "oh, does red mean danger and green mean healthy?" -- which isn't the worst, but I think we just have to clearly explain to colleagues, like, this is a little [inaudible], and maybe, like, a little training session around it that can be delivered or something online.

**Interviewer**

Really interesting because we were talking about STEMI. We did the Long QT before the STEMI work. So obviously, with a QT interval, there is a normal interval, and there's an abnormal interval. So it makes sense to go from like a cold colour to a warm colour. And then we were like trying to apply it to send everyone like, hang on, there is nothing as a normal STEMI as me, there is no STEMI where it there might be a more subtle changes in the ST elevation or depression, but it doesn't mean that it's not unnecessarily less harmful occlusion. So it's like, this is why we started with orange to red to just highlight what you said as Oh, danger. So

**P10**

Yeah, or even like, yeah, I guess, like, extreme, like, you know, say if it's like subtle versus like huge, stonking, you know, tombstones... I don't know. Well, that's quite interesting as well, yeah, because like you said, there's no, like, good or bad flavour of STEMI really. It's not great for your heart.

**Interviewer**

Yeah. It's not great for you know, exactly. I mean, there are events that are less or more occlusion. But yeah, it doesn't always reflect like this an ECG anyway. So if you kind of,

**P10**

I guess, the other thing is, would you be colouring in, I guess, if the emergence of Q waves or if there's T wave inversion... would you be cutting that off and colouring in the inverted T waves?

**Interviewer**

Depending on the leads, that's obviously the next thing, you've got, obviously, inverted waves and certain leads, and then a T wave. Inversion needs to be collectively reflected across the leads. So this definitely adds some difficulty to it. But it's definitely what we will be aiming to achieve. How interesting actually, yeah, how do you think our method of colouring compares to current methods as in automated readouts and thresholds?

**P10**

For me, I quite... I quite like simple colours, to refer / resort to. It's not, perhaps, giving me, like, a cheat sheet and saying "this is an immediate, acute MI and this, this and this" -- it's just like "okay, here are some coloured sections, which are abnormal" and you can still use your diagnostic toolkit and your physician hat to go and explore more and then go and take in the patient as a whole. So yeah, I think colours in the first instance would be very good -- without, you know, being spoon fed, or, like, told this is the likely diagnosis. But I don't know if that's part of your guys plan is to then include, like, automation and saying, you know, "coloured ST segment, which is elevated, equals like, acute anterior MI" or something.

**Interviewer**

So you'll read out, but obviously trade offs with such things because people relying on automated readouts, they kind of they can be very helpful if they're accurate. And if there's nothing else going on, if it's if it's a clean STEMI, it's a clean STEMI. And we know what to do you have the patient, sometimes, ultimately redoes show a STEMI. But it's not a STEMI. And it's a different condition. But I think this is especially for junior doctors, looking at the automated readouts and reading STEMI, they are primed to find a STEMI I think, yeah. And then they've got the blinkers on and ignore everything else. And the bridge try really, really hard just to look for that. STEMI. But sometimes, yeah. So I think that's the that's another trade off between condition based and just highlighting abnormalities. Because yeah, the readout sometimes give a false sense of spotting things, I guess, and then you're not there.

**P10**

Sometimes a little bit of information can be quite dangerous, depending on which eyes or [inaudible]... you know, there are certain points in my sort-of-more junior career when I, you know... you see the readouts and like, pooped my pants and run to my senior -- and they'll be like, no, no, it's fine, like, you know, "let's go see the patient together and, you know, calm down". And there's times when things have been very subtle, and, I've had a patient who had, you know, very, very subtle T wave flattening, normal troponins... added on D-dimer, which was grossly elevated, scanned him... got a massive dissecting aorta, basically, from top to toe -- blue lighted to Wythenshawe.

**Interviewer**

It's yeah, it's always got to have a proper think about things, I think, rather than getting them pre cut and pre chewed for you to digest. So it's in terms of the algorithm, obviously, it's a computer doing the colouring and everything. And we use algorithms. There are two approaches, we can use explainable algorithms that are completely transparent. So we can see from a from the data that we get from your electrodes to be the actual colouring on the trace. Everything's transparent and explainable. So if the patient or clinician asks, How did the computer make this decision, we have a set of rules that we can explain. And this is how the algorithm works. Obviously, there's a lot of machine learning or deep learning, which is non rule based AI, where it's a black box, and we don't really know what's going on in the middle, between A and B, but they can come to an output b, that's highly accurate as well. What do you say it's very important for medical applications to be explainable of, do you say, I don't really care how the computer comes to its conclusion, as long as I can make an accurate diagnosis?

**P10**

That's a really good question. I think that if purely clinical, on call, I don't care -- just tell me the answer. As someone who's about to do a PhD in machine learning as well, I would probably want to know, under the hood, what's going on. And I think, I don't know if there's like, a gap between the day to day, perhaps juniors, -- who would just be able to, just, sort of, you know, not worry too much about what's going on in the black box... but maybe, I don't know, clinical leads, or like, you know, the data science leads within a trust or organisation... probably worthwhile them having a little bit more information about what exactly is going on, if it's going to then be implemented in patient care. Ultimately, at the end of the day, that's important. And I think, again, like a disclaimer to patients as well, you know, like, "this is a new piece of tech that we're using, obviously, there's a lot of things about AI in the news as well... and this is how we are beginning to incorporate it within our clinical practice" -- and see what patients make of it as well, because I think ultimately, they're the most important, guys that we do our jobs for.

**Interviewer**

Yeah. In the end, it's, it's, it's our job, but

**P10**

Exactly, exactly, yeah.

**Interviewer**

Cool. That was it with the interview? Have you got any questions or any debrief concerns after the interview?

**P10**

No, no, it's fantastic. It's I think it's really interesting project, I think clinically, like, it's very, like, practically useful as well. Are you guys going to be rolling it out? Soon? Do you think or readjust

**Interviewer**

Trialling the LQTS algorithm with MFT. The STEMI work just started yet because we got our funding in June 2023. So we're not even in a year now. And what we do now is to stakeholder engagement, because we don't want to develop anything, where a couple of people think, oh, that might be cool. But then clinicians and patients say actually, no, we can't use that. So this is the face where we just engage with everyone in the obviously, future vision will be to implement things as soon as possible, especially with like GE Muse or everything. I'm in there. So we're definitely wanting clinical outcomes with that rather than just being a theoretical project. But obviously such things take time, especially with software as a medical device approval of roads and everything is…

**P10**

Yeah, definitely. My husband’s doing clinical trial at the moment and wouldn't show ICU and he's an intensivist and NISS (?) test and it's very painful to watch. Where's my wrist? (?) such as all bioinformatics and very far removed from patients. Yeah, so mine was like super easy to get, but I think it's really interesting. And yeah, if there's any room for collaboration let me know

**Interviewer**

100% Of course this was the next question Are you okay to be kept updated and stay on a project as leader coins that are critical friend?

**P10**

Yes. Yeah, definitely. I'm interested from like, Yeah, cuz it's got all the components that are like cardio and machine learning. Not to patient heavy at the moment. Yeah, I'd be keen for my PhD anyway. So

**Interviewer**

This is chit chat now, so I'll stop the recording now.

**P11**

**Interviewer**

yeah, I've started recording transcripts on as well. I can't see the transcript options, I can turn on live captions. That's fine. I can use the audio anyway. So I'm not using the transcript. So the first question to start with will be, how often do you read ECGs? In your job? And what does it look like on a daily basis? So how do you generally on a typical day interact with ECGs?

**P11**

Yes, so I work at the ED, so we see a lot of ECGs, especially if we are working in the amber area. And yeah, mostly the ECGs, or the nursing staff and other staff bring the ECG in front of you. Because you're if you're competent to sign them, because we have got a badge if we are able to sign it or not. So they bring it in front of us just give a brief history, if it's chest pain, shortness of breath, and then we just sign if it's, so we decided that moment, if it's very if it's something acute ischaemic going on, or if it's something that can wait that decision is made at the moment. And if we are obviously concerned, then we always, if not here, then always go for a senior review as well. So that's what happens. We just rule out anything acute first. And then if there's anything needed further, further, PCI is required or requested. That's how it's goes on ED.

**Interviewer**

Now. Okay, brilliant. Thank you. The next question is, kind of split into your opinions, first, a subjective opinion about how you perceive it. And then if you could give us some insight about your colleagues, or what's generally known to be very difficult about this. So the next question is, which are the hardest pathologies to spot on ECGs? Or which are the ones that sometimes get missed or misinterpreted?

**P11**

Yeah. Okay, so for me, from my point of view, when I see an ECG, as we need to confirm it, just quickly look at the age of the patient, and ask about what the patient came with. And what's the present condition for the patient and then just quickly go through all the leads identify all the waves P, Q, R, S and T if they are fine. Quickly, go through the rhythm as well and then go for any ST elevations, depressions, inversions, any acute ischaemia changes first. And if everything is fine related to acute ischaemia any bundle branch blocks, right, left and Wellens Syndrome as well. And any electrolyte imbalances, like U waves and delta waves, and then afterwards, tented T waves, so everything acute, we just class will rule it out. And if it is needed, we go further checking the type of block, if the block, if we suspect blocks, we check the rhythm according to the card method and calculating PR intervals, QRS, and QT intervals if you're suspecting there's anything. Normally the ECG we see in the department date gives a quick, you know, estimation of the Q or QT interval as well, but we calculate it using the formulas on computer. Yeah. And also, first we check that as well.

**Interviewer**

Okay, brilliant. So that kind of goes, this kind of leads to the next question. What approaches do you mainly use to look or interpret an ECG? Because obviously, there is the pattern recognition. So you look at certain patterns on an ECG, and you compare them to normal one. There are mathematical ways of looking at the ECG, where you calculate and you look at squares, and you look on the intervals. But there are obviously also automated readouts. What's your approach, what are you using?

**P11**

Yeah, so I go through the interpretation and then realistically, because obviously, there could be a chance of being that being wrong as well. So otherwise, when I saw the ECG, I go with the, with the leads, like lead one aVL according to the wall area of ischemia, then two three we have and then we only do the interior leads and lateral leads. So this is how I see it was the lead than that. And then the rhythm lead because the ECGs we get have a rhythm lead for six seconds as well. So we can check it and if If there's anything mathematically needed, obviously, we use the formulas to calculate the number of, for example, if you need to calculate the QT interval, corrected QT interval, we use the formula was given online, they're like four or five formula. So we just we use the, I don't know, the name of it starts with B total, something like that. So we calculate it using that.

**Interviewer**

Generally not just about how you interpret or ECGs, this can be more from a mechanical perspective, as well as to think about the 10 electrodes for 12 lead ECG, for example, what are currently shortfalls of ECGs. So what do you think is particularly fafi? What is not working that? Well? Yeah, could be anything like you brought in,

**P11**

Like in terms, like in terms of the ECG, or basically interpretations

**Interviewer**

Both, you can say everything now. So you can say from the mechanical issues as in attaching 10 electrodes, you could refer to the paper strips that they're hard to read anything like that. So everything that's in the world of ECGs.

**P11**

See, usually any problem with electrodes attaching them hasn't happened. But just two days earlier, it happened, because of the leads got an ECG it was quite concerning, because patient was really old. So when we repeated it, it was fine. So it depends. I think it depends on the person who is performing the ECG, who is competent, that there's no problem with electrodes, it takes some time, but obviously, I think it's the most efficient, the correct method to do it. And the other thing about the ECG, sometimes is just, there are many artefacts, for example, but obviously, it depends upon patient to patient if the patient is very agitated and stuff like that. Otherwise, I don't think so. In ED point of view, we lack anything in terms of the ECG, because we don't want any long ECGs or any like, we like we're doing ambulatory care, or whatever. ED point of view, I think it's, it's fairly good ECGs that we get.

**Interviewer**

Okay, thank you. And if you want to have any wishes free if someone will come to you, and I can give you everything in terms of ECGs that you want, is there anything you would like to improve or that could be made better?

**P11**

If you've had previous ECGs, along with it, it is easy to compare. Yeah.

**Interviewer**

Yeah, probably. I show you, because that was all about a general now what we've spoken about. So I'll show you what we're actually doing at ECG. X. Can you see my screen is brilliant. So this is one of the examples we have been working on Long QT syndrome at the moment. So what you can see here is the risk assessment that we've pseudo coloured, so we're using colours, in this case to highlight any abnormalities in the ECG. So you could see that all cool colours from from a purple up to like a lime green tells you by looking at the ECG that the patient's got a normal QT interval. But then when it goes to more red colours, for example, you can spot that there's a prolonged QT interval that there's something wrong with the patient. I can show you a zoomed in version of that as well how it would look on on a strip. So you could then see again, the prolonged QT interval up to the dashed line, which is the Qt normal gramme line. And without calculating anything, or getting a ruler out, or mathematical formula, so you can basically see that it's going into red, so this will be at Intel for the patients. What we're also working on now, which is the second step is highlighting STEMI on on ECGs. So that will be one of the first prototypes we've used for STEMI via could see that there is an ST elevation in this specific ECG reviews again, so basically the segregation review to do now is to talk about our colours the right thing to use, should you have a gradient is this helpful in this particular case? So, this is what we are working on at ECG X at the moment and having seen these visualisations Do you think that this is a way of enhancing ECG readings? Do you think this is helpful in terms of interpreting ECGs?

**P11**

Yes, definitely because this is quite helpful. It decreases the chance of missing a lot of things to be honest, and sometimes when the changes are very subtle, I believe these interpretations can also help us in diagnosing things. Obviously, in ECGs, it's very rare to get a very ideal trace. And but while performing the ECG is on paper, but this kind of innovations, I think, because, for example, just take an example in ST elevations, let's say, normally, if just a lead moves up and down, and you know, a patient is moving the lead isn't corrected properly, obviously, there could be, you know, it will be difficult for us to interpret it sometimes. We take a chance, oh, yes, maybe the patients moving or maybe the leads are connected this way. But I guess we can get, you know, a really good, really good interpretation detail about that, yes, it will be helpful for us.

**Interviewer**

Brilliant, thank you. And we've got a bit, we've got a little analogy of looking at ECGs. And looking at X rays, for example, with X rays, we are generally medical imaging with CT scans or MRI scans. We can adjust the weights, we can adjust brightness, we can zoom in and zoom out of X rays on the screen now. Do you think this will be something that will be helpful in ECG as well? Would you like to be able to zoom in or rewind and go back to Lesson features?

**P11**

Yes, please. Yes, please. That's the problem we always face because at the moment the ECGs we record, we can't zoom in it. I think it will be very helpful. Yes.

**Interviewer**

Brilliant, thank you. And then obviously, what I've shown you the is LQTS, and STEMI. So these are both conditions that we've coloured. In this case, there are two ways of approaching the whole thing of colouring ECGs. One way will be highlighting any abnormalities. So it just colours you everything that's abnormal on an ECG. The other one will be as we've shown in the prototypes now that we highlight specific conditions, so you see a STEMI, you see a Left Bundle Branch Block, whatever you name it, basically, do you genuinely think it's more helpful to have a coloured ECG where it shows you an area of abnormality and it's up to the clinician to interpret what this abnormality might be? Or do you prefer that it tells you this coloured area shows a STEMI, for example? So the difference between just highlighting any irregularities in an ECG or a condition specific approach to it, what do you think will be

**P11**

Sorry, just before I answer, the condition specific approach, really just identify the specific conditions or including everything.

**Interviewer**

I’m able to highlight specific condition. So it's like a filter where you could say, oh, I want to see if that's a STEMI or not the neutrals if there's a STEMI or not, basically,

**P11**

Okay, so I believe this approach will be better, rather than highlighting anything, everything abnormal on an ECG, because to be honest, the ECGs we get there is always something abnormal. It depends how, what conditions, so I believe specific conditions will help us more and the rest, we can put it on the clinician to identify. Okay, thanks.

**Interviewer**

And in terms of the way we are visualising ECGs. Do you think colour is a good way to do that?

**P11**

Definitely, it's good.

**Interviewer**

How do you see our visualisations in comparison to things that already exist to help interpretation like automated read out of threshold calculations, for example?

**P11**

Yeah, so if I know the amount of information I have about this project that is going on, definitely, it's a very, you know, giant leap towards improvement of ECG interpretation. And I think it will help us a lot to be honest - yes. The already preset automated, I, to be honest, I look at their reporting, because I don't trust them a lot. Because it's not even not in just the UK. What in fact, in Pakistan, I saw the before a few times these automated interpretation, I never trust them.

**Interviewer**

Okay, thank you. It's just it's a very general conception of thing to not trust and we had a Foundation's doctor and she was like, she was even primed to ignore the automated readouts. Because it's like we shouldn't be looking at these ones, which is which is quite interesting because I think, still quite a lot of people We'll use them I guess, and making a decision. So yeah. Now speaking more generally about the future of ECGs. Is there anything from your perspective that you would change in how we use ECG? So how we record and store ECGs?

**P11**

Like in what terms that could be, it

**Interviewer**

could be anything. So we shortly spoken about that you would like features to zoom into an ECG, for example. Some people that we've interviewed spoke about hive, how the ECG stored in there and devoid of different features when, when they look at an ECG, so all those things in your daily thing.

**P11**

So if it's, if in HIVE programme as well. So one thing is there should be something that we can compare ECGs. In the HIVE programme, we can not open two ECGs at a time. This is a problem. The second thing we can't zoom in, we can't do anything on on the ECG. So there should be an edit option. It helps reading the scales and everything. Yeah, I think that's the only problem we get every time is we can't open two ECGs at a time on the programme,

**Interviewer**

which makes sense because it is also helpful for us. Because if we, for example, could overlay to ECGs. Or just to compare them and you have colouring and you see that instantly in one ECGs everything is fine. But then in the new one, there's an accurate Yes, happening. Isn't that

**P11**

exactly, yeah. So that colouring will definitely be good.

**Interviewer**

the other way around, if you look at the patients, and they always had, like slightly acuity vapes or something and you'd be like, Okay, if that was done two years ago, but it's nothing changed, really. So that that would help you. In terms of the algorithms that we're using, how important is it for you to have algorithms that are explainable? So we know exactly how the algorithms comes to that decisions in terms from putting the data in, then we know what the algorithm is doing to reach the output as then this is a STEMI. So it needs to be coloured read based on these rules? Or do you think we could use something like machine learning or deep learning, so called blackbox algorithms? So we don't really know what the algorithms are doing, but they come to an accurate output? So what's your approach? Do you think it's clinically important to have an explainable algorithm? Or do you think I don't really care as long as the outputs accurate?

**P11**

It's a difficult question. If algorithm, algorithm-related output, how accurate is that? So that's the first question. Okay. Well, yeah, if the black box algorithm is more accurate, obviously, I need accuracy, to be honest. But I think it will be more justifiable to go with an algorithm method studies[?]. Yeah. Yeah, we can make that make that accurate as well.

**Interviewer**

Brilliant. Okay. Are you generally have you had the option in the, in the survey to stay on board of the project? As leader coins as a critical friend, because obviously, project goes on till June and 2026. And we're just at an early stage, would it be okay for you to be contacted again, about Yes. Brilliant. Thank you. That was the interview, basically. So we've gone through everything. Have you got any specific questions about the project or about the interviews that we've just done?

**P11**

There's just, I just need to ask it to at the end of this project, if everything finding a very, you know, significant, everything comes out normal, really, how will you implement this?

**Interviewer**

So the grand vision is obviously implementing it with GE G's Muse system, okay. So you can basically they're more and more going towards like an iPad to call a cap cascade system of GE where you can actually have an iPad next to the patient and you can do a lot more than you can do with current monitoring. So the vision and of the project will be to have actually an app integrated into into GE system where you can use all these colouring functions. Okay, thank you and as much as you get a 50 pound Amazon voucher for for your time as a token of our appreciation, you will not receive it instantly. Yeah, these will be sent out the university finance ones the first cohort of engagement is done so it will be in the next couple of weeks if that's okay. Yeah, that's brilliant. I’ve stopped the recording now.

**P12**

**Interviewer**

So the recording is running now. So could you just tell me a bit of how often do you read ECGs in your job and how do ECGs relate to your daily clinical practice?

**P12**

I mean, I come across them daily when I'm working. I'm a locum doctor, so I don't work necessarily every day -- but when I do work, I definitely come across ECGs multiple times throughout the day. In terms of how I use them... it's an interesting one, because I feel like a lot of ECGs are put in front of you, and there's not always a clear distinction as to why it was done. So if there's chest pain, then someone will say "chest pain, ECG" -- okay, fine, let's rule out the nasty stuff. But more often than not an ECG is put in front of you, and you look at the notes... you think, why was an ECG done? Maybe it was a bit of vague abdominal pain... it was epigastric, so they thought it was chest pain... or there's some other reason. Query[?] collapse? Okay, fine, fair enough. But there are occasions when you think: "Why was this done?" And if I do find something abnormal, what exactly does it mean within the context of the presentation?

**Interviewer**

So that's discrepancy, basically, between how the patient presents and why the ECG was done. Interesting. And then in terms of when you look at the ECG, and you can split this question into two pathways, one for you subjectively, and the other one more generally, about your colleagues, or what's known in the field to be particularly hard to spot. So which are the hardest pathologies for you to spot on an ECG or which ones tend to get missed?

**P12**

That's an interesting one. I think I need to think about that for a second. I think for me, personally, it would be the... the kind of... for me, it's definitely... for example, if there's a poor trace, and you try to find out if it's flutter or AF, definitely, then you got to look into it a bit more... repeat the ECG, see if it's irregular. And also just when it comes to heart block, sometimes you can't always rely on the ECG interpretation. So first degree heart block: okay, fine, PR interval's prolonged -- end of story. But when it comes to the other ones, where there's dropped beats, or slow prolongation of the PR interval, I do think sometimes, you know, is that just the sinus arrhythmia making it longer? Is it the trace? Is it something else? I think, objectively speaking, a lot of people freak out when it comes to bundle branch block. And then you... you kind of measure the QRS complex, and you think, well, it's less than 120, so why are we really concerned? It's a partial whatever... you know, it's fine. Similarly, ST elevation, the amount of times that there's a one millimetre ST elevation, and everyone panics and you think, again, you know, within the context of the presenting complaint, is it really something we need to be worried about? And then you repeat it, and actually, it was just a raised isoelectric line or early repolarization -- whatever it is. So... I think those are the things that tend to... and rightly so you'd rather... you'd rather be very sensitive in seeing ST elevation and ignoring it than the other way around and missing it. But I do think it tends to err on the side of caution more often.

**Interviewer**

Yeah. Perfect. Thank you. And in terms of approaches you take to interpret the ECG? Do you think you're more looking for patterns? So it's more of a pattern recognition approach? Are you more of a mathematical guide that uses the ruler and counts to squares? Or do you rely on automated readouts?

**P13**

That's so interesting, because I feel like I'm a very scientific person, but I also, you know, after, you know, three or four years of doing ED, I'd like to think that there's a bit of instinct and gut that I can rely on. And the reason I say that is, the amount of times I've looked at an ECG, and automatically thought within the first two seconds "that's normal" ... and I have to catch myself and say, "okay, it's normal, but how about have a look at it?" And then you look at it and you say, "okay, fine, it is normal, I don't need to panic." But similarly, I also think I look at it and I think something doesn't feel right, and then I go through the steps, and I go, "okay, intervals are all fine, it's regular... what is it that's making me think about this?" And I'll often find a slightly prolonged QT interval or maybe an odd delta wave or something just a bit odd, and I think 99% of the time, nothing's come out of it... but at least there is that check and balance in my mind that, you know, I stopped myself. Either way, whether I'm doing it scientifically or whether I'm doing the gut approach.

**Interviewer**

well, it's very interesting. We got to talk about the automated readers later on a bit. Once I've showed you what we're actually working on at the moment. What do you think of the current shortfalls of ECG? So this is not just about diagnosing and interpreting ECGs but you can also think about the whole remit as an electron old's artefacts. Everything in the role of ECG is basically what do you think are like shortfalls that needs changing?

