**Can genomic testing prevent adverse drug reactions**

**Behind the Genes transcript**

**Vivienne: Hello and welcome to Behind the Genes.**

**Bill:** What we’ve seen is that the limited adoption so far in the UK and other countries has focused particularly on severe adverse drug reactions. They’ve been easier to identify and there’s a clear relationship between some drugs and some genetic changes where that information is useful. So, a good example has been the recent adoption of pharmacogenetic testing for a gene called DPYD for patients undergoing cancer treatment, particularly breast and bowel cancer. And if you have an absence of the enzyme that that gene makes, if you’re given that treatment, then you can end up on intensive care and die, so it’s a really significant side effect. But as you say, the most common side effects aren’t necessarily fatal, but they can have a huge impact upon people and on their wellbeing.

**Vivienne: My name’s Vivienne Parry and I’m head of public engagement at Genomics England, and today we’ll be discussing the critical role of pharmacogenomics in personalised medicine, highlighting its impact on how well medicines work, their safety, and on patient care. I’m joined today by Professor Bill Newman, professor of translational genomic medicine at the Manchester Centre for Genomic Medicine, Anita Hanson, research matron, a fabulous title, and lead research nurse for clinical pharmacology at the Liverpool University Hospital’s NHS Foundation Trust, and Professor Matt Brown, chief scientific officer for Genomics England. And just remember, if you enjoy today’s episode, we’d love your support, so please like, share and rate us on wherever you listen to your podcasts.**

**So, first question to you, Bill, what is pharmacogenomics?**

**Bill:** Thanks Viv. I think there are lots of different definitions, but how I think of pharmacogenetics is by using genetic information to inform how we prescribe drugs, so that they can be safer and more effective. And we’re talking about genetic changes that are passed down through families, so these are changes that are found in lots of individuals. We all carry changes in our genes that are important in how we transform and metabolise medicines, and how our bodies respond to them.

**Vivienne: Now, you said pharmacogenetics. Is it one of those medicine things like tomato, tomato, or is there a real difference between pharmacogenetics and pharmacogenomics?**

**Bill:** So, people, as you can imagine, do get quite irate about this sort of thing, and there are lots of people that would contest that there is a really big important difference. I suppose that pharmacogenetics is more when you’re looking at single changes in a relatively small number of genes, whereas pharmacogenomics is a broader definition, which can involve looking at the whole genome, lots of genes, and also whether those genes are switched on or switched off, so the expression levels of those genes as well would encompass pharmacogenomics. But ultimately it’s using genetic information to make drug prescription safer and more effective.

**Vivienne: So, we’re going to call it pharmacogenomics and we’re talking about everything, that’s it, we’ll go for it. So Matt, just explain if you would the link between pharmacogenomics and personalised medicine. And I know that you’ve done a big Genomics 101 episode about personalised medicine, but just very briefly, what’s the link between the two?**

**Matt:** So, personalised medicine’s about using the right dose of the right drug for the right individual. And so pharmacogenomics helps you with not only ensuring that you give a medication which doesn’t cause problems for the person who receives it, so an adverse drug reaction, but also that they’re actually getting the right dose. Of course, people’s ability to metabolise, activate and respond to drugs genetically is often genetically determined, and so sometimes you need to adjust the dose up or down according to a person’s genetic background.

**Vivienne: Now, one of the things that we’ve become very aware of is adverse drug reactions, and I think they account for something like six and a half percent of all hospital admissions in the UK, so it’s absolutely huge. Is that genetically determined adverse drug reactions?**

**Matt:** So, the answer to that is we believe so. There’s quite a bit of data to show that you can reduce the risk of people needing a hospital admission by screening genetic markers, and a lot of the very severe reactions that lead to people being admitted to hospital are very strongly genetically determined. So for example, there are HLA types that affect the risk of adverse drug reactions to commonly used medications for gout, for epilepsy, some HIV medications and so on, where in many health services around the world, including in England, there are already tests available to help prevent those leading to severe reactions. It’s likely though that actually the tests we have available only represent a small fraction of the total preventable adverse drug reactions were we to have a formal pre-emptive pharmacogenomics screening programme.