**P12**

I'm going to think about that from a very logical, stepwise fashion. So I'm going to ignore everything in terms of management, and the operational use of ECGs in the sense of "are we doing too much, are we doing too little?" But everything from when the patient is in the room... I think one thing is limb placement, limb lead placement. I do think I've definitely had a few instances where I think "this ECG just looks strange -- what is it?" and we've had to repeat it, and it's been fine. And I do think it's because of the placement of the leads. And that could either be because of an educational reason -- the nurses don't quite know where exactly to put it -- or, two, it's a body habitus reason: you know, there's... it's too difficult, they're sweaty, they've got hair -- whatever it is. And then that leads into number two, which is poor trace. I'm finding that a lot of poor trace ECGs are coming out more and more often, and I don't know why it is. I know there's a cleanup button on ECG. I tell them to turn off the lights... you know... try and reduce electrical interference... but it doesn't really seem to go away, and then you think, well, we just have to make it, but more times than I'm comfortable, there's been a poor trace that we couldn't get a clean trace of, and that that to me is just a little bit... I don't feel right with it. And then coming on to... in sort of the automated interpretation... I think, for the most part, the numbers in terms of QT interval and PR interval -- they're correct. I do think you definitely need to second check them yourself. But also in terms of the interpretation, when it says "signs of STEMI" and then you look at it's the odd T wave inversion in V1 and you think "well, that's fine, don't worry about it" -- that's happened more often than I can think as well. And similarly, with bundle branch blocks and things like that, you have to kind of go back and check and say, "okay, it's either something gone wrong with the interpretation, the algorithm, whatever they use... or it's just misinterpreted what it is because it doesn't know the context... after all, it is a robot." So I'd say they're pretty much the three or four main things.

**Interviewer**

Thank you. Is there anything that works particularly well? Or you say that's great that we have that in relation to ECGs?

**P12**

To be fair, the bog standard ones where it says everything is normal, I find actually, I can rely on that quite a bit to the point where, again, I can rely on my gut check -- look at it... it says it's normal... I can do a quick check: "looks normal, fine." I'm fairly happy with relying on that. Because it seems... like again, it seems like it's way more sensitive to abnormal, so when it is bog standard normal, it's normal, and you don't need to waste your time.

**Interviewer**

Brilliant. Are there any functionalities that should be added or will be desirable to be added in the future developments in general about how we use ECGs?

**P12**

With the best will in the world, I always forget about axis deviation. So I can tell when something is right or left, but I have to go back and then sometimes I Google which way, how much... and I think you do have the PR Q... I don't know, it's in the top corner, it does say the numbers -- but the numbers don't mean anything to me, and I don't... I feel like it'd be so useful, and it'd be so easy, for the ECG machine to just tell me "it's right axis deviation."

**Interviewer**

Especially the sequence of the leads don't reflect the anatomical structure of the heart. So you need to it's a leap of thinking to actually have the leads and then think of what regions are the hardest.

**P12**

Exactly.

**Interviewer**

So there's, there's a translation element in there that we need to do. I show you what we are currently working on one. The first part is preclinical trial. The second one is just in prototyping now, but it gives an overview about what we're doing. It's just going to share the screen now. Probably seeing yourself now at the moment. Can you see my PowerPoint? Brilliant. So what we are working at the moment is you see two ECG traces, the upper one has a normal QT interval. And you can see this that everything in the risk assessment is coloured in from cold colours over greens to like a lime green colour. And this would refer to the chart on the side of the milliseconds. So this patient in this case, has a normal QT interval. Whereas the patient with the bottom trace has a prolonged QT interval which is visible in more warm colours going from orange to red. So we basically can look at the trace and instantly see that there's a prolonged QT interval in this case, improve this patient. On a normal strip this can look something like this. You go from your purple colouring up to the red so you would see instantly that this is Long QTS in this case, where this ECG, this is a bit more zoomed in. So you just have to have a closer view of the colouring scheme and how this would work in the area under the under the curve under the wave. Basically, what we're also working on at the moment, which is the prototyping is highlighting STEMIs. So this will be an early prototype of actually highlighting an area where there's an ongoing ST elevation in this patient. And obviously, some might get tricked into the hyper acute T wave and just say that's just an hyperacute T wave there. But there's actually a verified St. Elevation STEMI going on here. So these are the things that we're currently working on. So we're basically using colours to highlight certain features of ECGs. And that's the project we are basically focusing on at the moment. So generally, if we look at that, do you think that technology can genuinely enhance the way we look at ECGs and interpret them?

**P12**

Based on what you've just told me? I wouldn't doubt it. I definitely think so. I guess it just comes with the nuance that, for example, the ECG machine gives you an interpretation anyway... it doesn't risk assess it like you're doing. But it comes with all of those caveats that I've mentioned. So if it's risk assessing, then what confidence intervals do you have in that risk assessment, and is it an appropriate risk assessment within the context of the patient's presenting complaint and within their past medical history? I think as long as you have those two things cordoned off, then I don't see why it would be an issue. You would actually be quite good.

**Interviewer**

So there are obviously two ways of approaching this. I've shown you two conditions, which are QTS and STEMI. Do you think highlighting specific conditions? is the way forward? Or would you rather prefer in your clinical practice that we highlight any pathologies or abnormalities in the ECG, referring to the patient demographic? So basically, it's a general abnormality based approach, as we call it, anything that seems to be not normal, because ECG, or do you prefer to have colouring for specific conditions?

**P12**

I think that the latter would definitely run into more problems compared to the former. And the reason I say that is again: the machine or the algorithm doesn't know the presenting complaint or context, and so it's throwing... obviously, like, if the QRS complexes are massive, it's gonna think left ventricular hypertrophy, if it's an 18 year old is it HOCUM in the context of a collapse? But again, you just run into so many nuances within medicine and clinical medicine is also not an exact science. So you're just... you're throwing uncertainty on top of more uncertainty and then almost masking it with mathematics -- and I don't necessarily know if that's the right way to go about it. However, getting the machine to do what it's good at, which is analysis and precision of the mathematical components... then that makes sense, because we're augmenting the technology. Well, we're augmenting our ability for interpretation with something that makes it even easier and better by doing its part. So rather than the machine doing the doctoring part, it's doing the machine part, and that makes us better. I think that's a definitely a better way to go.

**Interviewer**

A nice way to sum it up. Yeah. We've got an x ray analogy as well, because obviously, with the advances in medical imaging, and all the viewers, we've got now how we, I mean, probably two decades ago, we put the X ray up on an ice box, and that was how we're just using X rays. Now with everything digitally stored, we can zoom in, we can change the brightness. We can change weights on MRI scans, we have CT scans where we can basically render 3d elements of the body. So the ECG looks a bit archived, where if it's paper strips, and like a single away from the monitor, for example, do you think if we would approach ECG small from a medical imaging view as zooming in changing curves, I'm highlighting certain parts? Would that be something that will be useful or what to be overkill?

**P12**

That's really interesting, because immediately when you said that I thought of... when we do CT reconstruction, we obviously do it... you know, the patient sits in -- they're not moving around -- but because we're using different perspectives... afterthought... we can cut it up in any way we want and see what's inside. And I guess it wouldn't be a stretch because an ECG is basically different views of the heart, electrically speaking, so could we create a 3D map of how the electrical activity flows through the heart? I definitely think so, and I've seen cardiologists who do electrophysiology... they use ablation, they look at where all the things are going, and they ablate the part that is a variant. Do we think that that's going to help us within the kind of first line of defense in medicine? So by that, I mean, GP, primary care, ED, anaesthetics. I don't think we need it. I think... I think we need more of the other stuff highlighting things that we may miss. Do we need a 3D reconstruction of the electrophysiology of the heart? No. But I think that definitely has a part to play in, you know, tertiary care within cardiology EP studies. For me as an emergency doctor, you know, all I care about, is this a STEMI? Is this patient going to collapse? Or are they safe to go home? And we do that anyway. We're just making sure we're more accurate and we've got our eye on the ball. And I think, like you said, the former of what we do -- highlighting these things -- will just make it even easier, but I don't think we need to go overkill with it.

**Interviewer**

Yeah, those are absolutely valid. Do you think that colouring is generally a good way of highlighting these abnormalities? Could you think of any other methods that could be used to visualise or highlight pathologies and an ECG?

**P12**

Well, I get... the thing with colours, everyone understands it. That's the great thing about colour. Everyone knows red is warm, and it's probably bad, green is cold, and it's probably good. But some people are inclined to saying or thinking that, you know, a numerical approach may be quite interesting. Some people have, like, synesthesia, or whatever it is, and they can see numbers or they can graph it in their mind a bit better... and I guess that could work for them. But I guess then it just becomes a question of like, the issues of it. So you know, where are these colours coming from? Is it... are you going to find a district general hospital somewhere that uses your technology and prints it out in black and white? Then you're just back to square one again. So I think it'll be more the implementation of this kind of stuff than the actual practical usage of it. If it's not implemented correctly, then you're not really doing anyone a service really.

**Interviewer**

Yeah. How do you see the visualisations in comparison to automated readers and threshold calculations? Do you think they're complementary? Or do you think one method is better than the other if you would have all those three things? visualisation thresholds and readouts? What? What would you be your preferential one in terms of having or not having?

**P12**

Sorry, what do we mean by thresholds and readouts?

**Interviewer**

That most of the monitors just print STEMI question mark, for example, or QTS, so the machine interpretation, basically, of the ECG, and some ECG monitors, print new thresholds, as in the printed out a number range and say, based on that number, that's LQTS, for example. So it's a very numerical or word approach compared to the colour approach compared to more visual approach.

**P12**

I definitely think it... again, it depends on how you implement the colour. So if the colour is looking at, for example -- and this will correlate in some way -- but if the colour is red, because the ST elevation is five millimetres, and it's yellow, because it's four, so on and so forth... then the colour itself doesn't add too much apart from, you know, straight eyeballing and saying, that's red, that's bad. I think if it's a five millimetre ST elevation, and you're not catching that, something's going wrong in your clinical acumen, rather than anything else. But... and so, in terms of helping identify, you know, massive things? I don't think so. However, if the colour is related to the percentage of your confidence interval, your probability, or something... so if it's a two millimetre ST elevation, you think: "is it two, is it just a high isoelectric line?" I don't know. And it says: "actually, I have a confidence interval of 95%, that this two millimetre ST elevation is true ST elevation" ... I think that'd be fantastic. Because the number of times you look at ST elevation, you think "is that true, is it false, is it a variant?" -- whatever it is, and then you don't... no one can conclusively say yes or no, because no one's gone in there and done a further study or anything. We just repeat the ECG, look at the trop, and then, you know, Bob's your uncle. But if it gives you that kind of statistical basis, to kind of make you think twice, I definitely think there's remit for it.

**Interviewer**

Thank you. Obviously, bottom line of what we all talked about there are algorithms at work and it's a computer or a machine doing something. Do you think explainability is important? As in from the data that are the signals that we get from the patient to the actual output on the monitor or the visualisations. Does this route from A to B need to be completely explainable as we have got expert based rules that make the decisions, and we then know exactly what the computer has done or do you think as long as we've got a very high accuracy in the outcome, it doesn't really make that much difference if we've got an explainable algorithm or not.

**P12**

That's an interesting question. You know, I was very interested in cardiology, during medical school -- to the point where I'd go and search online and see, where do these funny squiggles come from? How does it work? And the more I delved into it, the more I understood it's less of a medical thing -- it's actually physics, right? And at that point, I gave up and said, "right, I'm not a physicist, I'm not going to understand this, and so what I need to know is the patterns and whether it's safe or dangerous." Saying that, there's a certain... I do feel like there's a certain threshold of understanding you need to have... a basics of why the QRS goes up or down, because then you can interpret it in your mind. Okay, well, if this patient's got an enlarged heart, this is why you get axis deviation... I think that's very important. So understanding first principles is very important, but understanding the underlying mechanistic mathematics and physics -- maybe not. But then coming on to algorithmic interpretation, AI, and all of these things... I'm also aware that when it comes to AI, there's something of a black box where it does its trickery, and it comes out with an answer 99% of the time, which is what you expect -- but you don't actually know how it's come to that answer. And sometimes it's found in the literature for other things, that it uses a surrogate marker of something... and there will be a time where that surrogate marker doesn't match up to what you're expecting to happen, and then you think, well, why did it go wrong? So I think as long as you... you account for that, and you're, kind of, have that caveat, that... that's probably important.

**Interviewer**

How important do you think is it for a patient to have an explainable algorithm?

**P12**

You know what, this may be controversial... but I think not really. Like, for a patient to understand what's going on? Nothing. I don't think that's that important. Because they devolve that responsibility to you as the clinician, and I like to educate my patients and explain "you know, this is what this means" -- but I find actually nine times out of ten, it just gives them more anxiety when you explain things to them. They just want to know, is it okay, or is it not okay, and why.

**Interviewer**

Yeah, yeah, that perfectly makes sense. Yeah. And this is, I think, what's mostly happening, because they just zone out when you start explaining things. And then they just hear the more technical jargon, the medical terms, they hear the moral panic, probably. Exactly. And then at the end of the day, they just leave with a big question mark.

**P12**

Exactly. So I've told people "you've got right bundle branch block; it doesn't mean anything; it's 99% normal." But I know in a couple of weeks time when they go to another doctor, they're gonna say, "oh, my previous doctor told me something was wrong with my heart, a 'bundle branch block'" -- and then everyone panics. And you think, "oh, I didn't want you to go and start telling people [inaudible] to panic." But now it's become a thing. And it becomes this like... self fulfilling prophecy where everyone starts running around. I think we've gotten better because we have access to old notes and things now, but yeah, I can imagine in the 50s and 60s, it must have been wild.

**Interviewer**

Yeah. Well, I think there was a lot of guessing on both sides, really, with the with the diagnostic tools back in the days. Absolutely. Brilliant. So thanks so much for that this was basically everything that I wanted you to ask today. As the project evolves, what do you like to stay on as a critical friend, as we call it, as we keep you posted about the project and we just ask you some follow up questions if you've got more developed if that's all right.

**P12**

Absolutely. Why not!

**Interviewer**

Perfect. Thank you and then I stop the recording now.

**P13**

**Interviewer**

Okay, so the first question is, how often do you read ECGs in your job? And what's your specialty?

**P13**

So I'm in emergency medicine really only just moved to Children's Hospital when doing well kind of adult medicine I do probably see an ECG actually every 10 to 15 minutes whilst on shift on the front door. Less so in paediatrics.

**Interviewer**

Ok, thank you. The next question can be split into two pathways really. So one is your subjective impression. And the other one is what might be known in your field as hard to spot or what your colleagues might say. So, which are the hardest pathologies to spot on an ECG, so which are the ones that tend to get missed?

**P13**

Until recently, personally, I would have said to kind of bifascicular blocks and lateral fascicular blocks. And now more failures and having extra seemingly real life examples [?]. And then the other ones that is kind of feel less commonly known areas. Maybe your Wellens, off the hat, sometimes you're kind of scattered [?], as well as your Wolff-Parkinson-White.

**Interviewer**

Brilliant. Thank you. And when you look at ECGs, and try to interpret them, what kind of approach do you use? Do you think it's more of a like pattern recognition approach or mathematical, or are you using automated readouts?

**P13**

I try not to use those messages, because I can [?] out to you and other people, I think, or I tend to use probably, initially pattern recognition and then would fall back. And if there's anything that doesn't fit with a normal pattern, would you kind of use that as a logical starting point on the job.

**Interviewer**

Thank you. And when you think of a bigger remit of ECGs, like putting electrodes on patients, how it's stored, how we use them, how we see them presented on monitors, what do you think are the current shortfalls of ECGs?

**P13**

I think sometimes the attachment to the patients themselves. So, they pull, if they are sweaty, getting a good reading in a good space without any kind of interference on the baseline at all would be quite tricky, especially in those that are moving around. I think that's probably a big sticking point.

**Interviewer**

Are there any features that work particularly well?

**P13**

Oh, you back?

**Interviewer**

Can you hear me? Are there any features that work particularly well?

**P13**

I like a rhythm strip. Just kind of for you, [inaudible: Jervell and Lange-Nielsen syndrome?] longer print out for me. I do refer back to kind of the numbers at the top kind of for your QT intervals and your QRS. I eyeball and go "is it wide, is it not? Well, a few years now we're looking at ECGs. But the actual number itself was by using [inaudible].

**Interviewer**

If you could wish for anything to change on an ECG, what would be things that you would add on, what would be desirable things to be added in the future?

**P13**

I don't know if that was possible, but previous ECGs for patients if they need some storage if that was because in my practice, I just I see a lot of things like bundles, are they new, are they old, they are presenting with chest pain. Is that T wave inversion, is it a U wave at all? So I think something like that will be exceedingly useful

**Interviewer**

Brilliant. Thank you. I want to share my screen now with you and show you what we are currently working on at the project. So you get an overview about that work. Can you see an ECG now? Yes, okay, brilliant. So, when you look at that, sorry, when you look at that, you can see two strips, the top one will be a patient with a normal QT interval, the lower one will be a patient with a prolonged QT interval. So, you can see that the normal QT interval is coloured in cool colours going from a purple to like a lime green. So, we'll be talking about 350 milliseconds the bottom one is from a patient with a prolonged QT interval. So you see that the colours go into more from yellow to a dark red on an electronic strip. This looks something like this and can zoom in for you so you've got this a bit more clear on your screen. It just shows that one of the leads that are then highlighted in purple and go going into a more red one. So this patient would have a prolonged QT interval. In this case, this one is pre clinical trial stage at the moment, and we're prototyping another one for STEMI. So this would highlight ST elevation in ECGs. I've used this because sometimes we may tricked to think this is just an hyperacute T wave, but we actually have an ST elevation in here. And this is what we're working on at the moment to colour in the area under the ST segment, to show that there's actually a STEMI going on. So basically, what we're doing is we're using colouring methods to highlight specific conditions like LQTS, or in this case, a STEMI. On an ECG, I'm gonna stop sharing that now and come back to you. Do you think generally that technology can enhance the ways we see and use ECGs in the future?

**P13**

Especially if there have been things mixed, and now at the more senior level, and I've seen many, many videos and look for certain things, but I had no big deal at the beginning of this video. And indeed myself, that have less thing is that I would use days. And I think pointing them out in signalling where we're going, the areas we should be focusing on every day.

**Interviewer**

Cool. And obviously, what I've shown you is an approach to colour in certain conditions like our QTc or STEMI. The other option would be that we just colour in every pathology on an ECG that might be not normal related to the patient demographics, what do you prefer to have specific conditions highlighted or would you prefer to have anything that seems to be abnormal with this ECG in regard to the patient?

**P13**

Possibly anything abnormal, because then I'm not going to let that go. And indeed, some things might be normal for some patients with kind of [inaudible] conversions and have babies with Long QT and it's not the norm. But that would allow me to get reviewed separately, rather than picking up on certain conditions that need to be in the context of diligence.

**Interviewer**

Thank you for that. And do you think that colour is specifically helpful? So do you think that what I've shown you is a helpful method to colour in your ECGs? Could you think of anything else that might be helpful?

**P13**

No, my eyes follow those. Yeah, get that attention.

**Interviewer**

And how do you see our visualisations in comparison to current contemporary methods, like automated readouts and threshold calculations?

**P13**

I like that. A visual representation would be useful for me. I think, it’s then how we use it in that patient presentation at that moment is fine.

**Interviewer**

And, obviously, there are algorithms at work and it's a computer doing things, there are two options. Again, one option is that we have explainable algorithms. So Explainable AI, we know from the time we take the signals from the patient, and process the data goes into the algorithm, and then it colours out LQTS, for example, and we know exactly how the computer came from A to B. The other option will be what you've probably heard about Blackbox algorithms or deep learning where they can have really accurate outputs, but we don't know exactly what the machine is doing in itself to come to that output. For you, as a clinician, do you think it's important to have explainable algorithms? Or do you say, as long as the output is accurate I don't really care about that?

**P13**

I will say if the output is accurate I’m not really bothered.

**Interviewer**

And how do you see this? I mean, it's especially interesting if you're working in paediatrics, obviously. How do you see this from a patient perspective? How do you explain that what's happening is trustworthy. I mean, it's harder for kids because they often won't ask what's going on now. But yeah, how do you see this from a patient perspective?

**P13**

It's difficult at any point in time, it's obviously it's going to be easier for a younger generation, because they've grown up in a world in with technologies. I think it's a lot harder with the older generations. And often a lot will just stay whatever it is like that. Yes. And I'd love to chime in. They don't necessarily tell you how we've gotten to those decisions, but then by asking value standards that's shared decision making a little bit and explaining why we always need that position is nine times out of 10 people on board.

**Interviewer**

Brilliant. Thank you. That was basically the end of the interview already. Have you got any other questions for me?

**P13**

Have you guys actually kind of used this intended clinical testing?

**Interviewer**

Yeah, so the LQTS, we actually are using MFT data to just verify and test the algorithms further. So the preclinical trial stage now once to first verification is done, they will actually be included in clinical trials and be rolled out. Obviously, this assumes that the technical setup for this is right, so Hive could probably implement this or GE Muse could implement this. That's obviously further down the line. And that's the great vision of this project that we actually can implement this on CarePads or on Hive, but you can actually look at it and then it brings you the ECG colours as well. Obviously, with paper strips, it's quite hard to do that. So we need the technology in place at the trust as well. But yeah, so the grand vision is that this will be implemented in clinical trials and then rolled out

**P13**

The ECG that it's effective because obviously, when I'm looking at kind of even ECGs effects on the beat, there's often a lot of noise or dependence even by the [?] to see that effect. And you're seeing represented in your deck as well [?].

**Interviewer**

Sorry, it was just a bit interference that didn't follow.

**P13**

So the actual ECG themselves can be fairly dependent on kind of the electrode placement. Yeah. And that varies from user to user, especially someone.

**Interviewer**

So the algorithms will be baseline corrected, and they will use everything else. And they will be telling you it will run through several filters that probably correct artefacts and everything. But with the current machines, as you said, a lot of artefacts, patient moves electrodes come off. So this is one of the things that we often hear that, especially a lot of HCA staff, or nurses, they'll place the electrodes differently. And then obviously, you see a variance in the ECGs. But yeah, this will be corrected for

**P13**

I mean, like as follows

**Interviewer**

Yeah, and it's just prime to look different. I think a lot of us are visual anyway, in the automated readouts. And a lot of discussion with colleagues, it just it primes you to look for things that are sometimes not there. Because when you when you when you basically see the automated readout first, and it brings you a STEMI, for example. And there isn't one, you just try so hard to find one. And it just makes you go crazy a bit because what, why is it saying STEMI, but I can't see a STEMI what's going on now. And it just adds a bit to the panic that you make think like, I need to look for something that's been printed out now. And I think the colour can just help you to see something and say, Have a closer look at that. But then it's for you to interpret it at the end.

**P13**

Yeah, I would agree with that. And that's on the spectrum. I've got this problem with an ECG. And I've been like [?] just to see together. And know that is not what is going on in the context of this entry.

**Interviewer**

Yeah, exactly. I think this is what was very valuable for you. What do you say, which is very valuable as well as we, we actually need to compare previous ECGs to patients because some patients might have completely normal ECGs speaking for demographics, but then look up when you see it for the first time. But you don't actually look back and say, Oh, the T wave looked exactly like that five years ago already. So you know, it's not something that's acute going on. So yeah, that might definitely be something that should be fed into hive and make a bit more easy because we can't really display two next to each other at the moment.

**P13**

Definitely. But I think even if you've got that visual representation and thinking more about kind of ST segments themselves. [If you've got some ways that virtually no follow then then you can go too long. Yesterday, words look similar and much more variants that would clearly send them in contact]

It's definitely something very interesting to work on. And if it's been rolled out and successful, then it clearly helps to change the way we view ECGs I think because it just is a different way of looking

**Interviewer**

You’ll a 50 pound Amazon voucher that will be sent out at the end of the first engagement cycle by university finance. So over the next couple of weeks I guess if that's okay. And once you want to stay on as a critical friend, as we say to be kept up to date with the project, and if you've got something else coming up that we might include your again brilliant I've stopped the recording now.

**P14**

**Interviewer**

So how often do you read ECGs in your job? And when do you come across them? And how do you come across them?

**P14**

I mean, I would say almost every single shift, I would be reading ECGs it would be rare not to, I suppose that could vary from anywhere between maybe one to 10 per shift.

**Interviewer**

Okay, so it's part of your clinical routine. Um, the next question can be split into pathways, one your subjective on your answer for yourself. The other one can be what's generally known to be or what you know, from your colleagues that they struggle with. So which are the hardest pathologies to spot on an ECGs? What are the ones that tend to get missed or overlooked?

**P14**

Hmm, I mean, I, I think probably speaking, for myself, but probably also my colleagues, I think the main worry would be to miss the kind of subtle, early changes of MIs, whether that could be you know, things like hyperacute T-waves. You know, just those, I think it's those ECGs. Where I mean, so maybe, I don't know if I've gone off topic slightly. But it's sometimes it's easy to interpret it when you're next to the patient, because you can look at them, but often, you'll be given an ECG, just on its own. And I think there are issues with subtle changes of early MIs where if the person in front of you looks really sick, you'd be like, "Yeah", but if, if you don't know how the patient looks, you could very easily just say, "Oh, this looks like it's probably normal". And so I think there's the subtle changes. I think, perhaps some of the more junior colleagues are worried about missing STEMIs versus kind of high takeoff normal variance. I think those of us more experienced not so much. But I think that's a lot of the anxiety, perhaps the F2s and other juniors have. They don't want to miss something, which is really obvious. Because I think that just you know, it's, it's almost acceptable to miss something difficult, but to miss something maybe obvious, is more worrisome for them. And I'm just thinking outside of kind of ischemia.

**Interviewer**

Yeah, that's absolutely fine. If that comes to your mind that's great. When you look and interpret an ECG, what kind of approaches do you take? You'd say, is it more like a pattern recognition thing that you look for certain patterns, or your modern mathematical type to count squares and gets the ruler out? Or, obviously was also there are automated readouts?

**P14**

Yeah, so I mean, my I mean, I always try my hardest to not look at the inter, the machine's interpretation. Sometimes, you've seen it before your eyes have averted themselves, but I try to not look at that. And I think probably 90% of my interpretation is just looking at the ECG globally, and the pattern recognition. But then I do. I'm guilty that I don't manage to this every time, but I do try to then take time to go through it systematically. Just to kind of satisfy myself that I've not missed anything. So yeah, I think it's yeah, it's mostly just eyeballing it and looking at the pattern. But then again, it also depends on the indication, perhaps, you know, but I do then try and go through that, like, kind of be a bit more disciplined, rate to rhythm, look at all the P waves, all the QRSs, the T waves that access just to be systematic and so I tried to do a bit of both.

**Interviewer**

So you could say if you're, if you're satisfied with one specific pattern, and you're like, Yeah, that's a STEMI. You kind of don't look as rigorous through the A to Z.

**P14**

I'm always conscious that, you know, you can have more than one thing wrong with, you know, an ECG and X ray or anything, so it's not so much, you know, if you spot something to stop, if anything I try probably, if I spot something, to then look harder for more things. I think actually the temptation is to look at one and to say "that's normal", and then not look at it more closely. Which is why I tried to force myself to study in more detail.

**Interviewer**

Cool. Thinking more globally, not just how we look at and interpret ECGs what are the current shortfalls of “doing” ECGs? So you can think from 10 electrodes for 12 leads, up to Hive, for example, so everything fits in whatever the whole remit of ECGs.

**P14**

Okay, I guess I'm just thinking out loud, probably trying to go from the start of the journey. I mean, it's not so much a problem with ECGs. But, but I suppose it is a problem that just the delay to doing them, I know, we have a target of, I think 15 minutes from a patient presenting with chest pain. I know, for example, that patient I saw just last now didn't have it done for about two hours just because, you know, time and space. And I suppose you do wonder, you know, with all the leads and the cables, if there was a way to make it more quick and efficient, then you would, you know, have fewer delays. In terms of, again, those leads, you do see from time to time ECGs where people have put the leads in the incorrect order. And you can normally work that out and decide so it's not a big problem. But then probably on those lines when you're doing a repeat ECG for someone, you sometimes get a feeling that where the perhaps the chest leads were on the first ECG isn't the same place where they were on the next ECG, because the pattern of the you know, perhaps the QRS progression sort of has moved to the point where I think probably where V1 was now is where V3 is this time. So that is probably one issue. Again, I don't know, to be really picky, you know, I guess, the 12 leads again, in the in a kind of more acute situation, perhaps a sick patient in resus, when you're kind of push to res clumping around and do whole things. It's probably ECG is important, but then trying to fit that amongst, yeah, putting in lines and stuff. You know, if there is a way to make that easier, I can't see how but it would be better. I guess that's the physical doing it. I know the machines, you know, I'm not an expert on this. I know, they've got various kind of filters and things to try and account for noise and movement and so on. But you still sometimes, you find someone who's is obvious, or the people who perhaps are hairy that you're gonna get bad traces. But sometimes you still do get someone who's you feel like the trace should be great. But there's obviously something that's causing interference. And I guess, the more we can improve that the better. I suppose that comes at risk of filtering out useful information from the signal. And and then I guess that's physically doing the ECG. I mean, as we kind of I ended up before then interpreting it. You know, a lot of the time in our day to day practice, particularly in the ED, we just get handed ECGs with no context of what's wrong with the patient, seeing the patient. So there's always a risk of something. Maybe it looks normal, but then if you saw the patient, you might think actually, maybe that ST segment is a bit up. HIVE itself, actually, I think it's pretty good to be fair, you get a lot fewer kind of lost printouts and things like that. Sorry, we're thinking about problems with ECGs.

**Interviewer**

But you can also tell me about the things that work particularly well,

**P14**

I just say, so we've talked about doing the ECG, the physical leads the traces, review reviewing them. Yeah, I mean, again, I think just with reviewing them the sheer volume of ECGs, you have to look at if there was a surefire way to filter out, you know, ones, which is normal, for example, it would make it easy to spend more time on the ones which are not normal. But yeah, I think just the volume and seeing them away from the patient is a big hurdle.

**Interviewer**

If there would be a magic ECG fairy, and you could wish everything of her what you want help for, or how would you improve ECGs for the future? I mean, you've touched a lot upon needs with both more context.

**P14**

Yeah, I mean, you know, I guess just that's just the opposite of everything I've just said, isn't it? I mean, totally. ECGs are great, but you know, if if there was a way to get that information, with fewer physical cables. Now that'd be lovely, it just be you know, not only would it be quicker for perhaps you know, that support works to do it, but I'm just thinking if I'm in a room with a patient, and I just want to quickly see if the ECGs changed rather than having to get in the machine, if you could just do it. Yeah, you know, instantly, that would be fantastic. And in terms of the interpretation, you know, the I always hear mixed, you know, I'm not an expert on the evidence myself, I always hear mixed opinions on, you know, the machine saying an ECG is normal. But, you know, if we could say, for certain, you know, the machine in terms of ECG as being is normal, then that would be fantastic. I mean, the other problems, probably not having to ECG themselves, but more just, you know, the environment and that stuff, you know, we often get interrupted all the time with ECGs, which is, you know, is important, but it's also sometimes really irritating. But if there was a wait, but that's not a problem with the ECG is it's a problem with the NHS. But no, it's I think, yeah, you know, if we could just do ECGs more quickly. Almost, you know, is he you know, because I often put on the comparison, if I'm seeing someone, I'll just put on the SATs probe, just to get an up to date, what are the SATs? What is the heart rate? And their blood pressure is probably good enough. But there's no kind of Super Easy ECG equivalent of that, you know, put on the watch and get a yeah,

Oh, yeah, definitely. I mean, I suppose as soon as I saw that first picture, it seemed kind of obvious that probably one thing that isn't on an ECG is colour. And that would be something that would very quickly give you you know, just, you know, even just eyeballing it, you know, if there's red, you know, rather than having to look at the numbers and do counting, get a reading good reading.

**Interviewer**

Cool. So now we get into the project. So yeah, this is what we're doing. This is pre-clinical trial stage. Now, this is stage D4. Basically, we are developing algorithms to pseudoscalar ECGs. So the first condition that reviews to us Long QT syndrome, okay, and see here. So all callers from cool to like a lime green, will tell you that there's a normal QT interval. For example, everything that goes on to more orange or red colours, falsehood at the patient's got a prolonged QT on a printed electronic on a electronic strip or trace that would look like that this assumed in so tells you the prolongation, basically highlighted in colours. Long QT s was one thing, the thing that we're currently working on as well is STEMI. So this is how you visualise as STEMI, for example, not to be tricked, but a hypercube T wave, because you can see, as you'll see that there's an ST segment elevation. And so this is basically what we are working on, and what we're doing with ECGX. So the first question will be, do you think this technology can enhance how we interpret ECGs?

**P14**

yeah, especially with QT interval, I think it would be calculated, then you've got your ultimate readout, obviously, this is hit and miss. And then you get out and done, you probably go on your phone and have a calculator and try to type it in. And then as you know, that is that's good. So this is basically what we're doing.

**Interviewer**

This is basically what we're doing. I've shown you two conditions now, which is our pts and STEMI. There's obviously another option that we just use algorithms to highlight any pathologies in ECG, but we don't define them. Watch, do you prefer to have a condition based approach? Where it tells you, oh, that's now going into a prolonged QT or that's a STEMI? Or would you prefer that the algorithm just shows you an abnormality in the ECG, but it's for you to interpret it?

**P14**

No, I think I think I'd rather it tell me what it was thinking. Just because I mean, the comparison that just popped into my mind, for example, is with X rays, the radiographers will often put on a red dot if they think something is wrong with it. And sometimes I will look at it and think it's normal, and I've no idea why they've red dotted it. So then I have to ask them, and I suppose this would be the same that if these did you sort of said something was wrong, but I thought it looked normal. I wouldn't know why it's, and at least if I know what it thinks is wrong, because it might say the QT is too long. And then I might decide that you know, I disagree or I think it's irrelevant, or you know, some at least I know why if it just says something is up, then I'll be searching. And if I can't work out why, yeah, at least it's narrowed down on you know why I might disagree with the machine.

**Interviewer**

Quite interesting that you mentioned, Xray. Rick's X ray analogy as we called it. So how does the way you look at an ECG compared to other imaging techniques, you can extend it to CT scans, MRIs, because we obviously can change the weights, we can change the brightness, we can zoom in, we can zoom out with holographic CT scans, we can alter the heart around the CT anatomy of everything. So it's very more plastic than an ECG. Is that something you think would be useful for your cities as follows? Is that something you think? No, that's like over engineered? Why would I need, you know, zooming in an ECG or not, for example.

**P14**

So yeah, as in, it'd be good to see

**Interviewer**

what you can do with ECG. Exactly. Just think of what you can do with medical imaging viewers

**P14**

I think that'd be useful. Because I think to the extent you already do that a little bit, I'm just thinking more when I'm on perhaps the ICU, and someone's on the monitor, you know, you do sometimes change the speed just to kind of, you know, see it in a more detail or change the amplitude, just to, you know, get a bit more of a closer look. So I think, you know, it's something that we do for patients on monitors, we don't do it on ECGs, because it just comes to us as a static printout. But I could well imagine that, you know, if you could manipulate it, then you would, and I suppose to be fair, now I think about it now that we have something like HIVE probably would actually be easier just to like, for example, zoom in as opposed to just do that, because we do do that. If it's a bit dodgy, your your Yeah, put it next to your face. And I think the more we could do that, the better to be honest. So you do a bit on the machines on the monitors. So why not for 12 lead?

**Interviewer**

The visualisation, I've shown you the colouring. Do you think that will be the method to go forward? Or could you think of any other methods that will be useful? Have you think colour is actually rather nifty to have that think

**P14**

Colour is nifty once I saw it just because it's something that isn't used already. You know, one thing I suppose you worry about is if you're modifying the ECG trace itself, you don't want to distort it. So again, a crude example, I know, sometimes people circle that you should use or draw on them. And then you're like, "Well, I can't see what is on it, because you've just drawn over it". Whereas I suppose, because I just think of other things, you could do that you could make the line, different thickness, but then you'd probably lose detail. I suppose you could change the colour of the line. But will it become harder to look at? So I think colouring in the the area, yeah, I think it's probably a good way. I mean, other than just highlighting that the whole area behind I think that's probably a good call.

**Interviewer**

Thank you.

**P14**

I guess it's just you don't want to do something that doesn't distort the ECGs and I suppose it probably depends on the way that this is done, you know, if it was to present you a static image, then that'll be important. If it's actually something dynamic, where you could turn it on and off for like, remove the annotations, and it probably does, I feel like yeah, because you can always go back to the original then. So

**Interviewer**

Cool. Comparing this method to contemporary methods, like automated readouts or thresholds, pro cons going for colour, readouts? What are the pros of having a colour compared to a readout?

**P14**

And I think they both complement each other, I imagine because, you know, the readouts are useful, you know, because I often tried to interpret the ECG, and then look at the readout and see, you know, which bits I agree with, that it agrees with which bits, you know, have I missed, or what bits has it said that, or but I think, you know, it's, if you could have that readout with you, because I think sometimes it gives you its read out, and you just think that's silly. But I suppose if there was a way then for it to kind of say, it thinks this because of this change, it might just give it a bit more context, and either make you more inclined to agree with the machine or actually give you more confidence to disagree with the machine. If it's actually pointed out the thing it's seen, and you think it's just an artefact or so I think they, I would think they wouldn't use one or the other. I would have both.

**Interviewer**

Obviously, it's algorithms at work. Do you think it's important to have expandable algorithms as in from putting the electrodes on the patient getting the actual signals running through the algorithm to come to an out Put as an ecology ECG wave, does this need to be explainable from ATP? Or can this be something like machine learning or deep learning methods where we have got a black box? That does something that we all don't really understand, but it comes to a rather accurate output? So is it for you, as long as the accuracy? Is there? Fine. I don't need to know what's going on? Or do you think, No, we should have explainable algorithms?

**P14**

No, I mean, I think for it to be a mysterious black box is fine. I can understand, you know, that, perhaps people's mistrust or discomfort with that, but I think we probably have to accept that, at some point, these algorithms will become so complex that you can't just, you know, go through it like, you know, an equation on a sheet. So, no, I mean, for me, personally, it wouldn't bother me. Good, I'm probably more interested in the results being useful. I mean, I'm just, I'm just trying to think, am I contradicting myself, because, you know, whenever I'm outside of ECGs, if I'm talking to your other doctors about their thought process. You know, I'm always very keen for them to tell me what, why they think what they think. And I say, you know, I just say, I don't care what the diagnosis is, you give me I just want you to tell me how you've got to it, and then we can. But that said, I think I would probably say this is something slightly, it's the same but different. And, I think, you know, if I can appreciate the computers doing a lot of sums and a lot of maths, which, you know, it is, it doesn't bother me, even if I feel like I'm slightly contradicting myself, there's some kind of,

**Interviewer**

No, it's fine, because I think the difference that you've mentioned is the chat with a colleague is to get to diagnosis and get it confirmed, because then you are the one that's basically putting the word into stone.

**P14**

I suppose there's maybe still an element, I'm trying to justify myself that maybe sometimes you, you have, you know, a patient with x, and you think it's a, b, and c. And, but because of my gut feeling, I'm still going to do that. And, you know, maybe that gut feeling I can't really explain, you know, I'm liking it to the Top Gear where Jeremy Clarkson was like, this car is better because of x, y, and z, but I still prefer this. Yeah. And there's maybe, you know, there's probably an element in our thinking of, you know, the whole gestalt and experience where you can't necessarily put it, define the working out. And maybe that's, you know, that's

**Interviewer**

interesting. So it's basically the black boxes, a bit of like, a gut feeling.

**P14**

Yeah. Because yeah, there's definitely patients where, you know, you say, actually the obs are fine, the bloods are fine, the ECG looks okay, but there's just something which isn't right. So let's just keep them a bit longer. And I probably, you know, you know, if I'm trying to get a colleague to explain that to me, I can't, you know, yeah, so that's probably the blackbox equivalent, isn't it? Yeah.

**Interviewer**

Well, yeah. And thanks for the analogy. That was it with the interview. We've gone through everything. Have you got any specific questions?

**P14**

I don't think so.

**Interviewer**

Stop the recording.

**P15**

**Interviewer**

So this is split up into five blocks, we're going to start with two blocks at the beginning then if you would need a break, we're gonna have a break. But it's just the interview will be quite fast and going through everything. The first block is about their general interpretation of ECG. So the first questions that I would have is how do you use and interpret ECGs? In your clinical practice? Can you just give me a bit of a overview of what is your clinical background? And how often do you read ECGs?

**P15**

I am a qualified emergency physician, A&E reg. I'm working in MRI Accident & Emergency department. I've been working as an emergency physician for 22 years. I didn't work in any other specialty other than that. Regarding the ECG, we are the first responder of reading an ECG. And in our hospital, the one who should read the ECG or sign the ECG is... should be a senior, or a reg, or a consultant. So all the ECGs done in the department just come to us to read it and sign it to decide if this patient... just like an eyeballing, does this patient need to stay in the waiting area, go to a bed, go to monitor bed, or go to Resus. This is how we will get... we'll come across with the ECG. And definitely we are seeing... I cannot say a number... if our numbers of patient to the A&E is like 400 to 600 per day, 90% of them have an ECG. And it has to be read and it has to be interpreted.

**Interviewer**

Thank you. So a lot of ECGs which are the hardest pathologies to spot on an ECG. So from your perspective, but also from your colleagues or in department, what do you think are the pathologies that probably get missed or are hard to spot?

**P15**

Yeah, and the confusion mostly from... mostly from the juniors comes from the heart block, the types of heart block. But again, from the A&E point of view, we just need to know: "does this patient need an immediate intervention, do I need to go to Resus or not?" That different type of heart block is... every one of them has a different approach. But when you go to a higher type, like type one, type two, type three... and type two has two subtypes in them. So from type two, type three, doesn't make difference, the patient end up in Resus, and in the emergency management. Type 1, we usually take it easy, we don't interfere with it. So it's... I think it's only heart block that makes people a little bit confused. The other thing is the electrolyte changes that cause an ECG change. It's always the reason such confusion was when it comes to interpret the ECG of an electrolyte problem. And especially how wide the QRS. If it's very wide, or if it's a little bit accepted wide, or it's narrow, they all usually confused. Is it... I don't know if I can say medical words?

**Interviewer**

Yes, sure.

**P15**

I'm talking about the ventricular tachycardia. Usually the QRS is wide, but if it's severely wide it doesn't mean there is a problem in the heart... it's a problem outside the heart, which is usually the potassium. If... also the rate of the ventricular tachycardia makes a huge difference. Usually, if the patient has a ventricular tachycardia, due to a lesion in the heart -- so you need to give medication to treat that -- and usually the heart rate will be more than 150. But sometimes you will have a heart rate of 120-130 wide QRS... which is still V-Tach, but it's not from the heart, it's actually something outside the heart, causing the heart to beat that way. And you don't give a treatment for the heart, you treat the cause, that's the confusion comes from here. And we learn during our own experience in A&E that sometimes actually, if you follow the book, without having a background of what you're treating, or what you're doing, you can kill the patient. And we have a lot of drugs -- cardio drugs -- called the black box. And, like the amiodarone... they're calling it the clean killer. You're in the guidelines in the pathway in the ALS of British Association, Resuscitation Association... they're saying, yeah, if the patient has V-Tach give amiodarone, but actually if this patient, if you give amiodarone... you will kill him. That's why ECG itself, it needs more deep thinking -- not only to read it and diagnose it. All these, like, people with high potassium, people with antidepressant toxicity (like the people using amitriptyline) if they took an overdose -- they will come with V-Tach. And someone will jump -- "oh, this is V-tach!" "Are you sure?" "Yeah yeah, let's give amiodarone." ... and actually, if you give amiodarone to these patients, you will kill them. And when he go to the coroner or the court... "yeah, the book said V-Tach, give them amiodarone." No, that is a very, very small difference in the ECG that makes you think it's not the amiodarone, it's not the problem. This is the thing that makes him [inaudible].

**Interviewer**

Very interesting. Thank you. In terms of how you read ECG is what approaches do you take to come to diagnose? Because obviously, there are various forms that you look at it and it's a pattern recognitions. Some approaches will be very mathematical, where you look at the squares and you measure something. Others are when you have certain monitors, they have automated readouts. What do you think are you going for and what do you think others use a lot?

**P15**

You see, when we start, I told you, they came to the right guy. I have my... my approach, and actually started this approach... to teach that approach to emergency physicians. At North Manchester General Hospital, I was giving regular teaching. It's called a complaint approach. So we don't as an A&E, we don't need to know every detail in the ECG. In A&E the patient has a very limited time with me. Either he will be stable, and discharged or admitted -- or he will die. So I need to work with that. So when I hold the ECG, my first question is: what is the complaint of the patient? So from the complaint, I will put in the back of my head, the differential diagnosis that I need to look for them in the ECG, then I will look for them. I don't really go for reading rate, rhythm, p wave QRS? Yeah, this is the usual way, and a lot of people using it, but I found... personally I found it just makes you lost. Yeah you hold an ECG: "yeah, the tachycardia, narrow complex tachycardia... okay, there is p waves, so yeah, it's a sinus sinus tachycardia..." Okay, but when you know the patient comes with... for example, comes with bleeding or with shock, septic shock or whatever. You just need to know this is a tachycardia related to shock. It's not a problem in the heart. Usually people when they hold the ECG they look for... is there a problem in the heart or not? Yes, that's definitely right. But again look at the complaint: what's the complaint of the patient? A lot of patient comes to the A&E above 70 or 80. When they come to admission, they have to do a baseline ECG for admission. Then the patient comes with a fractured neck of femur. He's going to orthopedic. Nothing related to his heart, but eventually he'll go to anesthesia for operation, so you need to do an ECG. When you see the ECG -- "oh, it's a right bundle... it's a left bundle branch block." Then one of the junior come running: "I have a patient with left bundle branch block -- need to go to Resus and..." "Hold on -- what is the complaint of the patient?" "No, just came with neck of femur." "Yeah, you don't have to do anything. This is not a problem now. Yeah, it's a left bundle branch block, but it's not related to patient presentation. It's something could be in there, so it's... still you read it right, but you applied clinically wrong, because there is no complaint." That's why I use a complaint. A patient comes with chest pain, what I need to do in ECG... to see an ECG... to say this patient go to PCI now, or no, he can stay in A&E for another investigation. And usually, I concentrate on the diagnosis that only need an ECG... you don't need any blood investigation for it. We're calling it... I am calling them the ECG killers. You don't need anything except a patient comes with a complaint, or what will kill this patient from the ECG -- five things or six things -- I need to look for them, then I will write on the ECG "negative negative negative negative 4444." Okay, that's okay. His problem is not from his heart. That's okay. He can stay. And only I'm looking for what will kill the patient. This is an... I can say this is an emergency point of view approach. We are different than Cardiology [inaudible] looking for everything: small boxes, large boxes. For us no, we look for: "do I need to act on anything on that ECG or not?" That's my approach.

**Interviewer**

Thank you. What are the current shortfalls in how ECGs are recorded, interpreted or stored? Do you think that are things that are particularly hindering in your work as well, fleet of 10 electrodes? Are the monitors right to see ECG? Do you think the paper strips are the right form to bring the ECG is? What do you think are shortfalls generally in clinical practice of how we use ECGs? Yeah.

**P15**

What I have noticed that... the people who are doing the ECG, of course, they are usually... they are the health worker, support worker, sometimes the nurse or junior nurse. The machine is adjusted on certain parameters. But when you are a little bit professional of how to look for things in the ECG, you may ask to change the parameter on the machine -- but they don't know that. So usually, the paper of the machine is working on 10 for 10 seconds, and the hertz, it's either 25 or 40. So the machine is adjusted on 40. Then when you ask the nurse "can you make it on 25?" -- "What? What are you talking about?" "Yeah, I just need to see the proper P wave... is it a P wave there or not? I need to change that -- this wave -- so I can see." And of course, there is a lot of things that advance it... to look at ECG like... like one month, I just say a word, something called Fontaine ECG. Only the consultant Rick only know about it... not a lot of people know about it. It just... you are rearrange the electrodes in a way to look at specific parts of the heart -- not only in the whole heart, you want to look at specific parts of the heart. So you are re-arrange. People are not familiar with it, because we don't use it... we don't see it a lot. It's something not... not famous presentation. But, however, the indication of using these Fontaine lead -- or Fontaine leads -- is to diagnose the second most common cause of sudden death in young people in the UK. And no one actually knows about it. A lot of people knows about it, but we don't see it a lot. But it's actually in the book. The second most... the first most common cause of this in cardiac disease in young people is HOCUM, which is hypertrophic obstructive cardiomyopathy. But the second one is... it's called arrhythmogenic right ventricular dysplasia, which is in the book... this is the second most common cause of death in young people in UK. And to diagnose it, you need the certain rearrangement of the leads, but no one knows it. So again, it's a little bit advanced, but this is from the electrodes, we have a lot of... a lot of incidents that happened over the last two or three months, the leads were... the ECG comes -- again when you are expert, you will know -- there is a problem in the leads, a lead displacement, or misplacement. So they put V1 and V2, then they put V3 in a different position, where it shouldn't be. That's why you will see it on the ECG, but if you are not expert to see it, you will just misdiagnose the patient. So I don't know if there is a competency for the ECG leads, but there is also a defect that doctors doesn't...don't do an ECG. Which is bad. So the nurse is still here: "this is a lead displacement/ misplacement." "No, I did it right." So she will tell him -- "okay, show me!" You cannot show her because you don't know how to do it. So I think doctors need to know how to do the electrodes, how to do the ECG. This is one of the things.