**Vivienne: Now, I should say that not all adverse drug reactions are genetic in origin. I mean, I remember a rather nasty incident on the night when I got my exam results for my finals, and I’d actually had a big bee sting and I’d been prescribed antihistamines, and I went out and I drank rather a lot to celebrate, and oh my goodness me, I was rather ill [laughter]. So, you know, not all adverse drug reactions are genetic in origin. There are other things that interact as well, just to make that clear to people.**

**Matt:** Yes, I think that’s more an interaction than an adverse drug reaction. In fact frankly, the most common adverse drug reaction in hospitals is probably through excess amounts of water, and that’s not medically determined, that’s the prescription.

**Vivienne: Let me now come to Anita. So, you talk to patients all the time about pharmacogenomics in your role. You’ve been very much involved in patient and public involvement groups at the Wolfson Centre for Personalised Medicine in Liverpool. What do patients think about pharmacogenomics? Is it something they welcome?**

**Anita:** I think they do welcome pharmacogenomics, especially so with some of the patients who’ve experienced some of the more serious, life threatening reactions. And so one of our patients has been doing some work with the Academy of Medical Sciences, and she presented to the Sir Colin Dollery lecture in 2022, and she shared her story of having an adverse drug reaction and the importance of pharmacogenomics, and the impact that pharmacogenomics can have on patient care.

**Vivienne: Now, I think that was Stevens-Johnson syndrome. We’re going to hear in a moment from somebody who did experience Stevens-Johnson’s, but just tell us briefly what that is.**

**Anita:** Stevens-Johnson syndrome is a potentially life threatening reaction that can be caused by a viral infection, but is more commonly caused by a medicine. There are certain groups of medicines that can cause this reaction, such as antibiotics or anticonvulsants, nonsteroidal anti-inflammatories, and also a drug called allopurinol, which is used to treat gout. Patients have really serious side effects to this condition, and they’re often left with long-term health complications. The morbidity and mortality is considerable as well, and patients often spend a lot of time in hospital and take a long time to recover.

**Vivienne: And let’s now hear from Jane Burns for someone with lived experience of that Stevens-Johnson syndrome. When Jane Burns was 19, the medicine she took for her epilepsy was changed.**

**Jane:** I remember waking up and feeling really hot, and I was hallucinating, so I was taken to the Royal Liverpool Hospital emergency department by my parents. When I reached A&E, I had a temperature of 40 degrees Celsius. I was given Piriton and paracetamol, and the dermatologist was contacted. My mum had taken my medication to hospital and explained the changeover process with my epilepsy medication. A decision was made to discontinue the Tegretol and I was kept in for observation. Quite rapidly, the rash was changing. Blisters were forming all over my body, my mouth was sore and my jaw ached. My temperature remained very high. It was at this point that Stevens-Johnson syndrome, or SJS, was diagnosed.

Over the next few days, my condition deteriorated rapidly. The rash became deeper in colour. Some of the blisters had burst, but some got larger. I developed ulcers on my mouth and it was extremely painful. I started to lose my hair and my fingernails. As I had now lost 65 percent of my skin, a diagnosis of toxic epidermal necrolysis, or TEN, was made. Survivors of SJS TEN often suffer with long-term visible physical complications, but it is important to also be aware of the psychological effects, with some patients experiencing post-traumatic stress disorder. It’s only as I get older that I realise how extremely lucky I am to have survived. Due to medical and nursing expertise, and the research being conducted at the time, my SJS was diagnosed quickly and the medication stopped. This undoubtedly saved my life.

**Vivienne: Now, you’ve been looking at the development of a passport in collaborating with the AMS and the MHRA. Tell me a bit more about that.**

**Anita:** Yes, we set up a patient group at the Wolfson Centre for Personalised Medicine approximately 12 years ago, and Professor Sir Munir Pirmohamed and I, we wanted to explore a little bit more about what was important to patients, really to complement all the scientific and clinical research activity within pharmacogenomics. And patients recognised that, alongside the pharmacogenomic testing, they recognised healthcare professionals didn’t really have an awareness of such serious reactions like Stevens-Johnson syndrome, and so they said they would benefit from having a My SJS Passport, which is a booklet that can summarise all of the important information about their care post-discharge, and this can then be used to coordinate and manage their long-term healthcare problems post-discharge and beyond. And so this was designed by survivors for survivors, and it was then evaluated as part of my PhD, and the findings from the work suggest that the passport is like the patient’s voice, and it really does kind of validate their diagnosis and raises awareness of SJS amongst healthcare professionals. So, really excellent findings from the research, and the patients think it's a wonderful benefit to them.