**Interviewer**

Are there any things that work particularly well that you wouldn't change?

**P15**

Yes, the Hive. The interpretation on hive... through the ECG is directly connected through... directly connected to Hive. Once the patient has an ECG [inaudible] on Hive. It's... it's an amazing detail. So you just need to click what you see. I wouldn't change that. But there is only one thing I think needed to be added. Yes, it's in the patient file on the Hive... his complaint, and... but it's in different places. So I want when you go to interpret the ECG, one of the items need to be added is the complaint of the patient. So when you write the complaint, then you start to click on the interpretation, and at the end, they give you a space to write down either your [inaudible] impression, your diagnosis, or whatever you want. So you can... both the complaint and your finding, and you can write your suspicion in that area. But there is no complaint. So anyone can open the ECG interpretation that I wrote -- "oh, he will know, this patient came with this complaint, and he was looking for that, and he found that [inaudible]. I don't need to go to another page of the patient file: what was the complaint, what did he come with?" That what we usually do when we have an ECG. I will ask the nurse, what's the complaint? She... "I don't know, it's on Hive." So I have to open the patient on the system, then I open the ECG... there is no complaint on the ECG page, I have to go to the triage. We need an item on the ECG page interpretation to see what's the complaint.

**Interviewer**

We've already answered the other questions. It would be time for break now. Do you need a break? No. Okay, so I'll show you.

**P15**

No, no, I'm alright. Do you need a break?

**Interviewer**

So I'll show you now some visualization on what we're working on at the moment. So this would be a visualization of Long QT s. Yeah. So if the patient hasn't got a prolonged, our key normal syndrome is normal. We've used cold colors. If there's any abnormal is a prolonged QT interval, it goes into dark red colors. So this would be one of the visualizations that we are currently working on, which is independent from the patient's heart rate. So you can still use the normal Graham's line and count, but it will still color it.

**P15**

Yeah, this is regarding the long QTc? A lot of times see the [inaudible]... will sit and have a paper and then try to calculate it. I always say the computer... yes, he doesn't... he's not doing good in the diagnosis, because it's computer. But calculation, he's more accurate than us. Because they need to calculate small squares and count where the QRS has ended -- in the inside the box, or outside the box, or at the line of the box? The machine is is a computer. The calculation... any calculation on the machine, it should be taken accurately. But... but people are wasting time, so long QTc comes on the ECG... it's 460... then I found a doctor calibrating "No, no, no, it's 600, it's 500." "How do you find it's 500?" The machine is calculating it better than you. Now of course you are using the formula called Brett's formula. But yeah, I don't want people to start to calculate with their head. So this one... so, what do you mean by this? This would be a bit on the...

**Interviewer**

This would appear on the screen for example. Yes sir. We are looking at visual aid. So this will be if you run it on a monitor if you have if you use cap hat for the iPad or in hive, you would see not from calculating it but you would see it In Colors, yes that there's something wrong with the ECG because it goes into red, for example if it goes into red that mean it's prolonged, prolonged. So you can see here from the time so you can see everything that's between over 250. And 370 is fine. Everything, then it goes higher up above 570 goes into dark red. So people should instantly look at it and say, No, that's something you're off. So this is what we do with LGTS. We're working on this condition at the moment. And we also looking into STEMI. Yeah, so this will be one of the early visualizations of STEMI, as you could see it, for example, that you could see Oh, there's the uplifted St. Segment. Yes. And this is instantly looking you in the eye, basically, because it's got a red color on it.

**P15**

Yeah, this is the thing that... so here's the problem with this one. We will doesn't look here, once they see something distracting them, which is the hyperacute T-wave... so they don't look at that. They look at the hyperacute T-wave, right, but no one look at this -- but it's very nice that you knew... you know what you do? The problem is here, and of course, it's one of the first the first thing with having an MI is the hyperacute T wave within minutes, then it will start to go ST elevation. Yeah. Okay.

**Interviewer**

So this is basically what we are working on the concept of visualizing ECGs we were just looking, this is one of Rick's questions. The X ray analogy, how does the way you look at ECGs compared to other imaging techniques, such as an x ray, do you make a difference between imaging? Do you look at an ECG in a particularly different way than an x ray, for example? How would you what sorts I think what the question Rick wants to answer is, if there's an inherently different way of one of the things we talked about is to miss something on an x ray, is different than to miss something on an ECG. If it's a broken bone, or if you've missed a broken bone, but the urgency of missing something on an ECG is usually more urgent than than an x ray more dangerous. Yeah, yeah. So I think that will probably what it's coming from what we don't need to go.

**P15**

Yes. Okay. Well, I will tell you something here. Yeah. Again, that's why I myself, use the complaint approach because I know what I will look for. Sometimes when you go for "okay, let's go for the rate, the rhythm..." you're looking for the things that you are already programmed to start to comment on: rate, rhythm, QRS complex, T wave, P wave... and you actually miss the things that you need to look for. And again, from the emergency point of view, I missed it and it's a big thing. But if you use... if I'm using my way, which is "okay, this patient came with syncope, so I need to look for Brugada, long QTc, HOCUM, AR VD, and I need to look for Wolff Parkinson White syndrome." These things, I will specifically look for them first. Once I rule them out... because these five things, I'm calling them the five killer, if the patient went to home without spotting them on the ECG, most of the cases who discharged it on our own base without diagnosing this ECG, they come next time in a cardiac arrest, and no one's know. "Their ECG was normal." "No, it wasn't normal, because you wasn't look for it." If you know what you're looking for, you will look for it. If you're just reading the ECG normally, sometimes you will miss what you need to see. But yes, you're right. It's the way you are interpreting the ECG will make you miss what's important. But yes, there is the X ray... is again, different. But again, from my point, okay, the patient came with cough: why I will look for his ribs, for his fracture? He doesn't have trauma. He doesn't have complaining of pain in the ribs. Yeah, I missed the rib fracture. But he didn't come with it. I'm looking only for pneumonia or pneumothorax. That's the approach. That's the directed approach.

**Interviewer**

Also, in terms of when you look at CTS, MRI scans, X rays, you have got a lot of functions to modify the image. You can change the brightness, you can zoom in, you can zoom out, you can apply different weights on an MRI. What this be something that will be nice to have from an ECG as well. Would you like to rebind would you like to zoom into waves? Exactly, yes. Okay. Yeah, cool. So this is somehow generally leading to how could digital technology enhance the way we interpret ECGs Is there anything particularly that you would find? So we've spoken about hive that you attach the interpretation directly more than planes of the patients directly on to the visualization to the ECG. And we have talked about that would like to assume and modify the image a bit more. Are there any other digital things that you could think of that?

**P15**

You know, I don't know if it will be applicable or not. You see, when, for example, in ICU, people are being admitted in the ward and in the rooms and the nurse or the doctor sitting on the desk seeing the continuous monitoring on a rhythm... I don't know if you can see that on Hive or not.

**Interviewer**

Not at the moment.

**P15**

Like Hive is recording? And you can see, like a monitored bed on Hive?

**Interviewer**

This is what we're doing at the moment, because this was one of the things that we identified ICU patients, they are monitored. 24/7. Yeah. But all that we record just goes down the drain, basically, because it's not stored in

**P15**

Yeah, it doesn't store on Hive, and the Hive don't recording as of the same time?

**Interviewer**

What we do now. There's we're working together with a company called Massimo because they run the background of the SpaceLabs monitors to the ICU. So we actually just trying now to get all the ECG data of ICU patients out onto the server and store them somewhere else. Because, as you said, if you don't look at it right in time, you can miss something. Yes. And it's not stored. And and yeah, so this is something that we're looking at at the moment to to get this actually,

**P15**

This one I've seen, one of the most important ones, because we usually also... a lot of confused with is this elevation an MI or something else? So the ST elevation says the shape of it... always confusing people, either make us do extra miles and extra investigation for the patient, and actually, it's not, it's not specific ST segment elevation. And sometimes someone will say, no, no, it's not specific, and the patient actually has an ST elevation and needs a PCI. So I don't know how you will manage to fit in that and to change that.

**Interviewer**

That will be the next question. No. Obviously, there is the there is a difference between giving a diagnosis in saying this is colored red, because it's a STEMI. Or it's it's yeah, let's say it's a STEMI for now, all the other way round. We could say we just colored the ST segment if there is some abnormality with it. But it's the clinician who then says, Okay, thanks. You've helped me, I see that there's something going on. But I'm seeing now that systemic, yes. So do you think that our visualizations will be more helpful in making a diagnosis about a condition as this is a STEMI? Or do you think would it generally be more helpful to highlight that something? Or that could be something

**P15**

In the second option? So always keep an option to the physician to see what his opinion, because if you made it that way, and the machine say, no, it is a STEMI, and the doctor decide that it's not... yeah, you have to go with the machine because it's now in the system, and it's legal, and... and all of this legality things. No -- keep it for the physician. He should be trained enough to decide, "okay, I know there is something here the machine showed me, but I think it's... it's an early repolarisation or it's the pericarditis... no, it's not a STEMI, this patient doesn't need [inaudible]." But yes, I think this will help us rather than sitting and calculate how many boxes this ST segment elevated? Or is it an elevation here or not? Yeah, this one would be very, very bad.

**Interviewer**

Perfect. Thank you. And then that's rather interesting what you said, because obviously, if the computer interprets something, and there are automated readouts, yeah, so a lot printed STEMI but then it's not a STEMI. Yeah. That kind of drives and I think that's my personal opinion. Now, it drives especially people that are not as versed in interpreting ECG. It drives them into a certain direction. Is it wrong if a junior doctor looks at it, and it sees ultimate readout? STEMI Yeah, it just kind of puts you in a box automatically. Which is also can be quite dangerous, at times

**P15**

Dangerous, and to be honest, it will just make the doctor just... anyone can do that, so there is no difference like... if you got -- with all respect of the housekeeper -- "Yeah, the machine's saying it's a STEMI, call PCI." "No, you have to go doctor... I have to go doctor." "Look if the machine says it's a STEMI, it's a STEMI." Yeah, I think... so it's better to give... give some chance for the doctor to start to learn more.

**Interviewer**

shown you colours now. Yeah, highlight abnormalities in ECGs. Do you think colour is the right way to go forward? Or do you think there could be anything else that might be helpful in visualising abnormal abnormalities in ECG?

**P15**

No I think colours would be... it's better than the words, like... the machine is already interpreting a very, very big interpretation there. We hardly read it. And it doesn't actually give us an idea. And the first... the first rule we learned when you read an ECG, don't look at them, the ECG machines.

**Interviewer**

We've just touched upon automated read outs. There are obviously threshold calculations as well that the computer does for you. What are just comparing ultimate readouts thresholds to our colouring approach? Do you think that's better? That's worse? I know, you've said that readouts just people should ignore that and to their own interpretation. So what do you think is the specific pros or cons in having colouring as opposed to thresholds?

**P15**

And we know that colours, they just take your eye away from other things. So, colours... the only problem with it or one of the problem with it, it will make the people concentrate on the colours and ignore everything in the ECG, because it's the first thing pops in my face? "Oh, there's an ST elevation!" Just look for everything else. Yeah, this is the only thing... but again, it will identify things. But it will make you just ignore the other things and ignore your approach of seeing the whole picture. This is one of them.

**Interviewer**

And if I will be, unless a very broad question, you can dream now. So will be the magic ECG theory. And so you've got one which will Hamlet, what would you change in ECG interpretation in the future? So what is the ECG of the future? This can not just be in terms of how we present the reader. This can also been how we take it with the just think big in terms of electrodes, machines, cables read us, yeah, okay.

**P15**

I need the machine -- or I need an approach -- to show me every specific area of the heart on itself. Like, when I mentioned the Fontaine wave... Fontaine leads... Fontaine leads only looking at the right ventricle, only the right ventricle, because this ARVD is the arrhythmogenic dysplasia... only a problem in the right ventricle. So when I do this Fontaine machine, only give me the right ventricle. So that's what I want. I want to think again: how we can put the leads to show me specific areas of the heart. Like, when we have a patient with posterior MI or he has inferior MI, they might usually have an ST elevation in the inferior leads. Our next step is to see if there is a right side infarct [inaudible]. So from the normal ECG, we have some idea: okay, there ST elevation in V4, but still I need to do a right side ECG. So we usually take either we take V4, put it here, so it will look at the heart, at the right ventricle, or I will take the whole ECG to do the right side. So I again... and the nurse should write 'right ECG.' Do I know what I'm looking for? So I want to see... and sometimes, yes, the ST elevation is just subtle... how can I make it more obvious? I need a more concentration electrode to tell me: yes, there is there is an elevation here. The ECG, it's a subtle elevation, but can I see it more big? More concentrated, more obvious? Yeah, that's that's actually what I want.

**Interviewer**

Brilliant. That was it from our side. Thanks very much for your input. Have you got any other questions? Thank you. I will keep you updated. Right?

**P15**

Yes. That is it. Yeah. Yeah. Great.

**P16**

**Interviewer**

Okay. The first question would just be around implications of using ECG. So if you could just tell me about your job role and how you are using ECGs on a daily basis? And yeah, how you interpret ECGs in your job.

**P16**

So I'm currently emergency medicine registrar, ST6, about to become a consultant at the Manchester Royal ED. ECGs are usually, in my department, indicated when someone presents with a chest pain, palpitations, syncope, collapse, or diabetic patients just feeling unwell. And, of course, anything else that might request these... we probably request ECG, for example, in elderly patients with broken hip as a part of the hospital admission. And also patients who present with something that very, very remotely could be cardiac, or that the ECG is indicated for the sake of completion, as well as the electrolyte disturbances. I think these will be the major groups of ECG -- however, the clinician can decide to use the ECG as well for any other reasons.

**Interviewer**

Perfect, thank you. So you've mentioned for certain pathologies, the next question is split up in in in two pathways. One is your subjective impression or opinion about that, the other one is more objective about what you've heard from your colleagues, or what's genuinely known to be the tricky ones in your field. So are there certain pathologies that are particularly hard to spot on ECGs? Are there any that get misinterpreted or overseen a lot?

**P16**

I think people are not quite used to check for prolonged QTc unless there's a prolonged QTc alert on the ECG which may be false or actually right, but people still miss it. People are now much more aware of the Brugadas so they do check for Brugadas. People are still less aware of de Winters. People are less aware of the epsilon. And also, even myself, occasionally I get confused with the... with the STEMI criteria, because my STEMI criteria seem to be a bit different than what the cardiology thinks STEMI is. So I think these are the major things. So when I usually think it's a STEMI, cardiology thinks it's not a STEMI. When I think it's not STEMI, they think it is STEMI... unless it's like really, really obvious, then we all think it's STEMI. And we agree.

**Interviewer**

Thanks. And what approaches do you usually take to come to a diagnosis Do you? Do you think you use pattern recognition? So you look a certain patterns on ECG or your approaches more mathematical that you measure things? Or do you? Which is probably because you're a rich analysis? Probably you're beyond that stage, or do you think that people rely a lot of on the automated readouts?

**P16**

So I know that the first stage when ECG is done, people rely on automated readouts -- especially healthcare systems that triage. I am not sure this is the established official, but it's definitely non-official protocol: that ECG is read as normal, then the ECG is not escalated to the clinician. If anything is abnormal, including something very, very basic like sinus bradycardia at the heart rate of 55, that will be escalated to the clinician for the interpretation. How I personally approach... my personal approach is like, first impression, like, ah, can I see anything obvious? And then I go into the scrutiny. I scrutinise the ECG, I rely on heart rate, just to speed things up, on the ECG... I think it's quite reliable, especially in AF. I hope it's reliable. But then I scrutinise the ECG for the rhythm and I scrutinise ECG for ischaemia but then I scrutinise ECG for all those extras that I do not want to be missed. That will also depend on the age in the presentation and which I will put more focus... if someone is presenting with the electrolyte disturbances that I would try to find some signs on the ECG for electrolyte disturbances. If the patient is presented with a chest pain, chest discomfort or equivalence, then I will be looking for the signs of ischemia, including, you know, de Winters and stuff. If the patient is on a younger scale of age than I will be looking for Brugadas, epsilon waves. And I try to look for QTc purely because part of my Master's was... was influence of drugs on QTc prolongation, so I think I'm a bit biased in that point of view. But when I try to teach all the juniors -- because they all have their own methods of doing it, and most of those methods are quite similar to each other -- I try for them to incorporate the QTc analysis, and teach them how to check for QTc on an automated reader, but also how to manually calculate QTc when there's something abnormal.

**Interviewer**

Perfect, thank you. You'll be pleased what you see later on, I guess, what are the current shortfalls of ECGs? And just don't think of how we interpret them, but also think of like electrodes, monitoring, how they're reflected in hive. So, the whole world of ECGs basically, yeah.

**P16**

So for me, as a clinician, I think I'm overwhelmed by the number of ECGs that are presented to me. And especially if I am one of the EPIC -- EPIC means 'emergency physician in charge' So you literally get every few minutes, "can I have a look... can you have a look at this ECG" and this ECG is actually normal.... they just like you know... you had another five junior doctors queuing to ask you questions, you have a couple of sick patients coming in, with 150 patients in the department. So that's... I need some relief from that point of view. And then when it's something [inaudible] and I'm not sure about the ECG, that's additional, like, I see something is definitely not abnormal... but I have no idea what is not abnormal, this is not a thing. When it comes to ECG electrode placements, I quite often... in just passing by emergency department to see how ECGs are placed, I can see they're not placed correctly. But then I have like, I can't intervene with absolutely everything. I usually point out like this is not right, ask a senior nurse how to do it... but then the same people do the same again. People are struggling with ECG when I request posterior, right sided, this is a big thing. And it usually involves instead of me explaining it, it was a bit of Googling and showing them diagrams and pictures. This is the easiest way. Then the people are difficult in getting this change on the ECG, so we actually know what we are looking at in the end, because that ECG will be recorded as a normal ECG with a V1-V6... then I need to figure out which one is actually not corresponding to the posterior. So, this is another thing. When it comes to how... oh, okay, very rarely people change the leads, which is relatively easily recognisable. Then I just ask them, you need to go do it again. Occasionally, people roll their eyes, when I tell like ECG needs to be repeated in half an hour, especially for anything that sounds essentially to be cardiac ischemic. Then they roll their eyes, because it's a lot of work. And what I noticed is quite a lot of elderly patients they shake so much so because a lot of artefacts... and waiting for this green screen on an ECG can be also quite time consuming, for all the electrodes to go into the grid, and then occasionally you just want to override them, and for some reason you can't override it, because you're actually happy what you see on the screen, despite the machine not being happy. What else did I noticed? Yeah, on Hive. We have some periods where these ECGs aren't being uploaded. We know they are done, it shows they are done, but we can't see the ECGs -- they're lost. And then we need to go to Muse, they are usually on Muse. Also, it's quite annoying when I don't believe that all of these ECGs are still being retrospectively uploaded from Muse to Hive. What else did I notice... [inaudible] view usually when we see that the system is falling in general, we usually tend to upload ECGs as a folder to media. That kind of goes as a message to the older healthcare system and all the nurses will do the ECGs but then, those ECGs are gonna get probably lost, because they aren't going to be in the ECG section. I think that's all...

**Interviewer**

Thank you. Are there, as opposed to what doesn't work, is there anything that works particularly well at the moment?

**P16**

I mean, the... how one thing that is quite, well, quite bad is when you request the ECG in the Minors area, it takes forever for ECGs to be completed. What works well? Well, I think in all the majors and Resus areas, ECGs are done quite quickly. I personally think that the automated reader is quite reliable, I think. I don't have any data. This is my impression. I usually don't look at automated reader at first. I check myself with the automated reader -- then if I find discrepancies, I kind of have another look, and think oh, actually, it was right or it was wrong. Most commonly right and wrong. But I also noticed the automated reader does not recognise certain patterns. Like I don't think it'd recognise Brugada. I have never seen Brugada [inaudible] and I had never seen epsilon waves, or De Winter, or a lot of stuff... those kind of special ECGs not to be missed. What else works? Well... I think with the new machines that we started working with, I think there was more issues with all the machines that they had a lot of artefacts, I think these machines now, are with less artefacts. What I believe is that probably there's quite a lot of settings that you can get deeper into machine and optimise the ECG, but people who do these ECGs are usually nurses and healthcare assistants have no idea about those.

**Interviewer**

So is that if I will be the magic ECG theory, and you could wish for everything in terms of ECG from me? What will be desirable in the future? So how do you see the future of ECGs? Basically? Okay,

**P16**

This is a really interesting question, because 10 years ago, when I was... when I just graduated, I had a chat with one of the MIT students who was very interested in medical technology. And we were talking about what does ECG needs to do. We wanted at that time -- and I still want it and nothing has changed much, to be honest, in the last 10 years, when it comes to our issues -- we want wireless electrodes. We want electrodes to be in that position... so there's... there's a picture on the electrodes as how to set them up, and how to put them in place. We want some spare electrodes with a picture of how to put them in the posterior electrodes and right electrodes position -- and when you connect those electrodes you automatically change it on the ECG. You want ECG to give us the current graph, basically, electrocardiogram... but we want them to give us interpretation, not only on the rhythm, that there is an ST elevation... we also want them to give interpretation in which area of the heart is affected, and what is the next best step? Basically, at that time, without knowing much about artificial intelligence, we wanted AI analyse the ECG with some practical aspects as well. Like wireless stuff. We also wanted the ECG to be incorporated in in every monitor, ideally. So people are not looking for the ECG machines.

**Interviewer**

Yeah. Well, that will be that will be really helpful. Yeah.

**P16**

And I'm sure it'll come at a cost.

**Interviewer**

Everything comes with a cost and especially in health care costs are extortionate for right, and what do you think a simple thing, right, right. And often wrong reasons when you see but this is off of record. Now, when you see the margins that they put on health care devices, and it's just ridiculous. And then people will know the NHS.

**P16**

Trust me, I know. I used to work in Croatia. I was in charge of getting the equipment for the ambulance service. So defibs, ECGs... At one point, it was my decision to expel the 12 lead ECG is because we have a standalone ECG on every ambulance. It was my decision to expel those because the maintenance was expensive, and you had to carry one more device and actually just to get it onto the defib machine.

**Interviewer**

It's yeah, it's ridiculous. It's it just doesn't make sense. It's just not worth the money, basically, I'd say and then you've got licences, maintenance fees and everything.

**P16**

I'm gonna share one more thing that just crossed my mind: would be alert on hive when there's major critical results on ECG, okay, to the clinician and to the nurse that is allocated to the patient -- or if no one is allocated, that the critical message goes to the on call consultant. ,

**Interviewer**

Brilliant, thank you. And not bad, because I'm going to liaise all the hive stuff back to the group clinical lead for hive. So hopefully we can get some of those in return. I'm going to share my screen now with you. I hope you can see that. Can you see my screen now brilliant, if so, that’s what we're basically working on, and the QT interval algorithm is the one that's pre clinical trial now. So what we have done or what we basically do in is we use colour to visualise certain conditions on ECGs. So what you can see here is the upper ECG shows a patient with a normal QT interval, and the colours go from a purple to like a lime green. So the risk assessment tells you there's basically no risk of a prolonged QT interval. Whereas in the bottom ECG, you can see that the ECG is coloured in orange to red hue. So it automatically tells you in a visual feature that there's a prolonged QT interval with that patient. This goes on to a further strip. So you can see how this would look like for example, on a different visualisation, you could see that it starts off with purple colours, because it's normal. And the longer prolonged the QT interval is, the more read the colours actually get. In the zoomed in version, you can see the strip that's that's coloured in again on the screen here. And the second condition that we're working on at the moment is STEMI, or generally ST elevation. So this will work in highlighting the parts of the ST segment that are elevated in this patient. And then you could see, for example, that this is not just an hyperacute T wave in there, but there's also some ST elevation going on so it Prime's you to look differently at the ECG hopefully. This is what we basically do and so we'll be using visualisations and colours to look at ECGs. January now, related to that, do you think this technology could enhance how you interpret TTS?

**P16**

Yes, especially for the... I would have to say there's a quite a lot of senior clinicians who are struggling with those things... But definitely for juniors.

**Interviewer**

Brilliant. Thank you. That's, that's good.

**P16**

In general for all of us. Yeah, brilliant.

**P16**

And I've got a bit of an analogy in there with X rays. So that's just to think a bit differently, because obviously, we have X rays or CT scans, MRI scans, we can adjust the weights, we can change the brightness, we can zoom in, we can zoom out, we can highlight certain parts, we can overlay all the X rays with new X rays. How does this compare with how we use ECGs? At the moment? Would there be certain features from medical imaging that will be useful for ECGs?

**Interviewer**

Well, I noticed that when I calculate manual QTC, I notice that once small square can make a significant difference. There is a measurement that is beyond or actually within the small square -- let's say that way -- and I can't measure it because it's too small. So what should I do? Shall I do half of the square? One quarter of the square to get the precise number? And is my eye actually so good -- because actually, I can't see it that well, where does it actually begin? This is my... this is my worry, that actually means, am I gonna give magnesium or not this patient?

**Interviewer**

Cool. Thank you. And obviously what I've shown you now I've thrown you to specify conditions one LQTS and the other one is a STEMI. There are two ways of approaching the whole project. Do you think it will be more beneficial to just highlight any abnormalities in the ECG as in every wave in that patient demographic that's abnormal is in a colour so it Prime's you to look at it differently or do you think it's more beneficial to actually have an LQTS visualisation? STEMI visualisation? A left or right bundle branch block visualisation? So, generally just highlighting and the clinician is the one who interprets or do you want a colour that colours in a certain condition and you look for the condition.

**P16**

I think different things work for different people. I would go for both. I'm more person for colours, especially because you have been using the generally accepted colour scale, red to warn, green or blue to say like actually it's okay, it's anything in between, amber like, hmm, could be, but we are not sure or it is, but it's not that dangerous, it's not critical. But visualisation, in for example, left and right bundle branch block in having some schematic of the heart, or whatever is going to be used, showing this is actually the area, this is the blood vessel affected... I'm, for example, quite dyslexic. And for me to try to remember certain things is very difficult. So always I need to, okay, so this area is inferior of the heart is supplied by this blood vessel... especially when you have only two or three, then I get things confused. I managed to graduate from medical school and obviously finish my training, so I managed to compensate somehow, but I still find it difficult.

**Interviewer**

That's that's very interesting, because obviously, being dyslexic colours work for you because it shows you some,

**P16**

For some reason, colours work great for me.

**Interviewer**

That's very good to know. Do you think in general, because there are obviously other ways of visualising things. You could have dotted lines, you could make the ECG wave thicker, but there's a problem in the heart. Do you think ours is generated by the right way to go forward with I think colours?

**P16**

I think colours are generally the right way to go forwards. People are used to colours, especially emergency medicine. They're used because we be triage our patients according to the core groups: red acuity one, amber acuity two, green acuity three, and then four and five are yellow and blue.

**Interviewer**

Oh, so that that kind of reflects that, right?

**P16**

And if you if you go on Hive, if you change your context to emergency department, you will see the acuity call, so go have a look.

**Interviewer**

Brilliant, cool. Um, I didn't know that. That's very interesting. How do you see our visualisations in comparison to current methods? Like, thresholds

**P16**

Oh definitely, definitely. This is... you know... the ECG, when you look at the ECG it has not changed in the last 30, 40 years -- except you have some sort of analysis, which is more or less accurate. Nothing else has changed. Maybe there was a bit of better organisation of the ECG in you know, V1-V6, because if I remember older ECGs there used to be, you could have like all lines, all electrodes, in just one line, that was it, from I to V6. That used to be the case, and there was no analysis whatsoever. And usually, there was no... you had to manually write the patient's name. So those things have changed. But everything else, absolutely nothing. From my point of view.

**Interviewer**

no, it's Yeah, yeah, I had a I had an interesting chat with a biomedical engineer. And I was like, How can we leap from having ISS and robot surgery to still plugging 10 electrodes on a patient's body that are often have artefacts and it, it was rather interesting, but he said, it's generally still the best method to capture different areas of the heart. And I was like, it's not like a spray that you can put on a big plaster that captures everything in one goal, because it's very faffy. And then I don't need to tell you how it is when when you've got a really hairy patient, for example, you need to it's and I was like, we in 2024. Now, why is ECG still so complicated, basically? So yeah, it's yeah, it hasn't evolved at all, rarely, also, the method has been, which is interesting.

**P16**

Probably, if the Apple Incorporated would get the job to do this thing, right, it would be done relatively quickly -- because where there is money, there is going to be relatively quick solutions, right. Now a lot of people are earning a lot of money with the current, the current licences, current products. So I think this is the issue. I remember 10 years ago, when my friend and I were kind of trying to think about these things, we were thinking about those wireless electrodes, there was already at that time protected solution, which meant that we actually can't... so we didn't invent it. But obviously it was in no application whatsoever. I'm not sure if anything has changed in the meantime.

**Interviewer**

Um, no, I think not really?

**P16**

Probably if it is, it's expensive as hell.

**Interviewer**

Yeah. And I mean, even if it's expensive, they want the return on the investment. So if it's not returning any big money for them, it's probably not.

**P16**

Because it a patent on it. So yeah, unless someone buys it out, and decides to get into mass production...

**Interviewer**

terms of going back to our algorithms, how important is that these algorithms are explainable, as in, you know, from the data that comes in to the code that happens, and then it colours you to STEMI as a STEMI, LQTS, and from A to B, we perfectly know what the algorithm is doing. It's explainable, and it's transparent. Or the other side will be if you have something like deep learning or machine learning where you've got blackbox algorithms, and they might have an accurate output. That visualises the right area of the ECG with high accuracy. But we actually don't know how the algorithm makes the decision. Do you think there's a difference between those two? Does it matter to you? Does it not matter to you? What's your

**P16**

It does matter to me, because I would like to know, if the machine on itself, artificial intelligence, can actually self evaluate what is the certainty of this diagnosis or this analysis. So if it tells me this is a 95%, then I will be happy. If it says it's 65%, then 'm actually not really happy.

**Interviewer**

But how it comes to the 95% doesn't really matter, or it does

**P16**

In everyday clinical practice, I actually want to know less, because we are overwhelmed with so many things. So this is... this is good for those who want to know more, so I would keep that option open, but to be hidden up [inaudible] in a small "I" and then you click on it and then the window flips, and there's like a lot of information... so I will keep you there.

**P16**

Okay, perfect. Thank you. So that was the main part of the interview. Are you genuinely interested in being updated or being part of the project? Sure, brilliant. So as soon as we've got more prototypes going, and we've got more information, I'll just contact you again. And you also receive an Amazon voucher. 50 pound just as a thank you for taking part. Yes. Send out by finance at the end of the first cycle. So this will be in a couple of weeks. If that's okay, that's okay.

**P16**

Don’t worry. Yes. I'm still in touch with my friend. Yeah. Who is he has opened a firm so he's from Croatia. Yeah. I think he's a genius. He has opened a firm that is only doing analysis of graphs. And the major businesses like Microsoft have been hiring him. If you at any point want me to connect.

**Interviewer**

Oh yeah, always good to talk to people.

**P16**

Yeah, because he might have some insights in the meantime, what? I haven't spoken to him in many, many years, but I'm sure he's such a lovely guy that we would be able to do. If it's for the Advancement of Science or project. It's not a problem.

**Interviewer**

Yeah, that will be perfect. Thanks so much for that, such as stop the recording now.

**P17**

**Interviewer**

So the first question won't be around What's your specialty? And how often do you use ECGs? In your daily clinical practice?

**P17**

I do emergency medicine when I'm at work, which isn't everyday, because I'm less than full time, but when I'm at work, I use ECGs every day, multiple times a day.

**Interviewer**

Okay, brilliant. Thank you. And the next question can be split up into two pathways. One is your subjective personal opinion. And the second one is, what do you hear from your colleagues? Or what's generally known to be tricky in your specialty? So which are the hardest pathologies to spot on an ECG, or which are the ones that tend to get missed?

**P17**

I think the thing we worry about the most is myocardial infarction, and particularly fear there is an ST elevation MI. Subtle changes that can be associated with a STEMI, I think, is what we're all very worried about. What's the easiest thing to miss? I worry that we probably miss a huge amount of stuff, because we don't... we don't know that we should be looking for it.

**Interviewer**

Okay, brilliant. And when you interpret the ECG, what approach do you take? Do you think it's more of a pattern recognition approach? Are you very mathematical? Are you getting the ruler out and count the squares? Or do you also use automated readouts?

**P17**

We do have automated readouts on a lot of our ECGs. We are advised to not rely on them. I can do a systematic approach. But that is absolutely not the first thing that I will go to. I will take a sort of a general overview, put it into the clinical context, and then, sort of, zoom in on particular things. So I will get a ruler out and check a corrected QT interval, if I'm dealing with someone who's taken an overdose, or someone who's got syncope, and I'm interested in their QT interval.

**Interviewer**

And when you just think of the bigger remit of ECG, so how we put electrodes on a patient's body, how the data is represented on the monitor, and I mean, we are both at MFT. So we're both using hive. What are the current shortfalls of doing ECGs?

**P17**

Oh, my goodness. So availability of ECG machines, availability of personnel that can do them... and it's interesting that, I suppose, because there's usually one ECG in a clinical area (for A&E at least)... that won't be the only blocker, but as a result of that, doctors don't do their own ECGs and will ask for them to be done... they're often... the patient goes to clinical support workers room, so there's kind of a bit of a delay waiting for that to happen. Then there's cables everywhere, sometimes the cables are broken, sometimes the signal is poor, the patient might be shivery and you get loads of artefact on the ECG... It doesn't always upload to hive, so sometimes we get photographs of ECGs taken on a rover and then those uploaded to Hive... yeah, those are the some of the ones that...

**Interviewer**

thank you. Is there anything that works particularly well?

**P17**

No.

**Interviewer**

Okay, brilliant.

**P17**

I think... I mean, the way that Hive displays the ECG... and you can really zoom in on it -- it's quite interesting. So if you do really want to look at something in a great amount of detail, then you really can get in on the digital file, whereas when you had a paper printout you couldn't get so close to it

**Interviewer**

Yeah, I think that's basically the only thing because funnily enough, we've got such medical advances, but then ECGs haven't changed for decades, really. But it's such a brilliant diagnostic tool, but yeah, it's kind of stuck in the past somehow. If I won't be the magic ECG fairy, and I would grant you every wish about ECGs. How would you envision ECGs of the future?

**P17**

Oh, wow, quite differently. I think what I say to students when I'm teaching ECGs, is, it seems completely mad to me that we are mapping this 3d structure which is moving in time and we're trying to translate that onto a 2d graph, and displaying in the way that we do display it. I would want to be able to sort of interrogate the ECG from different angles. See... I mean, how wild can we go with this?

**Interviewer**

go with the students because you can completely you can go completely wild, you can go spaceship alien wild.

**P17**

I... looking at the recent papers about, like, I can't remember the right terms, but the graphs of the isoelectric, kind of, charts and things like that... and looking at depolarization in 3D to the representation of the heart, being able to scroll back and forwards through that would be absolutely fantastic. I'd want to be able to interrogate by... by regions, so blood supply regions. I'd want a visual representation of it probably in 3d. I'd want to be able to look at the back of the heart as well. I'd want to not have cables involved, I'd want to be able to always get the same ECG from the same patient at the same place -- so there's not an issue that you've had to examine them and take the stickers off, and then put them back on again, you're not quite sure what you're looking at... yeah. I'd want immediate access to it on my mobile device as well.

**Interviewer**

Yeah, brilliant. Thank you. So that was the general part, I'm going to share my screen with you. Let's see, we're gonna show you something. Can you see ECG strips now.

I'm gonna try to get as big as possible. So what we're basically doing is when you look at the upper one, you can see a patient with a normal QT interval. And therefore the colours range from like a purple to like a lime green. So we've got from very cold colours to getting into warmer colours, but we'd be looking at about 350 milliseconds. With that patient. The bottom one is a picture of long QTc. So you see that the QTc's prolonged and we go from warm colours into very warm colours, like a deep red, where we'd be looking at like 515 or milliseconds on a zoomed in version, version, an electronic strip, you can see that it starts counting from from a purple area. And then in this case, the patient has got a prolonged QT C, so we go into a dark red. That's one application where we're looking at our Qt s, the other one is which is just prototype really is stemming. So, that will be a ST elevation might be tricked by the hypercube T wave test, but there is actually an ST elevation going on as well. So this would obviously not be used in the colour scheme from cold to warm, because there is not much using in highlighting ST elevation that que in that sense. But you can see that there's some misinformation going on. And it's basically visualised and colour. So to sum that up, what we're doing is to be visualising certain ECG features with colour, and make them hopefully easier to spot and to interpret. So first question, do you genuinely think and I think we've touched upon that? Do you generally think that digital technology can enhance the way we interpret ECGs?

**P17**

Do I think we can enhance the way that we interpret ECGs? Yes, absolutely.

**Interviewer**

Okay, brilliant.

And there is an x ray analogy that Rick brought in, how do you think do the ways compare? Looking at ECGs? And looking at X ray, what do you think are the differences of looking at it all?

**P17**

I'm wondering what Rick's analogy is, and I'm wondering whether he made a link to CT scans or something like that... but yes, I suppose, looking at ECG feels like looking at a plain film chest X ray from, sort of... I mean, it's from a couple of angles. But you have to do all of that in your head. There's a lot of technical knowledge... which I guess there is technical knowledge in a X-ray as well -- but X-ray, I'm usually just following lines, and seeing whether the lines are smooth and connected or whether they're disconnected. And I guess on an ECG, I'm following lines, I'm seeing whether they're out of place... but often it's... it feels more subtle. It feels that the... you know, if I'm looking at a wrist X ray and someone's fallen over on their wrist, and I've examined it, and I know where it hurts, I can look quite specifically in one place -- whereas an ECG, someone's just going to have chest pain or breathlessness. I don't know where to look, I have to consider everything, which may be an argument for being very systematic.

**Interviewer**

Yeah, yeah, that that's what we're looking for. Thank you. Going back to what I've shown you There are obviously two options. One is visualising conditions like I've shown you before without QTR, sort of stemming. The other option will be just to visualise any pathologies in an ECG according to patient demographic, but not Up to having a diagnostic or condition based approach, aka leaving the decision making to the clinician, as we just highlight something that there might be something wrong. But you make the decision which one would you prefer?

**P17**

Me personally or me thinking about colleagues?

**Interviewer**

do personally and then colleagues

**P17**

Me personally, I think I would be... I think this maybe says something about the age and generational stuff, but I think I would like to have the abnormalities pointed out and highlighted... I'd then like to do the work of pulling together and interpreting them. And I guess that's because you're putting it into more context than the ECG machine has. So I might be slightly uncomfortable with an ECG interpretation coming to a definitive diagnosis when it's only got the information available on the ECG -- whereas the list of abnormalities would be very helpful, and maybe some suggestions as to what they might represent. I think for colleagues... and I guess we're seeing more and more patients, we are doing more and more ECGs... almost everybody who comes to A&E is getting an ECG these days, and as a screening tool, it would be very helpful to have a... essentially a diagnosis saying, "this patient's safe, this patient's unsafe" -- that kind of thing.

**Interviewer**

Brilliant. And then when you think of the colouring approach compared to other approaches, like threshold calculations, automated readouts, how do you think compares colouring to the current methods?

**P17**

I think on your QTc example, the colouring is... I think the colouring sort of reflects the reality that there isn't necessarily a hard cutoff, that it's a bit of a [inaudible]... on a spectrum. I suppose the downside of that is that people want binary good, bad answers, and so we'll probably end up in a space where clinicians or people interpreting the ECGs are like, "okay, well, which shade of yellow is acceptable?" Does that make sense? You know, all the people who've got green T-waves, that's fine, but, like, how far am I comfortable over this direction? And I suppose the approach at the moment is that we'll use a number, more or less, as a cut off -- and then talk to somebody and say, "actually, I'm comfortable with that -- yes, it's prolonged or it's on the high end of normal, but that's alright." So it might not solve that problem... it might add more information to it, [inaudible] out in a different way. Because I suspect there's a lot of ECGs where you've got a slightly prolonged QT interval, but nobody notices because nobody thinks to check... then it's not visually, sort of, made obvious to you. Remind me of your question, because I went on a tangent.

**Interviewer**

How does colour compare to the different methods we've got now at the moment?

**P17**

So I guess we aren't using colour at the moment, so it's a whole another kind of class of information that we can have to highlight abnormalities. That's appealing.

**Interviewer**

Obviously, it's a computer at work using algorithms. How important is it for you to know how the computer makes its decision, as it has it to be explainable from the moment that data gets in? The algorithms work on a rule based system? So you can see that x equals y because of set? And then you know, how the decision was made? Or do you say because a lot of blackbox algorithms or machine learning, where we basically don't know exactly what the computer's doing, but it comes to a rather accurate output? So do you say as long as the outputs accurate? I don't care? Or do you think there is a need for explainable algorithms?

**P17**

I think for the majority of cases black box would be absolutely fine. And I think that's probably because clinicians are used to looking at research, where we say, you know, we give this patient this drug, we're not entirely sure how it works, but look at the outcomes and we're happy [inaudible] the number needs to treat and positive predictive value, and so on and so forth. So I think we don't always have to explain things from first principles. I don't think people can explain an ECG from first principles. So I think there are flaws in that argument of saying we need to understand every single step of it. The caveat would be if there are decision making rules included in the algorithm, where it says... not necessarily to make rules... if there are definitions including the algorithm, it'd be good to know what the definitions are.

**Interviewer**

Yeah. And how do you see this from a patient point of view?

**P17**

I suppose I don't in many respects. So I'd need to kind of... put myself into the patient mindset about that, because I think a lot of patients don't see their ECGs, we don't necessarily talk to them in any detail about their ECGs... we'll tell them, kind of, you know, "we've done a tracing of electrical activity of your heart and it looks essentially normal" or "there's an abnormality on it... we'll need to talk about that, looks like you've had a heart attack." We don't necessarily educate our patients on the ECG interpretation. They don't necessarily see them themselves. So I don't think it would necessarily change the patient's experience, other than you'd hope that it would improve the diagnostic accuracy and [inaudible] better health care, but they wouldn't necessarily know that they're getting better health care.

**Interviewer**

Yeah, it's a conundrum, isn't it? Because most patients don't ask about a decision making process anyway. They would come to a point of non understanding quite fast. And so yeah, no, brilliant. So that was the end of the interview. Have you got any questions for me?

**P17**

I'm really curious about the work that you're doing. And yeah, I'd love to hear more about it and process. Brilliant, per se saying I think ECGs are incredible tool, an ancient tool that feels slightly fast. And there's a lot of devilry involved in interpreting them and teaching them and so on.

**Interviewer**

No, definitely. I'm gonna stop the interview now.

**P18**

**Interviewer**

I'm sorry, I started recording now. So the first question is: tell about your specialty, and how often do you read ECGs in your daily clinical practice?

**P18**

So: emergency medicine and I read ECGS every shift -- maybe 4, 5, or 6 in a eight hour shift, maybe even one an hour?

**Interviewer**

I guess you're signing off a lot of ECGs as well. Yeah. The next question can be split into two paths. One is subjectively, just about your perception, the other one is what's known in your field, or what you hear from your colleagues. And the question is, which are the hardest pathologies to spot on an ECG? Or which ones do you tend to get missed?

**P18**

The hardest ones? I think some of the heart block ones can be quite tricky, like the Wencebacks, even third degree heart blocks. Sometimes it's obvious, sometimes it can be a bit more subtle, if it's not super slow. Yeah, I think they're probably the hardest ones. I mean, STEMIs, they're generally quite easy... yeah.

**Interviewer**

Anything that junior doctors tend to struggle with when they let you sign off something and be like, I don't know what I should do with that?

**P18**

Some of the tachycardias, like an atrial tachycardia, sometimes even AF, flutter, sometimes they get a bit confused with -- probably more so with AF I think. Sometimes I've seen people misinterpret like a SATs probe tracing for VT, like someone's called me to Resus to help with VT, and actually it's just a sats probe tracing.

**Interviewer**

I've had a lot with narrow complex, when the rhythm's quite fast, people struggle to actually decipher it properly

**P18**

Slow VT actually can be a bit difficult as well, obviously, normal VT's 180, but sometimes you can get slow VT with like, overdoses, toxicology... you can get slow VT.

**Interviewer**

Brilliant. Thank you. When you look at an ECG and try to interpret it, what approach do you take? Do you look more for patterns as in pattern recognition? Then we have the very mathematical approach with a ruler and counting squares, or do you use automated readouts?

**P18**

Yeah, probably the first thing you get taught when you interpret an ECG is is to ignore the the automated rule. So generally I don't really look at that. I think, for me now probably it is just kind of pattern recognition. So you look at it, and instantly (I think, because I'm a bit more senior now) often, you can instantly recognise... yeah that looks completely normal, that looks like AF. And then, you know, sometimes you might get a poor trace. If it is a poor trace, you ask them to repeat it. But I think if it's a poor trace, you, you kind of will look at those more intently, you'll look back at a previous ECG. But even a couple days ago, there was a slow AF, which was like in the 40s. And that made me think is this actually a complete heart block? But it actually was slow AF, because I measured it out and it looks similar to the previous one, which was a bit faster. So I think the harder ones are the ones I actually will then -- you know -- look probably a bit more systematically where you look for a P wave, P QRS T, check that it's regular. What I've started doing now with the QTC intervals... often you'll get like five hundreds, so I started to actually measure it or calculate it myself. When you calculate it, it isn't actually that fast. So that's a useful thing, because then you avoid sending somebody to Resus for monitoring.

**Interviewer**

Thank you. What [???] interpretation of ECGs. Just think of the whole world of ECGs from electrodes to how we look at it on a monitor, even think of hive and how we store it. What are the shortfalls of contemporary ECGs?

**P18**

I mean, Hive, sometimes you don't always get loaded up, which is a bit of a problem. My biggest bugbear of ECGs is people who've got an abnormal ECG, and they (a bit unfair of me) but I always say, I'll print them off and say, carry around that, carry that around with you. And I suppose people can't always feel when they've got it on them. But that's always useful. Because we're in Manchester, there's so many hospitals around the city, that if it's what if it's not in one of the MFT hospitals, it's hard to get ECGs from a different trust. And I think that's just historical, that there's so many hospitals around Greater Manchester, where, perhaps if you've received one or two hospitals for Manchester, it'd be a lot easier

**Interviewer**

I think it's getting better. Because I mean, to be honest, from from, from my recollection, most of the paper strips wants to work signed off to it are just thrown away somewhere.

**P18**

I mean, you're supposed to ask the patient take a picture of it as well... that'd be useful because people always have their phones with them. And you saying what the biggest issues with ECG is? It does take a bit of effort still to learn it. And then there's like, keeping on top of it as well, you've got to review blog posts and things. The more subtle things like right ventricular strain, can you diagnose a PE on an ECG... Like I said the abnormal ECGs that are kind of chronically abnormal, they always can confuse confuse you a little bit if you don't have access to an old ECG. The left bundle branch block? Is it new? Or is it old? You don't always know that. And obviously, that can lead to problems.

**Interviewer**

So a lot of comparison to patient history basically?

**P18**

Yeah

**Interviewer**

What works particularly well? Is there anything where you say, oh, yeah, that's great about how we do ECGs these days?

**P18**

Well, when HIVE works well, then obviously, you've got that record. And I always will look back at old ECGs to see, is there any change? I mean, what's good about HIVE? Actually, you actually write in your interpretation, and I suppose previously, people just put the signature on the ECG. But now actually, you can do -- I mean, I just free text it generally, because I think there's too many boxes to tick on Hive. Yeah. Whatever. If it's normal, it's normal.