**Vivienne: So, it’s a bit like a kind of paper version of the bracelet that you sometimes see people wearing that are on steroids, for instance.**

**Anita:** It is like that, and it’s wonderful because it’s a handheld source of valuable information that they can share with healthcare professionals. And this is particularly important if they’re admitted in an emergency and they can’t speak for themselves. And so the passport has all that valuable information, so that patients aren’t prescribed that drug again, so it prevents them experiencing a serious adverse drug reaction again.

**Vivienne: So, Stevens-Johnson, Bill, is a really scary side effect, but what about the day to day benefits of pharmacogenomics for patients?**

**Bill:** So, what we’ve seen is that the limited adoption so far in the UK and other countries has focused particularly on severe adverse drug reactions. They’ve been easier to identify and there’s a clear relationship between some drugs and some genetic changes where that information is useful. So a good example has been the recent adoption of pharmacogenetic testing for a gene called DPYD for patients undergoing cancer treatment, particularly breast and bowel cancer. And if you have an absence of the enzyme that that gene makes, if you’re given that treatment, then you can end up on intensive care and die, so it’s a really significant side effect. But as you say, the most common side effects aren’t necessarily fatal, but they can have a huge impact upon people and on their wellbeing.

And it’s not just in terms of side effects. It’s in terms of the effectiveness of the medicine. Because if a person is prescribed a medicine that doesn’t or isn’t going to work for them then it can take them longer to recover, to get onto the right medicine. That can have all sorts of detrimental effects. And so when we’re thinking about introducing pharmacogenetics more broadly rather than just on a single drug or a single gene basis, we’re thinking about that for common drugs like antidepressants, painkillers, statins, the drugs that GPs are often prescribing on a regular basis to a whole range of patients.

**Vivienne: So, to go back to you, Anita, we’re really talking about dose here, aren’t we, whether you need twice the dose or half the dose depending on how quickly your body metabolises that particular medicine. How do patients view that?**

**Anita:** Well, the patient in question who presented for the Academy of Medical Sciences, I mean, her take on this was, she thinks pharmacogenetics is wonderful because it will allow doctors and nurses to then prescribe the right drug, but also to adapt the dose accordingly to make sure that they get the best outcome, which provides the maximum benefit while also minimising any potential harm. And so from her perspective, that was one of the real benefits of pharmacogenomics. But she also highlighted about the benefits for future generations, the fear of her son taking the same medicine and experiencing the same reaction. And so I think her concerns were, if we have pharmacogenetic testing for a panel of medicines, as Bill mentioned then, then perhaps this would be fantastic for our children as they grow up, and we can identify and predict and prevent these type of reactions happening to future generations.

**Vivienne: And some of these drugs, Bill, are really very common indeed, something like codeine. Just tell us about codeine, ‘cos it’s something – whenever I tell this to friends [laughter], they’re always completely entranced by the idea that some people don’t need nearly as much codeine as others.**

**Bill:** Yeah, so codeine is a drug that’s very commonly used as a painkiller. To have its real effect, it needs to be converted in the body to a different drug called morphine, and that is done by an enzyme which is made by a gene called CYP2D6. And we all carry changes in CYP2D6, and the frequency of those variants, whether they make the gene work too much or whether they make it work too little, they vary enormously across the world, so that if you go to parts of Africa, about 30 percent of the population will make more of the CYP2D6, and so they will convert the codeine much more quickly, whereas if you go to the UK, maybe up to ten percent of the white population in the UK just won’t be converting codeine to morphine at all, so they won’t get any benefit from the drug. So at both ends, you have some people that don’t respond and some people that respond a little bit too much so that they need either an alternative drug or they need a different dose.

**Vivienne: So, all those people who say, you know, “My headache hasn’t been touched by this painkiller,” and we say, “What a wimp you’re being,” actually, it’s to do with genetics.**

**Bill:** Yeah, absolutely. There’s a biological reason why people don’t – not for everybody, but for a significant number of people, that’s absolutely right, and we can be far more tailored in how we prescribe medication, and get people onto painkillers that work for them much more quickly.

**Vivienne: And that’s so interesting that it varies by where you come from in the world, because that means we need to give particular attention – and I’m thinking, Anita, to working with patients from different community groups, to make sure that they understand the need for pharmacogenomics.**

**Anita:** I think that’s really important, Vivienne, and I think we are now having discussions with the likes of Canada SJS awareness group, and also people have been in touch with me from South Africa because people have requested the passport now to be used in different countries, because they think it’s a wonderful tool, and it’s about raising awareness of pharmacogenomics and the potential benefits of that, and being able to share the tools that we’ve got to help patients once they’ve experienced a serious reaction.