**Interviewer**

I mean, at least people can't scribble on them anymore.

**P18**

Well exactly, yeah. It's interpretable isn't it.

**Interviewer**

It's just everything's just scribbled over the waves? Is that what I think it is? Well, my paperwork...

**P18**

Another thing that annoys me about ECGs is when people write on the like... You know, someone's trying to, I don't know, maybe mark it or something. Although, yeah, the, the ST elevation, you might draw a line on to measure it. That really bugs me, because it makes it harder to interpret the next time but of course because it's on Hive now, you can't do that. You've always got the pristine ECG. The other thing, the J point as well -- like, measuring the J point like, benign early repolarisation, right. But yeah that's perhaps going back to one of my earlier questions. Benign early repolarization can be a bit difficult as well, particularly in a young person who's got chest pain. Because obviously, it can be a STEMI mimic as well, and that can give you a bit of a headache, so....

**Interviewer**

Just thinking of like, how often do you get across like something like Brugada, CPVT, and stuff,

**P18**

I've never seen it

**Interviewer**

Do you think people are aware of that if it if it would happen, or

**P18**

I've never seen it. So I always wonder have I missed it. But it's not always at the forefront of your mind is it, Brugada, because it's it's pretty rare, but obviously it's a devastating illness.

**Interviewer**

Wolf Parkinson White? Anything like this?

**P18**

Yeah, that that I do often look for, particularly when I do children's A&E, for children who have chest pain, or what they describe as chest pain. You're saying, could it be an arrythmia which has caused them to feel something they described as chest pain? Yeah, I always say, oh, yeah, always in children, young people with palpitations, always look for delta waves.

**Interviewer**

Brilliant. So what I do now is, I'll show you what we actually working on. So this is all very general. We're working on algorithms to basically colour ECGs to make them easier to interpret. So what I mean by that is, you see at the upper strip, the patient's got a normal QT interval, so everything's coloured in from cold colours to like a lime green colour. You can see that goes up to about 370, or let's say 400 in this case. With the bottom strip, you can see that patients got a prolonged QT interval. So you can see that this goes into red colours and warmer colours. And you can see that we are ending up at about over 530 in this case. On a strip, this could look something like that... if we zoom in, you can see that it measures the QT interval. And you start with cold colours, and if the QT interval is prolonged, you can just see instantly basically, we've arrived at something wrong because it's in the reds. This is pre clinical state, preclinical trial. Now, what we're also working on is on STEMI. So that will be a patient with a STEMI and hyperacute T wave. Some people might get tricked and just looking the hyperacute T wave and miss them as a STEMI. Yeah, this is basically what we're doing. So we've got algorithms that colour certain parts of the ECGs and hopefully make them easier to spot. So having shown you this, do you think that digital technology generally could enhance ECGs?

**P18**

Yeah, I mean, if it's picking up abnormalities, yeah, you would... you certainly would warn that there is something abnormal there. I suppose if you're doing the real bad abnormalities in red, I suppose that's useful as well, because red is a danger colour, isn't it? Our eyes associate red with danger or whatever, so yeah, really useful.

**Interviewer**

And obviously, there are two approaches, I've shown you two conditions that are coloured: LQTS and STEMI. The other approach will be not condition based, but just highlight any pathologies in the ECG, according to the patient demographics. So when you've got the strip and you see oh, okay, there's something coloured in, but it doesn't tell you the condition or it's not primed to the condition, would you prefer something that colours your specific conditions, or would you prefer to have something that's just genuinely visualises any abnormalities in the ECG?

**P18**

So -- both are just colours, they don't actually give the diagnosis?

**Interviewer**

They could... this is specifically done for LQTS, so it doesn't colour anything else, apart from our QTS. It doesn't colour anything apart from STEMI. So you can see there's a filter, you click STEMI on and then you can see, yes, highlighted red, there's a STEMI. Or you can just run the ECG, and then in whatever lead there's an abnormality according to patient demographics, it just shows you a different visualisation or colouring. So it could be a heart block, branch block, whatever, you name it, and it's just coloured then.

**P18**

I mean, there's so many subtle abnormalities maybe on ECGs that I don't... not that you ignore... but it's rarely that you get a pristine ECG that's completely normal... My only concern is you know, every report on the ECG is could be this, could be that. And you do ignore that. My only concern with something like this will be you're going to be highlighting everything and because it's been highlighted more, it's going to lead... well it's going to lead to more uncertainty and might lead to overinvestigations. It might just speed up the process -- sorry, not speed up, it will just prolong the process of signing off an ECG. And it might make things worse.

**Interviewer**

That makes sense. Yeah. Just generally, do you think colour is a good way of visualising things on an ECG?

**P18**

Yeah, because it shows up doesn't? Yeah. I don't know what... obviously that's on a white background, what that would look like on a pink ECG crossfield. Yeah, you might just think about what colours would... because red on a pink square thing...

**Interviewer**

This would generally assume that we've got something more like I personally interpret anything on a more like Hive based computer monitor. How do you see the visualisations in comparison to current methods as in threshold calculations and ultimately readouts?

**P18**

Well, I mean, I guess the downside is just what... the results are only as good as the machine that's doing the algorithms. So like I say, if if you see a prolonged QTC on the machine, you're still going to measure it yourself, because I think some of those machines are not always that accurate. And I don't know whether that would be similarly accurate.

**Interviewer**

It's a different algorithm

**P18**

Is it like a diagnostic algorithm? However it interprets that?

**Interviewer**

This literally measures agnostic of a heartbeat as well. So it literally just catches the QT prolongation because often with the calculation with heart rate is affecting such algorithms, for example. And, yeah, I was just agnostic of heart rate. And it works in terms of showing if... if it's going red, there is definitely a prolongation in there, if that makes sense. Obviously, we've got algorithms at work. One way is we've got complete explainable algorithms. So from the time we put the electrodes on the patient, and the data goes into the system, up until what the algorithm does, it's all rule based, it says if it's over one millivolt, then do this... So it's a set of rules that everyone can interpret, and it's very transparent how the algorithm comes to the output that this might be a STEMI. The other option would be as we've definitely heard about deep learning and machine learning blackbox algorithms where we don't really know... we know the input data, we know the output, but we don't really know how the machine is making its decisions. But the output can be very accurate. So it's useful to have applications that use machine learning. We don't know what's going on -- but we know with a 98% certainty that this is picking up things that we can use to diagnose. How important is explainability of algorithms for you? So do they need to be explainable from A to B? Or do you say, as long as the output's accurate, it's fine?

**P18**

I mean, yeah, I probably wouldn't understand all their algorithms, but you know, somebody like you, or Rick, or whoever says this, this algorithm is 98% accurate, then, dunno, I think that's probably good enough. But then I suppose you're going to be missing 2% of STEMIs. I don't know.

**Interviewer**

So do doctors probably?

**P18**

Well, yeah, fuck it, to be honest, yeah....

**Interviewer**

It's always people ask me: well, it's not 100%. But then what is 100%? Yeah, nothing really is 100%.

**P18**

If it's as good as maybe you can get it to be...

**Interviewer**

If someone publishes a paper with 100% accuracy, I will probably doubt the whole paper, because... yeah. From a patient perspective, do you think patients care about the explainability of the tools that diagnose them? Or, I mean, it doesn't even have to be ECG related. We use a lot of other. I mean, a CT scan or an MRI scan. Without a computer, we couldn't do that. So we need to trust a computer that is rendering the anatomical structures correctly.

**P18**

I don't think patients... I don't think it even crosses their mind. I think they just trust that whatever task has been done is accurate.

**Interviewer**

Brother, brilliant. Thank you. Have you got any further questions? Because we are at the end. Okay, any questions anything else. Brilliant. Stop the recording now.

**P19**

**Interviewer**

So the first question is around how often do you read ECGs in your job? And can you tell us a bit more about what that looks like in your daily clinical practice?

**P19**

Yeah, well, it's a bit of a cheat. I don't know if it’s the same. But in primary care, we get all our ECGs reported for us. So I'll probably look at an ECG maybe once or twice a week. I'll see an ECG and it'll either be an ECG I've requested that they send across to me, or the healthcare assistant will do an ECG, and she'll get your, she'll get a report and ship that, or can you just have a look at that or it will be that the healthcare assistant's felt an irregular pulse has done an ECG, and then wants me to have a look at it. So yeah, it's probably at that point, that's probably a couple of once or twice a week, I'd say, And then, but then it comes with it comes with a full report. And so it sort of breaks, it gives you a fairly good breakdown of rhythm and it breaks down, you know, all the different segments and abnormalities and I sort of, I sort of eyeball it to make sure that there's nothing, nothing crazy, that's been missed. I mean the reporting is done by a group of reporters. So it tends to be very accurate, actually. So yeah, and then they report it to a certain degree, and then it's sort of clinician to decide on further management. So that's probably that's probably the extent to which I sort of use ECGs, day to day, What's often helpful is comparing to previous ECGs. To look for sort of acute or chronic changes, so that's having access to previous ECG, I think is always the biggest, the biggest help in the acute situation. And, yeah, it's fairly straightforward. Where, it's different. Sometimes we, if we've done them, if they're fairly easy to find, and we can bring them up, often secondary care, and we'll do them but they won't send us an ECG report, they'll just give us one line of what the ECG showed. And when I worked in a hospital, there was a like a database that you can go in and they've got they had a bit of a historical record of ECGs. But yeah, I think that that tends to be the most helpful thing is obviously the report having a look yourself and then comparing it to previous ECGs. And often, it's all sort of long-standing changes really.

**Interviewer**

Cool. Thank you. So from, in terms of as they are reported, it might be hard to answer the next question, but you can probably refer back to when you've done your foundation stuff at hospitals and junior doctor life. Are there any pathologies that were the hardest to spot, have were colleagues had predominantly problems of spotting certain things on an ECG?

**P19**

Erm, the hardest things to spot? I think the biggest one in hospitals, that obviously we don't get so many in GP, is the tachy arrhythmias where the rate's so quick that everyone was, you know, is this SVT? Is it? Is it AF is it, you know, is it this isn't that and you know, especially, the especially the narrow complex ones. I think when the rate gets to a certain degree, now, everyone's a bit flummoxed as to whether you know what the abnormality is really.

**P19**

Cool and in terms of how you look at an ECG, would you say it's more like pattern recognition that you look for certain patterns in the ECG. Do you use mathematical approaches where you get the ruler out and count the squares? Or do you rely on things such as automated readouts for example?

**P19**

Yeah, so, I think it's probably fairly standard, isn't it, where you look at the rate and then you'll highlight I'll just sort of look at the rate and it will give you the rate and then I'll sort of eyeball it, let's go, yeah, that roughly correlates with what that is. And then yeah, rate, rhythm PR interval which I'll, I'll have a look into, you know, is it less than five or more squares QRS complexes, I look at the axis that I look for bundle branch block, ST segments and T waves. It's I mean, it's the fairly sort of standard undergraduate, this is how you grow up in CG. I still I still use that method to be honest. And I think it's a lot of so it's something Yeah, for rate. I'll be more rates and sort of PR interval, I'll sort of count things a bit more. And then things like bundle branch blocks tend to be more sort of pattern recognition.

**Interviewer**

Cool, genuinely just thinking of the world of ECGs, not just about how we look at them and interpret them, but also think of like electrodes and whatsoever or the machines that are used to record the ECGs. What are the current shortfalls of ECGs? And how they are stored and processed and everything else? You can speak about the whole big world of ECGs.

**P19**

In hospital, I found that I don't think the lead positioning was always great when they were doing the ECGs. I think that was a problem in hospital and how these ECGs have been done. And then I think that was the main issue. And then in clinical practice, I'd say I think the main thing is just having access to previous ECGs, which can sometimes be there's no, you know, with X rays, GPs can go into the hospital system and have a look at some x ray reports and have a look at some blood. And even if you really need an extra report or scan report, because we can look back six months for blood scan reports and all that sort of thing. But there's no, there's no good way of looking back and getting previous ECG reports. I think that's one area that's quite lacking is that communication between primary and secondary care in terms of ECGs because and everything else, you know that NHS computer systems are a bit of a shit, but generally speaking, there is, you know, there is there is a fairly established communication if you want if you want some sort of investigation result, but ECG is the one where you never really gonna get a copy of a previous ECG, especially when it's secondary care.

**Interviewer**

Cool that basically answered the next question about what will be good, probably desirable to have added in the future. I got to share my screen now with you and show you what we are actually working on. Which one do you see now? Do you see my presenter notes or the full one?

**P19**

I can see both the thing and presenter notes which was trying to see your presenter notes.

**Interviewer**

Why does it say swapping? Well, I'm just going to do that right now. Can you see that?

**P19**

Yeah, I can see the whole.

**Interviewer**

So what we're basically working on will be Long QT syndrome, for example. So we have developed a method that colours ECGs. So if you see the upper part, it's just cool colours going from a purple to like a lime green, which indicates that the QT interval of the patient is normal. In that case, the lower one will show you a prolonged QT interval. So you can see that it's going into more warmer colours from like yellowy orange to red. And you should then be able to easily spot that the patient's got a prolonged QT interval. On a strip that will be looking something like this. So you can see that it starts off with a normal interval, but then it goes into red. So it shows you that the QT interval in this patient is prolonged. And I also show you a zoomed in version a bit where you can see the colouring of the waves. And so this is the one that's preclinical trial stage. Now the other one that we are working on is STEMI. So we look at the ST segment elevation in ECGs. And what you would, what you see now is one of the forms that we use to colour in a significant ST elevation before we get into an hyperacute T wave in that case. So what we're basically doing to sum it up is we are currently colouring in certain conditions on ECGs to make them easier to interpret. Going back to that now just in general, what would be ways that digital technology could enhance ECGs for you? I think you can think of everything flashy future for what now like an iPad and whatsoever but don't be hindered by the current setup.

**P19**

Yeah I think in the usage from an ECG point of view, I think, you know, because the main, obviously, the main things you don't want to miss are things like ST elevation, significant ST depression. And I think what they're very good at the moment is giving you a technical report of, you know, this is the QTc interval, this is what the ST segments are doing, this is what the, you know, this is the rate, this is the rhythm. But I suppose it would be that next step of offering provisional diagnosis or differential diagnosis of, you know, please consider ST elevation MI, please consider this, please consider that. Just to sort of offset, I think this is the way medicine is going to go more generally with this with as technology evolves as where you know, you put in, it's gonna pick out certain symptoms and certain results and say, you know, have you thought of this diagnosis? Or have you thought this, and especially with cardiology, when you've got non specialists looking at it. The certain syndromes, you know, things like Wolff Parkinson White, you don't see a lot of things, you know, there's fairly niche syndromes where the clinician wouldn't necessarily think twice about it. I remember when I was in F1, F2 we had a junior doctor read an ECG, and they just put nonspecific ST changes, like they just didn't look quite right. And theirs was nonspecific. But actually, the patient had a heart attack. So if it said nonspecific ST changes, consider MI, then they probably would have thought a bit more about it. But I think, yeah, that would probably be the most helpful thing really acting as a, as a bit of a prompt, to at least, you know, consider a broader range of diagnoses, especially the more sort of more nuanced ones. Yeah.

**Interviewer**

This leads general to the next two questions, basically, because obviously, the two approaches to it. One would be in the future to generally highlight any abnormalities in ECGs. But don't be condition specific, or what you've seen now with what we're doing, because it just narrows down the remit of the algorithms. And it's just easier to have early proof of concepts with that, that we look at specific conditions like LQTS or a STEMI. So would you think it would be more helpful for you, in your practice, if something is flagged as abnormal, but you then make the interpretation and the decision of it? Or do you actually think it would be more helpful to have conditions flagged up?

**P19**

I think the conditions would be the more helpful because I suppose an example would be we were always on when we were on psychiatry, when you start people on antipsychotics that can prolong the QT interval. And so we were getting, we'd get all these ECGs of just old people with borderline QT intervals. And we were just a bit like, no one really knew what to do with them. They're like, cardiology weren't particularly interested. But it's a bit long, who cares? We didn't you know, so I think if it's if it said, you know, look, in that case, it could be this condition, this condition or this condition. And then you could say, right, well, they don't have any of the symptoms of this, any of the symptoms of that. And you can do that you can be fairly reassured that you've considered you know, you can, because I think like, when I end up what I will say is like, you need to, it's not about knowing everything, but it's knowing enough to know that you need to go and google something and be like "Oh, that sounds weird". And there's something in the back of my mind. And that's like a condition I've heard about going to look that up. And I think if ECGs could get to that point where it's like, alright, this is a bit weird, but here's three or four things you might want to look up, and it might be relevant to this ECG. It might not be, but you know, it just a little bit of a prompt, really. So I think that would be the most useful way to look at it.

**Interviewer**

Do you think colouring can be specifically useful? Or can you think of other methods that would help more?

**P19**

Yeah, I mean, I think colouring could be useful. And I think, you know, it's, I suppose it's then how that interpretation is, you know, how that's interpreted. And I think, you know, especially in I think in the acute situation, where you're looking at an ECG, I think to have things like you know, some colouring that said that would indicate to you this could represent ST elevation or this could represent, you know, ST elevation would be a good example this could represent ST elevation, then that leads you to a diagnosis of ST elevation MI doesn't it? So it puts that diagnosis in your mind for you to either exclude or investigate further. So I think colouring could have use in that. In that context, I think in the long QT context, if you said, right, this patient's got a slightly long QT interval, then I'd still be like, I'd still be looking at causes of Long QT interval. And it gives me you know, give me 10. And then it probably say, you know, they've got this ECG change and a Long QT interval, then, you know, it's more suggestive this condition. So I suppose a bit cut out that middle step with me having to look up refer back to the ECG, that would be it, that would be a really useful, you know, really useful step.

**Interviewer**

Thanks. And obviously, there are algorithms at work doing things to colour the ECG, and how important is it for you, as a clinician to have interpretable algorithms as in explainable from you get the basically you put the electrodes on the patient, they get the signals, the signals become data, and then the algorithm wrangles with that data and as an output and saying, Oh, this is coloured up to red, because the QT interval is prolonged. And we perfectly know from Step A, to B, what the algorithm is doing. Whereas there obviously are blackbox algorithms, but we don't know what the algorithm is doing. But outputs can still be accurate and it can still be used for a diagnosis. How important is it for you to have explainable versus non Explainable AI?

**P19**

So I don't want to have to make you listen to me go into it. I think we're gonna, I think, moving towards non explained AI is probably the way things are gonna go anyway. And I think we have to, to me, it's not a huge issue, in in terms of, it's not a huge issue in terms of like, I don't know exactly how this algorithm works, because I think, you know, there's a certain amount of trade off, and that you don't quite understand how it's coming to its decisions. But I think there's also fairly good evidence that even if you don't quite understand how it comes to its decisions, that it still comes up with fairly valid decisions. Because as I was, I was at a conference a few years ago, and they were talking about how, like, X ray, like, X ray interpretation, and skin lesion interpretation can be done just as accurately if not more accurately, by computers, and by AI. And now, in our area, we're now piloting a dermatology AI thing where you take a picture of a lesion, or you put it through this algorithm, and it says, it gives you an idea of is this could this potentially be a skin cancer, essentially. And again, that's that blackbox AI, but I think there's, you know, there's very strong data, that, you know, has utility, and so I think the variability is no more. There's no more than say, you know, a blood, a blood test with a 94% specificity, and then 96% sensitivity. Okay, well, then you factor that into your clinical decision making process. And I think as long as we've got some sort of, as long as there's some sort of research and some sort of checks and balances, that says, you know, this is this, this technology is, you know, 92% sensitive for ST elevation, MI, then that just goes into your clinical reasoning, and I think it's to aid the clinical reasoning of the doctor rather than replaced the clinical reasoning. So I think as long as it's approached in that way, then I don't think sort of blackbox AI is necessarily something to be worried about. And I think it's, there's potentially a lot more utility in it than just an algorithm that we put in because I think that then becomes a lot more limited and very, you know, like, you can look at one specific thing and give one specific, you know, a number of outcomes. So, yeah, that's what I would.

**Interviewer**

What do you think is the patient's perspective on this? So if the patient's asked about, you've told me there is something or you've seen something on your computer? How do you think the patient's opinion will be about having something that supports clinical decisions that is not completely explainable AI.

**P19**

I think, mostly I would I think they wouldn't. I think for the most part, they wouldn't think about it. I think as long as it gave good results, I think they'd be all for it. And I think generally people generally, patients tend to have, you know, basically the more technology, the better. And I think they've already got something unexplainable making clinical decisions about them in terms of clinicians, like they don't really know how the clinicians come to their decision. And they hope they come to a right conclusion and they've asked the right questions, but you know, there's a certain black box thinking to our GP [day to day].

**Interviewer**

You're right.

**P19**

Exactly, I think it, I think it forces the clinician. Because I think if you don't consider a diagnosis, so like, when we're trying to teach clinical reasoning, if you, if you've not considered a diagnosis at all, then that's one thing. But if you've been forced to consider a diagnosis, and then forced to generate a rationale for excluding that diagnosis, I think that's a much safer process than never having thought of it at all. Because if we can say, look, you do this with patients all the time when they come in with something that they think is worrying. But you say, look, yeah, here's your ECG. Here's your ECG. And it says, it could be a normal variation, it could be an MI, it could be atrial fibrillation, or, you know, whatever. And you can say, well, you know, look, these are the symptoms of an MI, you don't have any of these, these are the risk factors, you don't have any of these. Atrial fibrillation, it doesn't look quite like atrial fibrillation to me. So this is what you know, based on that, that's why I think it's a normal variant. So I think, in some ways, it makes it safer for the patient because it pushes the clinician to think a little bit further and, you know, to have more of a to engage a bit more with the ECG and with the clinical reasoning process.

**Interviewer**

we're at the end of the interview. I don't have any questions anymore. Have you got any questions?

**P19**

No, no, I think it Yeah, I just think it's all very exciting. There's a lot I'm very interested in this whole area. So I think it's yeah, it's it's very exciting.

**Interviewer**

Cool. So one of my colleagues has coined that as the term critical friends as the person staying on and give some input. So do you want to stay on as a critical friend as in we're going to keep you posted about the project and if there are any other considerations to be contacted?

**P19**

Yeah, that's a great.

**Interviewer**

You also receive a 50 pound Amazon voucher that will be sent out by finance at the end of the first engagement cycle. So give it a couple of weeks, but then it should be sent to the email address specified. I'm going to stop the recording

**P20**

**Interviewer**

So the first part of the interview will be very general about how you use ECGs and how you interpret them. And this can be from all over your career stage. So it can be things that you train as a medical student, or later on in your foundation years and things. Generally, now, how often do you read ECGs in your job, and what's your job role?

**P20**

So I, I read ECGs definitely every week, probably three or four times a week. And that's me working as a salaried GP.

**Interviewer**

Okay, brilliant. The next question can be split up into pathways, one for you subjectively, and the other one, what you heard during your training, or what you hear from your colleagues. Which are the hardest pathologies to spot on an ECG, or which are the ones that tend to get missed?

**P20**

I think I'd say maybe the bundle branch blocks sometimes are a bit... especially if they're a bit kind of borderline, and we're just not used to seeing them as often in primary care. And maybe also... yeah, and then from is that also from what my colleagues have thought as well?

**Interviewer**

Yes, it can be both.

**P20**

Yeah. So I think my colleagues as well, they've also said, like different types of heart block, particularly like, second degree. And what else... Probably, they'd be the main ones, I think. And then, and for me, I always check it. But I think also sometimes the, like prolonged QTc can sometimes get a bit missed. And that's, I think, especially important in primary care. Especially because you know, with the kind of drugs some of our patients are on. So yeah.

**Interviewer**

Brilliant. Thank you. And when you interpret ECGs, or look at them, what approach do you take? Is it more like a pattern recognition approach, when you look at it? Are you very mathematical getting a ruler out and counting the squares? Or do you use automated readouts?

**P20**

No, so we have to manually check all of our ECGs. And I tend to like, I mean, I'll have, like, an overall glance at it just to see if there's anything that, you know, there's anything really glaringly obvious. But then I actually stick to kind of like the pathway I do, which was taught in medical school. So, you know, I check each of the leads, and I think you just feel that responsibility. So yeah, so I do it all and kind of like a systematic review, just to make sure we don't miss anything. Because sometimes it can be really hard, you know, you might miss first degree heart block, for example, or some or something like that, oh, you might miss a particular change on a lead. So yeah, so I tend to do it like, systematically, like in medical school.