**Vivienne: So, pharmacogenomics clearly is important in the prevention of adverse drug reactions, better and more accurate prescribing, reduced medicines wastage. Does this mean that it’s also going to save money, Bill, for the NHS?**

**Bill:** Potentially. It should do if it’s applied properly, but there’s lots of work to make sure that not only are we using the right evidence and using the right types of tests in the laboratory, but we’re getting the information to prescribers, so to GPs, to pharmacists, to hospital doctors, in a way that is understandable and meaningful, such that they can then act upon that information. So, the money will only be saved and then can be reused for healthcare if the whole process and the whole pathway works, and that information is used effectively.

**Vivienne: So, a lot of research to make sure that all of that is in place, and to demonstrate the potential cost savings.**

**Bill:** Yes. I mean, there are very nice studies that have been done already in parts of the world that have shown that the savings that could be accrued for applying pharmacogenetics across common conditions like depression, like in patients to prevent secondary types of strokes, are enormous. They run into hundreds of millions of pounds or dollars. But there is an initial investment that is required to make sure that we have the testing in place, that we have the digital pathways to move the information in place, and that there’s the education and training, so that health professionals know how to use the information. But the potential is absolutely enormous.

**Vivienne: Matt, can I turn now to the yellow card. So, people will be very familiar with the yellow card system. So, if you have an adverse reaction, you can send a yellow card in – I mean, literally, it is a yellow card [laughter]. It does exactly what it says on the tin. You send a yellow card to the MHRA, and they note if there’s been an adverse effect of a particular medicine. But Genomics England is teaming up with the MHRA to do something more with yellow cards, and we’re also doing this with the Yellow Card Biobank. Tell us a bit more.**

**Matt:** So, yellow card’s a great scheme that was set up decades ago, initially starting off, as you said, with literally yellow cards, but now actually most submissions actually come online. And it’s important to note that submissions can come not just from healthcare providers, but majority of submissions actually come from patients themselves, and that people should feel free, if they feel they’ve had an adverse drug reaction, to report that themselves rather than necessarily depending on a medical practitioner or the healthcare provider to create that report. So, Genomics England is partnering with the MHRA in building what’s called the Yellow Card Biobank, the goal of which is to identify genetic markers for adverse drug reactions earlier than has occurred in the past, so that we can then introduce genetic tests to prevent these adverse drug reactions much sooner than has occurred previously.

So, what we’re doing is basically at the moment we’re doing a pilot, but the ultimate plan is that in future, patients who report a serious adverse drug reaction through the Yellow Card Biobank will be asked to provide a sample, a blood sample, that we then screen. We do a whole genome sequence on it, and then combine these with patients who’ve had like adverse drug reactions and identify genetic markers for that adverse drug reaction medication earlier, that can then be introduced into clinical practice earlier. And this should reduce by decades the amount of time between when adverse drug reactions first start occurring with medications and us then being able to translate that into a preventative mechanism.

**Vivienne: And will that scheme discover, do you think, new interactions that you didn’t know about before? Or do you expect it to turn up what you already know about?**

**Matt:** No, I really think there’s a lot of discovery that is yet to happen here. In particular, even for drugs that we know cause adverse drug reactions, mostly they’ve only been studied in people of European ancestry and often in East Asian ancestry, but in many other ancestries that are really important in the global population and in the UK population, like African ancestry and South Asian ancestries, we have very little data. And even within Africa, which is an area which is genetically diverse as the rest of the world put together, we really don’t know what different ethnicities within Africa, actually what their genetic background is with regard to adverse drug reactions.

The other thing I’d say is that there are a lot of new medications which have simply not been studied well enough. And lastly, that at the moment people are focused on adverse drug reactions being due to single genetic variants, when we know from the model of most human diseases that most human diseases are actually caused by combinations of genetic variants interacting with one another, so-called common disease type genetics, and that probably is similarly important with regard to pharmacogenomics as it is to overall human diseases. That is, it’s far more common that these are actually due to common variants interacting with one another rather than the rare variants that we’ve been studying to date.