**Interviewer**

Brilliant. And you can think, really for basically of the whole ECG remits -- so from putting electrodes on to how it's presented on a monitor, how we store ECGs... you can think of the systems to exchange them, what are the current shortfalls in ECGs, and how they're recorded, interpreted, and stored?

**P20**

I think so probably some of the barriers -- I mean, for example, the ICT at the moment in our practice isn't working, so there's some like technical issues, sometimes, like it's pretty old, and it hasn't been like, you know, had it's regular checks. That's what we suspect. So that's tricky. And then, you know, so all the ECGs we get, each day get put into like a pile, and one of us will review them each day. And it's kind of just whoever gets there first to the box. But subjectively, we're going to all maybe have slightly different ways that we interpret them and pick up things. Also, I think it affects things, a lot of you know, the patient, and, you know, the indication which for ours -- I know, you can put that in so many ECGs -- but for our side, we don't. So It either means you have to [...] like, it takes time to go and look through the notes, see what it was done for. Because that's really significant if it was like for actual symptoms, or meds monitoring or whatever. But that takes a bit of time. And it's not actually something we have, like a policy on. So actually, some of GPs will do that, and I quite like to do that, but some of them won't necessarily. So, you know, there's a bit of discrepancy there as well. There's also just a little bit in terms of just like the logistics of you have to sign them and say what your findings are, and then they get [...] and then they get sent away and filed and uploaded. But the findings aren't necessarily coded. And also there's sometimes a delay with an ECG and it actually being uploaded. So you know, it's just... there is, like, room for error. Definitely. Yeah, in a few ways.

**Interviewer**

Okay. Thank you. Are there any features that work particularly well, I mean it and I always think from... ECG hasn't changed over decades, basically because we still put on electrodes on for a 12 lead ECG. So it might be hard to say that anything particularly changed that works particularly well, but is there anything that you say, oh, no, these are things that I wouldn't change about ECG that works really well?

**P20**

I think just the fact that it's so readily available in primary care as a non-invasive test... we're really lucky where we are, we don't have problems with appointments generally. And we've got really well trained healthcare assistants who can do them. So in terms of for the patients -- you know, accessibility -- I think it's really good. Similarly, I love the fact you get the instant result. And that's really, really useful, especially if you've got an acutely unwell patient. So I think there's, I think there's loads of benefits of it. And it does pick up a lot of stuff, I appreciate. It's not, but yeah, so it's good.

**Interviewer**

Okay thank you. And if I would be the magic ECG fairy, basically, and you could have all the wishes that you want and I'll grant them: what would be, what would you like to add on... what would be desirable for you of the ECG of the future?

**P20**

I think maybe a bit of a hybrid. So I've worked in practices before, where they do have, you know, they record them, and it's so clever how they put it through the phone, and then it goes over to a cardiologist who interpreted it for you. That's amazing, because you've got that expert knowledge and it kind of like... it's great for patients and patient care. But then it de-skills us as, like, primary care physicians. So it'd be lovely if we had some kind of in between where you have an instant, like, you get the ECG and the [??] as they attempt to interpret it... but then it almost gets like a final check over, like a, you know? And that whole kind of like coding and uploading, if somehow that process was a lot smoother, so it was just kind of like, instantly put, instead of a paper, it was just instantly put into the notes clearly for us to see, and then can be reviewed by a primary care physician, but also we get that, like, added learning feedback, and easy communication route and that would be amazing, you know, with a specialist, just so we could like learn and actually get better at the skill.

**Interviewer**

Brilliant. So I show you what we are working on now. I share my screen for that. You should see my screen now. Does that work?

**P20**

Yeah.

**Interviewer**

Brilliant. So what we are working on, basically, is we are using colour to enhance certain features of ECGs. So the upper strip that you see is a patient with a normal QT interval. It's interesting that you've said QT interval is sometimes the things that tend to get missed. So the upper one is a normal QT interval: there's no prolongation, you can see that the colours range from like purple to lime green, which we are speaking about... like 350 milliseconds, or something about that. The bottom strip, however: you can see that it goes from like yellowish to dark red colours, which would mean that in the case of this patient, they've got the prolonged QT interval. So, these are all cases of patients that are suffering from Long QT syndrome, for example. On a more digital strip, this looks something like that... you can see that the colours are first normal and the longer the QT interval goes the darker red the colours become. That's the zoomed in version for you to see how the algorithm and visualisations work, basically. This one is just preclinical trial stage for LQTS. We've worked on another one now, which is STEMI. So we'll be colouring in STEMIs. I've used a particularly tricky example here, because someone might just think, oh, it's a hyperacute T wave, but there's no STEMI just yet, when we can actually see that there's a ST elevation going on as well. So bottom line, we are using colours to hopefully make ECGs easier to interpret and just highlight certain features or conditions on an ECG. First of all, generally, do you think that digital technology can enhance the way we look at ECGs?

**P20**

Yeah, I do. Definitely.

**Interviewer**

And with the two approaches I've shown you obviously, there is one approach is a condition based approach. So we highlight everything that's an LQTS, or that's a STEMI, or that's a branch block for example. Or would you think for you as a clinician, it makes more sense to highlight any pathologies on an ECG, but you are the one that interprets them. So it's more like a decision support system. Both help making decisions, but the big differences are a condition based approach or just generally highlighting pathologies.

**P20**

Although both will be useful, I think maybe the one that helps highlighting pathologies but we still get some kind of decision making it would be good just because I imagine it'd be a bit broader.

**Interviewer**

Do you think colour as I've shown you is a specifically useful way or can you think of any other approaches to highlight specific pathologies in ECGs?

**P20**

I can't think of any other examples. I think colours are a really good one. Obviously the old school ECG machines, you know, and like the ones we still got the paper copies, you know? So to have that, like digitally on the computer uploaded ready would be... would be great and visually, you know, I think, yeah, colour would be really effective.

**Interviewer**

Cool. And how do you see our visualisation approaches compare to current contemporary ones -- as in automated readouts, or threshold calculations?

**P20**

Much more eye catching and more likely for you to act on and identify.

**Interviewer**

Okay, thank you. And we've got an x ray analogy: how does the way you look at X rays compare to how you look at ECGs? And this can be not just in the way you look at them, but also in the way how you would modify them. Because obviously, we've got modern medical image viewers these days, you can zoom in, you can change the brightness. So how do these two compare for you?

**P20**

Um, it's difficult to say because I don't ever interpret X rays anymore. So is this kind of like historically how I would?

**Interviewer**

Yeah that's fine. Yeah.

**P20**

And how they sort of compare, do you mean?

**Interviewer**

In terms of how you how you go about looking at an x ray, how we go about looking at an ECG. Do you think X rays are easier to miss things, or ECGs easier to miss things? And obviously, how you can transform them, because with modern image viewers now we can zoom in on X rays, you can change the brightness, you can... even with CT scans now you get full on 3d models of the organs on your computer. And the ECG compared to that is something completely different still.

**P20**

Yeah. So I think in terms of that, there's like, there's still a long way for ECGs. Like there's still lots of potential for them. I still, for some reason, would find it a bit easier to interpret an ECG accepting the fact that I'm probably a bit rusty with X rays. But I think like, you do have a bit of a structure with X rays. But yeah, it's probably down to me... just like, you know, what I've got more experience with, to be fair.

**Interviewer**

Obviously, it's algorithms that work, we have one way of doing things which is completely explainable. So we know how the data from the patient goes through the algorithms, and then we have the output, which will be LQTS coloured with a prolonged QT interval, for example. The other option would be we use something like blackbox algorithms, where we basically don't know what they are doing. There's machine learning or deep learning approaches, and they can come to very high accurate outputs, but we can't completely explain what the algorithm is doing itself to come to that output. For you, as a clinician, do you think you want to have an explainable algorithm? So you know perfectly well how the computer is coming from a to b? Or do you say, as long as the output's accurate, I don't really care what the computer is doing?

**P20**

Yeah, it's a good question. I think my gut feeling is having something where I can explain the algorithm, because I just feel it at QTc is a really good example, that actually little things like the rate I mean, how much you trust the computer algorithm, but there's lots of little nuances out there that do affect the QTc in total, and how you'd interpret it. So like, as well as just, like, the quality, but there's all these different things. So I think I'd rather have something, because I can think of lots of examples where we have algorithms in primary care. And so many times, we have exception ruling and things like that. And so and, you know, patients don't usually fit into a box and, even when it comes to say ECGs, so I just think maybe something where we have a bit more understanding about the algorithm will just make us feel like we're a bit more in control of what we're interpreting.

**Interviewer**

And how do you see this from a patient side?

**P20**

Um, I think it totally depends. There are some patients who are really embracing this kind of deep learning sort of technology. I think there are... I think there's still a lot who kind of like the idea of having a trusted physician who they can kind of put the responsibility for caring and having like a clear person who was or has overall responsibility, rather than kind of like diverting it to this kind of blackbox sort of thing. So yeah, I think they may prefer it too.

**Interviewer**

Brilliant, thank you. That was it. Basically, all my questions are answered. Have you got any questions for me or anything you would like to add?

**P20**

No, just it sounds really interesting. And when you kind of mentioned, I was like, Oh, that's great. Why don't we have that?

**Interviewer**

Brilliant, that's good to hear. And another question is, we coined the term critical friend, those are the ones that stay on the project and get updated from time to time or ask some questions. Would you agree to being such a critical friend, so that you can you be contacted again? Yeah.

**P20**

So I would, it just kind of depends on the timescale because I'm going on maternity leave. So I'll tell from here, but yes, so and then I'll probably go for around a year. So I don't know how long this project lasts.

**Interviewer**

So the projects goes for three years. So you probably hear two years when you've got baby and everything and you'd be like, yes, let's Do something medical again please. Yeah,

**P20**

I mean I'll have an out of office so you'll know I'm not ignoring

**Interviewer**

No, that's fine but but so it's good to know because obviously we don't want to contact you if you say no guys that was it. Thanks bye. So we're just going to keep that you also receive an Amazon voucher this will be sent from finance once the first engagement cycle on which will be in a couple of weeks so you should receive and email and if you haven't received it in the next half year probably please give me a shout because it's 50 pound and it's better than not having it as well. I stopped the recording now.

**P21**

**Interviewer**

So the first question is just about how often do you read ECG in your daily clinical practice? And what is your job role?

**P21**

Yeah, so I'm a GP partner. So I'll probably get every other day, we'll have ECGs coming back to us.

**Interviewer**

brilliant. And the next question can be split into two pathways. First, your subjective one. And then what you hear from colleagues are both generally known in primary care to be hard to spot. So which are the hardest pathologies to spot or which are ones that often tend to get misinterpreted or overlooked on ECGs?

**P21**

Uh, a difficult one, because obviously, if we are misinterpreting them, then I suppose it's probably the opposite, the opposite in terms of what ones are we confident in interpreting. I mean, I think generally, we're not that confident at all, because you get deskilled in primary care, as a kind of hospital trained doctor, you'd be looking at them a lot more. We then went to a stage where we had ECGs commissioned and done by an external service Broomwell. And so they would provide the interpretation along with it, so there is no need to interpret. And even the ones we used to send off to the hospital now, we'll come back with a manual report rather than an automated report. So we're doing far less now in terms of actually having to read ECGs ourselves, we are very reliant on the interpreting comments.

**Interviewer**

Okay. And when back in your foundation years, when you trained as a junior doctor, what approach that you use when you were looking at ECGs? Was that more a pattern recognition approach? Did you use mathematical approaches as in rulers and counting the squares? Or did you really,

**P21**

Generally, methodical as you say, in terms of rate and rhythm, and then looking at access and and looking across the leads in terms of categories of leads. So now, on the few occasions where I still need to interpret it, that's kind of what I'm doing is still going to that more kind of basic approach of going through things systematically.

**Interviewer**

Okay, thank you. And when you think of that, just have a look at these searches and interpret them. Think of everything starting from how we put electrodes on the patient to how it's being interpreted and sending back to you. What do you think are the current shortfalls of ECGs?

**P21**

So the biggest issue we have in primary care is it's a funding situation. The funding is very limited for ECGs, which is why we end up doing very little if none in-house nowadays. And so very much now it's about referring on Excuse me. It's about referring on for that ECG test to be done within the hospital setting and then waiting for the for the report that comes in. One of the things that we haven't yet done, but which I'm aware, other practices locally are using is the more mobile based devices like the Cardia mobile type devices instead. And it's something we're currently looking at as well, which may allow us to not send as many off for formal 12 lead ECGs.

**Interviewer**

Okay and is there anything that works particularly well,

**P21**

In terms of the current setup, the current setup we are referring on, I wouldn't say it's going particularly well, because there's long waits to get them done. Of late, we found that the manual comments for interpretation are not being provided anymore. So I think there's probably more things going wrong. And then well, with the current system.

**Interviewer**

If you could have anything you'd want in terms of ECGs in the future, what would be a desirable development for you? And what would you wish for would change in the future in terms of ECGs

**P21**

When I do think of more a point of care thing that's funded, whether that's Cardia [?] our own ECGs, and the the ability to go back to be being provided with interpretation reports, again, because of the fact that we do get deskilled. So it would be helpful to have that point of care and interpretation advice.

**Interviewer**

Brilliant. Thank you. I'm gonna share my screen with you. Okay, and show you something what we are working on at the moment. Can you see this on your screen? Yeah, brilliant. So this is what we are currently working on at the moment. This specific one you see is in stage defaults. On one stage pre clinical trial. You see two ECG strips, the upper one is of a patient with a normal QT interval. And you consider the colours range from purple to a lime green. So we look at about 350 milliseconds on the x axis. And the bottom strip shows as a patient with a prolonged QT interval. So this patient will have Long QT syndrome. And you can see that it's going from a yellow to a red colour, indicating that the QT interval is prolonged. On a more real world situation on a strip, this would look something like this, we'd go from a purplish to red, indicating that the patient has a prolonged QT. And this would be a zoomed in version. So you could see the colour scheme that we're using, apart from [inaudible]. Yes, we're also working on highlighting STEMI. So you would see a patient with an hyper acuity wave and the ST segment elevation, which is coloured in red at the moment. So this will be priming you and making you aware that this patient has got a STEMI. So to sum it up, we are basically working on algorithms that detect and then pseudoscalar certain conditions on ECGs. And the next part will be referring more to to the things in specific, leave what I've shown you, do you think that genuinely digital technology, and you've already mentioned cardio, that you're looking into this for your practice? Do you think in general, a digital technology can enhance how we interpret ECGs in the future?

**P21**

Yeah, no, definitely, I think there's if there's that ability where we get, I suppose the key thing is reliability of that interpretation advice. But if it was reliable, I think the digital means would certainly be a positive step forward.

**Interviewer**

Brilliant. And obviously, I've shown you specific conditions that have been coloured, which were acuity s and STEMI. Another option would be just to flag everything that's pathological in an ECG, but give the power of interpretation back to the clinician, or do you prefer having a system that's condition based? Or would you rather prefer having something that just flags any pathologies in an ECG?

**P21**

Now, I think from a primary care perspective is very much being told to key issues rather than being told everything we need to be, because I'd say we're not seeing them that routinely enough that we can be confident in our own interpreting ability. I mean, some years ago, yes, but now it was very much about being provided with a summary of the key points.

**Interviewer**

And now imagining that you would have a system like I think cardio is a quite quite quite good placeholder for that. If you have a digital way of looking at ECGs on the screen, do you think the colouring mechanism is a good way to hell, a pathologist, could you think of anything else apart from colour?

**P21**

I mean, colour seems fine. I mean, I suppose my perspective one to be really focusing on is the if we get the interpreting advice, want more focusing on the report rather than the trace itself. So from my perspective I want to see just what the report was, and any onward recommendations, I'm less fussed about the actual trace.

**Interviewer**

Okay, so you prefer something that's basically more verbal based rather than having to look at the trace? Yeah. And how important is it for you? Obviously, all this is driven by algorithms? How important is it for you to have explainable and transparent algorithms, as opposed to we often hear in immediate blackbox algorithms, they can be very accurate as well. But we basically don't know how these algorithms make the decisions. So is explainability a important thing for you? Or do you say as long as it's accurate? I don't really care what it's doing. Yeah,

**P21**

I'm not too fussed about what it's doing for the end user as a primary care clinician, I just want to know if it's accurate, I can make a clinical decision based on what I've been told,

**Interviewer**

what do you think from a patient side?

**P21**

I think I'm not sure they fully understand the whole concept of ECG to begin with. So I'm not necessarily sure they would necessarily want the detail of what the algorithm's doing. I suspect it's more around, again, can a decision be made with trust on what it's putting out.

**Interviewer**

Okay, brilliant. Have you think what I've shown you now and going forward in terms of digital technology and colouring ECGs or providing a more easier way of interviewing MCs, have you got anything that you would personally add into this going forward?

**P21**

No, no, not particularly. I suppose it's, it goes back to the interpretation advices. They may highlight different aspects of kind of way of abnormalities, but what's the clinical significance of that and what additional advice would be suggested.

**Interviewer**

Brilliant, thank you. Have you got any other questions regarding to the project? Because it will be the end of the interview. So if you've got any

**P21**

No, no, no, no. I mean, I believe I'm pretty informed [...].

**Interviewer**

cool. I stopped the recording.

**P22**

**Interviewer**

Yes, we should be recording. Thank you. So the first question is, what's your job role? What's your specialty and career stage?

**P22**

So I'm a foundation year 2 doctor. I don't have a specialty at the moment currently working in respiratory medicine, but we rotate every four months.

**Interviewer**

Yeah, brilliant. Thank you. Being an F2, how often do you interpret ECGs on a daily basis?

**P22**

Quite a bit, I'd say at least in a normal kind of nine to five day covering a ward, maybe once or twice a day, on an on call shift that tends to be more if it happens to be a night where there's lots of patients complaining of chest pain, you might see kind of eight, nine.

**Interviewer**

Okay, brilliant. Thank you. And are there any, this can now be subjectively, from your perspective, but also generally from your colleagues. What's known to be hard to interpret? So are there any pathologies that are hard to interpret where you think "Oh, those are things that are easy to miss or overlooked quite often."

**P22**

I think when there's a patient who has a tachycardia for some reason, there have been a few situations where there's a debate between is it sinus tachycardia? Is it atrial fibrillation? Is it flutter? No one's 100% sure. And it seems to be very subjective between people. Also, the degree to which you have a significant result, so for example, there might be someone who has some ST elevation, but different people disagree about whether it's significant. If it's not, if it's not meeting the criteria, and the patient's not symptomatic with a ST elevation MI, it can get a bit confusing.

**Interviewer**

Okay thank you. So, tachy patients and ST segment elevation things that are ones that you've mentioned. Thank you. For you personally, what approach do you use to come to a diagnosis on the ECG? Do you think you use more pattern recognition that you look at it and look for certain patterns? Are you from the mathematical kind of actually count the squares and look at the amplitudes and things? Or do you rely on automated readouts and threshold calculations? What's your to go to? And how would you think you interpret it?

**P22**

I try not to rely on the automated readouts, there's just something that I've always been told all through medical school, say don't look at the reading at the top. No one's ever told me exactly why we shouldn't. But they always said just don't, don't rely on it, calculate everything for yourself and create your own impression. So that's why I tend to do I tend to look at the rate. First of all, just look at the rhythm strip along the bottom, look at the rate look at the rhythm on the rhythm strip. And then from there, calculate if there's something that would have made me concerned for example, like a long or short Qt, I'll calculate that separately. And I'll use online calculators to help me with that. And, and then I look at each lead separately. And because the thing I'm most scared of missing is an MI, usually, that's what I'm looking for. But if there's something that I think looks odd, or I'm not sure if, for example, T wave inversions in some leads are normal, and others are not normal. I normally have like references coming next to me, like I'll use, like Life in the Fast Lane or something just like always be comparing, because it's not something I'm incredibly confident in.

**Interviewer**

Brilliant. Thank you! Do you think, are there any particular shortfalls in contemporary ECG interpretation? That might be how it's recorded, think of all the leads and electrodes, how it's visualised, as in the paper strip and the monitor. Do you think there are particularly things in your daily practice where you think, Oh, my God, it would be so much better if this would be different.

**P22**

I think sometimes there can be a lot of interference in the lead, and when there's a poor baseline to ECG that can make everything else 10 times more difficult. Typically, if you're in a situation where there's tachycardia, so you're not, there's not a lot of space between different waves anyway. And then you add in something that looks like a flutter, but it's just from like a patient who's moving or something like that. And I think also, I sometimes kind of wonder about whether they're like this, this kind of project has got me thinking about the way we put it the way an ECG is presented with the leads in terms of the numbers, but really, what you're looking at is the anterior lead, and the posterior and the inferior lead and the superior leads, but they're not grouped together in a way that really makes sense. Like sometimes I do have to go back and remind myself of which leads I'm looking at that correspond with an actual anatomical area.

**Interviewer**

Yeah, I know what you mean. It's like really are because Life in the Fast Lane it's got this nice visualisations with the colours and then I try to remember the colours, but it's very hard. And it's not it's not a natural way of reading things, isn't it? Because it doesn't reflect how the heart is anatomically build. Are there any features that work particularly well by you say, oh, yeah, that's really helpful. I really like that how it's done.

**P22**

I think having the rhythm strip, because also sometimes in between, where, for example, like one lead goes along, and then changes to another lead and the readout, you can get a bit of interference there. And sometimes I have kind of wondered, whether is it just the interference where it's changed between the lead and that's why there's like a funny, like, a funny gap there or something like that. But but you can never be 100% sure. And actually having the rhythm strip at the bottom for one continuous reading is really useful.

**Interviewer**

Thank you. Before I explain what the ECG X project is actually doing, we're going to show you some things that we're working on. If you if I would be the magic ECG fairy, and you could imagine or ask me anything that could be improved on or any future developments, where you would say, Oh, yes. Could you please change that? I mean, you've touched upon one thing was that the leads could be presented differently. Other one was a lot of artefacts in there. But if it's like a, you've got a free ticket of improving ECGs what they'd be, yeah, what would you wish for basically?

**P22**

Oh, that's a tough question. I think yeah, if there was something that was a way of like removing artefacts from ECGs, I think that would be amazing. And I think also a way of identifying the so sometimes when a patient is being cardio inverted, you get a little arrow coming with the P waves. And that can help when you have a rhythm that can be quite unreadable. And almost as if there was an error picking out P waves, like we do with a monotone, like continuous cardiac monitoring would almost be really helpful. I have seen there have been some situations where there's been debates between different doctors about whether something's a P wave, or whether it's not. And again, coming back to like, is it like fibrillation, or flutter? Or is it just a like a sinus arrhythmia? That can be quite challenging.

**Interviewer**

Brilliant. Cool. Thank you. So that would be the time for the break now. Do you need a break? Or can we just carry on,

**P22**

Carry on.

**Interviewer**

Okay, perfect. So I'm going to share my screen now. And I show you some of the things that we are working on. So you get a bit of an overview about what we're doing. So what we've basically started to work on rather early on is on Long QT syndrome. So you use that you use the online calculator to look at the QT interval. So what we've started is we've actually developed an algorithm that pseudo colours, your QT interval, and you can actually see from the colours from going to really cool colours, so up to like 370 milliseconds. It tells you it's all in a normal range according to the patient demographic. And then you can obviously see that the bottom line is coloured in orange and red hues. And you see that that's something wrong basically, and that the QT interval is is prolonged. We've done this with several other strips so you can see a non coloured ECG and then one where the QT interval is coloured, so it starts up to the nomogram line and you can see that it goes into the red colour. So you can assume that this is a abnormal QT interval. And this would be a close up look again how this looks like. And what we're currently working on is visualising STEMI. So this would be a mock up of the algorithm that starts to look at the ST segment and highlights any abnormalities in the ST segment. In this case, we've got like the hyperacute T wave with the ST segment elevation. So, this is basically what we are doing. So we are working on different forms of visualising ECGs to make them easier to to interpret. I stop sharing my screen now again, and look at some questions. So first of all, after you've seen the visualisations, I just want to bring in an analogy about X rays. So we're looking at MRIs or CT scans X rays, you have got a lot of image modification function. So you can zoom in, you can zoom out, change the brightness, change the rates on an MRI. Do you think this will be something genuinely helpful for ECGs? as well? Would you like to modify ECGs? in some form?

**P22**

Yeah, I think I find myself zooming in on entities a lot. So that's something I think it's something that we can do now. But maybe it would be helpful to have something in the software where you could maintain the quality of the image better. I think even something like an overlay would be useful. Occasionally, when you're looking at an abnormal ECG, it'll be in a patient that has a history of abnormal ECGs. And what you're really trying to establish is that has there been any change that we're worried about, so you'll have someone who already has a right bundle branch block, and they already have, like, a, like, sometimes you just still see someone and they have just an odd looking, for example, let's say odd looking QRS, like, not all of them are perfect, but then you go back, and you see that they've having that every single time. And it's the same that you can do with chest X rays, where you bring up one, and we always look at the old one next to it, it's just something that everybody does. And more often than not something that's a bit strange. On the newer X ray, you see it on the old x ray. So you can kind of what the ways you can kind of adjust your expectations like is that something we need to investigate or be worried about? In this new presentation of like an acute onset shortness of breath, or chest pain, whatever? Like, oh, no, it will if if they had that, and it's exactly the same and unchanged as last year, that's probably not what we should be looking at, we should be looking for something else. So having, I think, a function of being able to look at to ECG side by side, which at the moment is in the hive software that we use, you can't do. And the ECGs that we have, like the physical ones, are immediately thrown away. So you can't or you wouldn't and even back when we had paper notes, I don't know if you'd be able to find an old ECG to compare. And even if you can't look at them side by side, some way of overlaying them, I think would be useful.

**Interviewer**

Brilliant. Yeah, that's a that's a great idea. And then, are there any other things that we could digitally enhance the ECG or is that it I mean, you've touched upon a lot of these things? Anyway, so I think you've you've kind of answered these questions with artefacts with a different arrangement of the leads with a window to the past basically, so overlaying historical wave forms of the patient, and in terms of interpreting ECG, so with ECG x, we are working on two assumptions. One is that we just generally highlight any abnormalities in ECG. So we look at a patient demographic and say, okay, there is an ST segment elevation is a prolonged interval in that as hyperacute waves there's inverted waves. Or the other option will be that we specifically aim to highlight or visualise specific conditions as an a diagnosis. This is a STEMI This is a left bundle branch block. Yeah, so would you prefer to have something that gifts you a visualisation, as in? That's an abnormality, but it gives you the space to diagnose and interpret, or would you prefer to have something that's more diagnosing it for you already?

**P22**

I think I would always prefer to have something that just visualises, you know, in some way, something that shows you that or highlights that an interval is longer, or that there's like an inversion where there shouldn't be or something's elevated almost like we do when we look at when we look at a whole list of blood results, and you'll see ones kind of picked out in red. And then it's up to you to interpret that however you will. So, for example, there are some people who their blood pressure is always in the red because they always slightly hypertensive, and you can kind of look back on all that data and make your own conclusion. But your attention has been drawn to it. And I think there is such a because I think I know other kind of junior clinicians about my level have also been told not to trust the interpretation at the top of the ECG, and I'm not sure that's something that's going to change, I think I've definitely seen because the computer is I guess, interpreting whatever is below, and then when there is artefact there, you can't trust it at all. And maybe it's because I don't quite understand how the computer is making that interpretation. I don't trust it properly. And it's not just following, like a really simple algorithm identifying something outside a range, it's somehow comparing it to previous ECGs. We do get ones as they compared to the ECG from 15th of January, there was no significant change. But I don't know, I don't know what basis that's made on.

**Interviewer**

Great insight, thanks. Do you think that colouring is the way forward in terms of highlighting these abnormalities? Or can you think of any other means to highlight pathologies in in ECG?

**P22**

I think the colouring is really useful. And I also think I think you might have just had it on the previous image, you showed me just for demonstration purposes, but almost having the lines like the parameters there. So for example, having a line where the start of the bike at the start of the P wave. And because also, that's something that might be a bit easier for a computer to calculate is where it's actually starting, you know, when if it gets down to a difference of a millimeter? You know, that's something that I think there could be a lot of variation in what I would interpret to be the start of a P wave or start of T wave and what someone else does.

**Interviewer**

Okay brilliant. Thank you. I think we've spoken already a bit of future for what you make differently going forward. And we've also touched upon to comparison to current methods. How important is it for you to know what the algorithm is doing, as compared to you don't need to know what the algorithms doing as long as it is an accurate interpretation in the end. So that's obviously explainability and transparency on one hand, and then a blackbox algorithm that does something, but comes to a right conclusion, how important is it for you to have the expandability in such algorithms?

**P22**

I think it's, I think it's really important to me, and if I understand how it works, then I feel like you know, not that nothing is completely infallible. So if there was something, if there was a slight weakness in the algorithm, I think I would be able to know when to trust it. More like you have different, you have to prioritise, you know, a million different things. And if, for example, I knew that whatever way the algorithm worked, meant it was less, maybe slightly less accurate. If someone was in like a really fast tachycardia or something, then I would know that if someone is tachycardic, I need to actually look quite carefully at that rhythm, or if there was a type of patient. So for example, if you had, like a patient who was like very, very obese, and that somehow changed the pattern on the ECG, then that would be useful or if there was something that occasionally you do get things that are picked up and highlighted to you. For example, again, lab results are whatever, that are physiological, and you kind of almost get into a habit of ignoring those things, but then you always worry that what if I'm just thinking I'm ignoring them and actually one time I do need to pay like almost Um, what's that word like when you become, like insensitive to alarms, because we get a lot of popups and notifications and stuff on the system we have at the moment. And because there are so many, there has been a real concern about doctors clicking them away, and then missing one that actually needs to be actioned. So I think it would help me to know when exactly like what are the weakness, what are the strengths and what sorts of things it would highlight and why.

**Interviewer**

Yeah, brilliant. Yeah, it's like currently, muting monitors isn't that it's just ultimately without thinking it's just mute, mute, mute, mute, because they Yeah, I think that the threshold to trigger the alarm is so low, that it's just in most cases, people are so bias towards ignoring it that you just look at that.

**P22**

I think I think as well, there's a lot of when the current system came in, there was a lot of worries about juniors who, but almost kind of like born into that system, that there would be certain skills that would be lost. And I think that's also maybe part of the reason why everyone has said, ignore the interpretation on the ECGs. Do it yourself, because it's such an important basic skill to learn, in the same way that you shouldn't rely on, like a blood result being highlighted to you to interpret that it's abnormal. And I think that's something that I would be, I could see myself relying on it, and almost really relying too much on it if I was busy or tired or whatever. And I think ultimately, the best, the best thing would be for everyone to be able to have to have a great understanding, but obviously, teaching in different places is very variable and ECGs are very difficult.

**Interviewer**

It's like with these automated readouts and things. I think the we had a chat with someone else before and they were saying that with the ultimate readouts, you came to put your brain into a box, because when you read STEMI, you're just so focused on looking for a STEMI on the strip that you actually forget about everything else that could be. So I think it's it kind of sometimes Prime's you to look for the wrong things.

**P22**

Yeah, and I have had that before. Like, very, very recently, there was a patient who had an ECG that I reviewed, and it said, STEMI at the top, and for the life of me, I could not see the STEMI. And it was it was terrible. I was terrified. Yeah. And I escalated to so many people to try and find this dummy for me, which didn't exist. But I also think they bothered me that I didn't know why the computer could see like, I guess it wasn't there. But I didn't know why the computer could see it. And I couldn't.

**Interviewer**

Yeah, that's very interesting. Yeah. Because obviously, it just you just hit the wall because the computer you can't ask it. Why are you thinking this istemi you can't go into a conversation and get through a differential diagnosis of the computer in some form. So yeah,

**P22**

Yeah. I think in the eventuality that, if I was if I happen to be the most senior person there, that I wasn't able to escalate up to loads of people that evening. And something adverse were to happen, then you think kind of medical, legally, if someone looked back at that report, because the people who tend to do that aren't that, you know, they're lawyers and people, they would say, well, well, if it said that, then why wouldn't you action? Yeah, that's

**Interviewer**

Yeah, it's like, grey zone. Isn't that because then, yeah, it's very interesting. And, yeah, I feel if you don't have the route of escalation, all of a sudden anymore. That will be the ad. That must be strange. So we are actually through all of the Topic Guides. There is one thing would you be interested to be kept up to date on his project? And if we proceed further down the line with new research and probably new algorithmic developments, can we contact you again about your opinion? Yeah, absolutely.

**P22**

I think it's really interesting is really, really interesting.

**Interviewer**

Thank you. And once the first cycle of stakeholder engagement is completed, you receive a 50 pound Amazon voucher as a token of appreciation just for for taking part. Have you got any other questions to us, or any debrief issues?

**P22**

No, no, I don't think so.

**Interviewer**

Brilliant. Well, thanks so much for your time. Lovely talking to you and get to know you. Thanks for thank you so much. If there's anything that comes to your mind, or whatever, just drop us an email, whatever you feel like and I'll definitely keep you up to date.

**P22**

Yeah, thank you and good luck.

**Interviewer**

Thank you. Have a lovely, day. Bye bye.

**P23**

**Interviewer**

Now, the first question is just about how often do you interpret ECGs? In your daily clinical practice?

**P23**

Um, so I'd say... probably a couple of times a shift, on average in critical care.

**Interviewer**

Okay, brilliant. And do you think - the next question can be split into Pathways basically - one for you subjectively and then the other pathway will be what's generally known as or what your colleagues say and what you heard about. So which are the hardest pathologies to spot on and ECGs? Are which one wants to tend to get misinterpreted?

**P23**

Hmm, good question. Let me have a [inaudible]. So I suppose subjectively, I think rather than... aside from obviously, like a barn-door STEMI where you can really see it, I sometimes find other, like, markers of infarction or ischemia quite difficult to spot -- you know, things like the T-wave inversion, or the depression, or the stuff that's slightly more... like, not... basically not like a tombstone. They never really... because like... so rarely do they actually present like that. So I suppose that I think, definitely, like, bundle branch blocks... I would really struggle subjectively to spot anything like as well. In terms of colleagues: I think, similarly, I would say, the different markers of ischemia would be another one for them. And I think, when you're dealing with like a tachyarrhythmia, as well, sometimes, I've heard people talk about, you know, the difference for when you're dealing with, like... like a ventricular tachycardia, or if it's going to be actually something from the atria that's, like, got a branch block or something that's making it look like it's ventricular in origin. So I guess tachyarrhythmias can be quite tricky. I've heard other people talk about that.

**Interviewer**

Yeah. Okay. Thank you. When you look at the ECG, and you interpret it, what approaches do you think you're using? Is it more like a pattern recognition approach? Did you look for certain patterns? Are you more mathematical get the ruler out and count squares? Or what do you think of automated readouts?

**P23**

So I suppose I try... I "try" [laughing] to stick to, like, initially looking at the rhythm strip, just to look at rate and rhythm. I really try and, like, focus my brain first on that to set... rather than jump straight in and look for, like, irregularity. But then I'd say after that, I can go straight on to pattern recognition. So, like, we learned at med school, obviously, like, "then you look at the P wave, and then you look at the QRS, and you look at the..." I don't think... I think after I've looked at the basic rate rhythm, I think I'm then, like, immediately looking at the ST... I'm looking for patterns that I know. And I think yeah, that's probably what I do at the moment.

**Interviewer**

And now think further. So you can take the whole remit of ECGs into consideration from electrodes to monitors ,Hive, how its presented in the EPR. So what are the current shortfalls of contemporary ECGs for you?

**P23**

Good question. So I would say the shortfalls are... sometimes finding where they are on Hive? And sometimes they've been done by the nurses, but they don't seem to make that jump onto Hive and then you've got the mixture of, like, a paper one flapping around somewhere, and not on, like, the cardiology tab that you think it should be on. I'd say, yeah, there's [inaudible] struggle with just the machines and the link to Hive would be the biggest thing that I come across, and then you end up with a paper one, and then we have nowhere to store paper notes at the moment, obviously, so it can just kind of get lost, I think, after that. And I'm concerned because it might have got lost with, like, just me looking at it, and I want someone more senior to have cast eyes on it as well. So, yeah, that would be... occasionally as well -- just one last thing! -- sometimes it's in the cardiology section, sometimes they take a photo of it, and it will have snuck into a media section... there's not really consistency about where it is.

**Interviewer**

I mean if stored, because when you work on ICU, you said, isn't it? I mean, the whole continuous three lead monitoring is not stored anywhere, isn't it? So basically need to be to see it on the monitor.

**P23**

That's a really good point, actually. You only see it for that snapshot you go and examine the patient. You stand there for a bit... the nurses might... they might highlight something, but if it's ectopic and stuff, you're not... you're not really seeing that, you're only seeing this... tiny snapshot and going off that.

**Interviewer**

Yeah. Because this is what we are currently not this project related, but I'm trying to get all ICU continuous monitoring into database because there's just so many waveforms

**P23**

So good! The amount of like AF, we see all the time post operatively and stuff... and then you'll go and see and you'll be like "but it's sinus, it's fine." And then the nurses will be telling you again, and it's just, like, you're constantly missing it... and then 24 hour tape... and it's all like... that's obviously got its own place, but to be able to look back over the last 24 hours and see what the heart's doing would be so helpful for critical care.

**Interviewer**

It's also grateful for research, because it's obviously such a wealth of data that literally goes down the drain at the moment really.

**P23**

Yeah. Yeah, it's going nowhere. It’s essentially going nowhere

**Interviewer**

Yeah, yeah. Is there anything that works particularly well on the other side? Or we can link that to what functionalities what you wish to be added in the future? Or what would you if you could dream of the perfect ECG? And how we do it and how we started? What would you wish for? What would your ECG of the future look like?

**P23**

What ECGs of the future would look like? You request it on Hive, and it actually communicates to the nurse -- because I think often we've got a request button as well, that just sort of says "ECG 12 lead" but I don't know if they look at that request from the nursing point of view. Obviously, I tell them in person to... but then that's there in record request. It's done quite promptly... I think, again, that you've said that I could compare it then to, perhaps, the... you know, looking back over it once I've got it. I think still I'd like... so the online wanting to go and know where it goes. Perhaps be given a paper one in person as well, just because I think I do sometimes still like to work with paper... but as long as we all knew it was exactly in the same place that's less [inaudible]. So have a look at it... and -- what can I say! -- I'd like to say some of its [inaudible]... I don't want to be deskilled, so maybe not. I suppose that I just got a good clear screen, and it's a really good trace that I can look at with a consultant, and then perhaps something to say "assessed" -- like a template, almost to say it's been [inaudible] and this is the abnormality and this is who saw it.

**Interviewer**

Yeah. Because this is this is this is what we obviously there was a quite interesting fact that I didn't think of that like that, because I was speaking to a GP and he was like, I don't really look at ECGs, because we get them reported for us and they get sent back river report, in clinical practice in hospitals is one of the only things where you haven't got a backup because all of the things obviously X ray, CT, MRI, they all get reported by a radiologist. And even if you think you spot something you'll always have like, okay, even in case if I've missed something, the radiologists will pick it up in a report anyway. But with ECGs, you'll never get that rarely.

**P23**

Yeah, there's a huge margin for human error, I think on ECGs. I wouldn't really like to think about what implication that may or may not have had for me. I suppose the other thing as well -- this is a very minor point, but I suppose it's kind of a practical point -- is: we often... ECGs in their own right are only often only useful in comparison to other ones. And you know, like, on Sectra, you can look at two things next to each other? It's really hard to do that with ECGs. It'd be good to almost have them all in one place, and you can click two, in between quickly, look at different ones... and just to see if there's any, like, big barn door differences, I suppose.

**Interviewer**

You're not the only one mentioning that. And it's obviously because you hardly ever get the gold standard ECG, and then you look at the patient be like, Oh, that's completely normal. But a lot of varieties and ECGs are not pathological for some patients, because they have they have a slightly elevated ST, or whatever, for the last 10 years already. So it's nothing acute. But obviously, you need the window to the past to know that otherwise, you look at it and be like, Oh, it's a STEMI What should we do? Yeah, so I guess that definitely makes sense. I show you now I share my screen with you and show you now what we are working on so it gets a bit more tangible.

Can you can you see what I'm showing you in the PowerPoint?

**P23**

No, not yet. just saying you try that again

**Interviewer**

Does that work? No?

**P23**

Yeah, yeah. Yeah.

**Interviewer**

So you should see two ECG strips now, if that's correct, yeah. So what we're working on the top one basically is a patient with a normal QT interval. And you can see that the ECG strip is coloured in cool colours from like a purple up to a lime green, which would go to up to probably 350 milliseconds. And then the bottom one is from a patient with a prolonged QT interval. So this patient would have long QT s in this in this case, and you can instantly see from the warm colours that it's going from yellow into more Brett colouring on a different strip visualisation, that would look something like that. So you could see goes from purple up until it's prolonged into into the red colours. And we've assumed in version that would look like this from the colouring. And the other thing that we're working on at the moment is colouring STEMI. So we'll see that STEMI is highlighted in orange going TO to read. And, yeah, I've specifically chosen one with a hypercube T wave, because some people might look just at the T wave and then miss that there's actually a STEMI ongoing as well. Yeah. And so these are the visual features that we're working on. So basically, what we're doing summed up in one sentence is we use colours to enhance certain features in ECGs. Obviously, this just works on we've got the right setups and the right technical abilities at hospitals. But that's just genuinely what we're working on hoping to to get done in the future. Going back to the questions now, do you think that generally digital technology can enhance the way we look at ECGs?

**P23**

Yes, I think that would. What I think is you've highlighted a really good point there when you said "I put hyperacute T wave" because (and the more I talk about this, the more's coming to me) like, I think it's so easy to get distracted by another... you focus in on something you think looks abnormal -- you know, like, huge QRS complexes or, like, is that like you said... hyperkalemia, the T wave's all over the place, and this, that, the other... and actually, there's something else underneath that is more sinister, and more dangerous that you are missing. And I think to have the colours there... because it would be really... would give some clarity and some focus to what you're actually looking for. So I think that'd be really cool.

**Interviewer**

And obviously, there are two approaches to it. I've shown you specific conditions being LQTS and a STEMI. Do you think it will be generally better for you as a clinician to highlight any abnormalities in an ECG with colour? And you're the one that makes the decision interprets it or do you actually prefer to have conditions specifically coloured in?

**P23**

I think almost conditions, to a point, because any abnormality... sometimes when... you know when you get an ECG printed at the moment, and it will, say, lists loads of like possible abnormal ECG, and there could be loads and loads of things, it could be artefact and everything that's getting in there? So perhaps more focused on conditions will kind of focus your mind more on particularly... then you can then interpret that in the clinical picture. So you've still got that element of interpretation.

**Interviewer**

So yeah, okay. And in general, we've got the X ray analogy, as we call it, because obviously, with modern medical image viewers with X rays be consuming, we can change the brightness, we can compare things you've touched upon, that a comparison will be really good. How does looking at ECGs for you compared to looking at X rays, and how you diagnose and interpret it?

**P23**

That's an interesting question. How's it different? I think... [inaudible]... first of all, that there's similarities: I think I still use pattern recognition a lot. I think I feel much more confident actually interpreting an X ray than I do an ECG, and I would probably think -- I don't know, because I can't speak on behalf of the foundation doctors -- is quite universal, when I speak to colleagues. I think there are so many... so much variability within an ECG that it's easy to lose the detail and the variability and to become flustered with a certain approach, whereas I think with an X ray, I find it easier to be more systematic. I think with an ECG I become... I almost... yeah, I lose the sort of systematic approach to the point where I think things might get missed more, because I'm not as confident in interpretation, because of the amount of variability you see from patient to patient to patient -- it's so vast.

**Interviewer**

Yeah.

**P23**

You never really, I think... [inaudible] you know, you learn in med school, the really clean ECG and what a waveform looks like, and it never looks like that, even when it's like... even when it is a normal ECG. I think with an X ray, you're like, oh, no, I can say that's normal -- like, confidently.

**Interviewer**

It's also, I mean, with X rays, usually one image, obviously, of the area of interest that you're trying to investigate. But then what I find so overwhelming with an ECG myself, is you've got actually 12 leads, and they all look different. There are different pathologies that you can spot in one lead but not in the other. And then they are so subtle, sometimes. So you basically need to interpret 12 images at once. Exactly.

**P23**

And you need to know the significance of it being in that lead, for example, but not in another lead -- or is it significant, because if it's in that lead, it might not be? It's all of that I just find very overwhelming.

**Interviewer**

Do you think colouring is a specifically helpful method? Or could you think of any other methods to highlight specific things and ECGs?

**P23**

I think colouring would work very well, for me, because I'm quite visual. And I think it's... we're very, you know... there's such a strong instinct to... that this kind of the colours you're talking about, you know, like the red being a warning. I was thinking when you were talking about it... about comparisons... and I suppose the only thing I think of is sometimes in CTs and things they do arrows to point to? But you wouldn't want arrows in an ECG because you're looking at more lines and stuff... so in that way, I'd say colour is probably most [inaudible].

**Interviewer**

Arrows is funny, because usually some monitors print errors over the P waves at the time when a patient's been cardioverted.

**P23**

Oh it's like a pacing thing? So yeah, no, colours is a much safer thing. Yes, you are dealing with a linear black and white kind of image and colour is much better.

**Interviewer**

How do you think those colouring compared to current methods of like automated readouts and automated threshold calculations?

**P23**

I, again, think that I really don't like the method at the moment -- I think, because it does a lot of... I don't know... I just never really trust that bit at the top anyway, and it's always like a ?abnormal ECG, or like, it's a bit of a vague sort of... and then you think... but you can't help but zoom in on it straightaway and be like... sometimes I think, again, what would be good about the colours... because I know you're seeing... you might go straight for the colours, but at least you're looking still at the ECG? Whereas you could literally look at the interpretation at the top and not even have taken a moment to look at the full waveforms. Whereas if it's within the ECG, you're looking, actually at the waveforms and stuff, as opposed to putting text at the top.

**Interviewer**

Yeah, that's very interesting. Thank you. That's yeah, that's true of you. You actually look at something that you are, you look, some of are you not supposed to look at basically,

**P23**

Yeah -- the first thing you look at, and I know you take demographics and things but then you could spend all your time just reading what the interpretation says at the top.

**Interviewer**

And then it's a vicious circle, isn't it? Because from from my perspective, it's, I hated to see the spotter read up first because then it Prime's, me to look for what the reader says. Exactly.

**P23**

So it's almost like you're looking... you... it's like a bias almost been put in your mind, and you're looking to see that, and you're like "oh, yeah, that's there." Whereas like, I try and always tell myself, like... look at it first. But it's so difficult to do that when you've got like, exclamation mark, exclamation mark [inaudible] saying like anterior STEMI... and you're like, oh...

**Interviewer**

Yeah. So it basically because this is what came out from the interviews with me, it basically Prime's you to look for it. And then you get really panicked if you can't find it yourself. And then you literally get stressed because you can't find it. And then it's like, Am I missing it? What's going on? Now? I have

**P23**

It makes you less confident... like, even more underconfident in your ability... so, yeah.

**Interviewer**

So obviously, the computer algorithms that work with what I've shown You, there are two ways of approaching things. One is using Explainable AI, which means that we have a rule based algorithm and we perfectly well know how the algorithm or the computer is making decisions. And we can explain it to clinicians and patients alike if they would want to know it. Other option is we probably heard of it's often the media blackbox algorithms and deep learning where the machine is doing something that we can't really interpret, why is it doing what it's doing? But it can have the same accurate outputs at the end? Do you think for you, it's important to have explainable algorithms? Or do you think as long as the accuracy is there, you don't really care how the computer's doing what it does?

**P23**

I think probably, if it was the same level of accuracy for both, I'd like to have an explainable algorithm -- if not for me, partly for patients as well. We deal with a lot of... a range of ages and things, and I think, particularly, like, some generations who are more wary of technology and AI, it might give them some comfort to know that we understand the machines that we're dealing with and the algorithms that are interpreting it, I think,

**Interviewer**

Brilliant, thank you. That was it basically from the interview side. Have you got any questions? And

**P23**

No, it's all very exciting, brilliant. What's what's like, what's, what are you doing going forward?

**Interviewer**

So what's happening now at the moment, I just stop recording.

\*\*\*END OF TRANSCRIPT\*\*\*