**Vivienne: So, it’s a kind of cocktail effect, if you like. You know, you need lots of genes working together and that will produce a reaction that you may not have expected if you’d looked at a single gene alone.**

**Matt:** That’s absolutely correct, and there’s an increasing amount of evidence to show that that is the case with medications, but it’s really very early days for research in that field. And the Yellow Card Biobank will be one of many approaches that will discover these genetic variants in years to come.

**Vivienne: Now, Matt’s a research scientist. Bill, you’re on the frontline in the NHS. How quickly can this sort of finding be translated into care for people in the NHS?**

**Bill:** So, really quickly is the simple answer to that, Viv. If we look at examples from a number of years ago, there’s a drug called azathioprine that Matt has used lots in some of his patients. In rheumatology, it’s used for patients with inflammatory bowel disease. And the first studies that showed that there was a gene that was relevant to having bad reactions to that drug came out in the 1980s, but it wasn’t until well into this century, so probably 30-plus years later that we were routinely using that test in clinical medicine. So, there was an enormous lot of hesitancy about adopting that type of testing, and a bit of uncertainty. If you move forward to work that our colleague Munir Pirmohamed in Liverpool has done with colleagues in Australia like Simon Mallal around HIV medicine, there was this discovery that a drug called abacavir, that if you carried a particular genetic change, that you had a much higher risk of having a really severe reaction to that. The adoption from the initial discovery to routine, worldwide testing happened within four years.

So, already we’ve seen a significant change in the appetite to move quickly to adopt this type of testing, and I see certainly within the NHS and within other health systems around the world, a real desire to adopt pharmacogenetics into routine clinical practice quickly and at scale, but also as part of a broader package of care, which doesn’t just solely focus on genetics, but thinks about all the other parts that are important in how we respond to medication. So, making sure we’re not on unusual combinations of drugs, or that we’re taking our medicine at the right time and with food or not with food, and all of those other things that are really important. And if you link that to the pharmacogenetics, we’re going to have a much safer, more effective medicines world.

**Vivienne: I think one of the joys of working at Genomics England is that you see some of this work really going into clinical practice very fast indeed. And I should say actually that the Wolfson Centre for Personalised Medicine, the PPI group that Anita looks after so well, they’ve been very important in recruiting people to Yellow Card Biobank. And if anyone’s listening to this, Matt, and wants to be part of this, how do they get involved? Or is it simply through the yellow card?**

**Matt:** So at the moment, the Yellow Card Biobank is focusing on alopurinol.

**Vivienne: So, that’s a medicine you take for gout.**

**Matt:** Which I use a lot in my rheumatology clinical practice. And direct acting oral anticoagulants, DOACs, which are used for vascular disease therapies and haemorrhage as a result of that. So, the contact details are available through the MHRA website, but I think more importantly, it’s just that people be aware of the yellow card system itself, and that if they do experience adverse drug reactions, that they do actually complete a report form, ‘cos I think still actually a lot of adverse drug reactions go unreported.

**Vivienne: I’m forgetting of course that we see Matt all the time in the Genomics England office and we don’t think that he has any other home [laughter] than Genomics England, but of course he still sees some patients in rheumatology clinic. So, I want to now look to the future. I mean, I’m, as you both know, a huge enthusiast for pharmacogenomics, ‘cos it’s the thing that actually, when you talk to patients or just the general public, they just get it straight away. They can’t think why, if you knew about pharmacogenomics, why you wouldn’t want to do it. But it’s not necessarily an easy thing to do. How can we move in the future, Bill, to a more proactive approach for pharmacogenomics testing? Where would we start?**

**Bill:** Yes, so I think we’ve built up really good confidence that pharmacogenetics is a good thing to be doing. Currently, we’re doing that predominantly at the point when a patient needs a particular medicine. That’s the time that you would think about doing a genetic test. And previously, that genetic test would only be relevant for that specific drug. I think we’re moving to a place where, rather than just doing that one test that might be relevant to one drug, we’d be able to do a test which at the same price would generate information that could be relevant at further points in your life if you were requiring different types of medicine. So, that information would then be available in your hospital record, in your GP record, that you could have access to it yourself. And then I think ultimately what we would really love to get to a point is where everybody across the whole population just has that information to hand when it’s required, so that they’re not waiting for the results of a genetic test, it’s immediately within their healthcare record. That’s what we’d call pre-emptive pharmacogenetic testing, and I think that’s the golden land that we want to reach.

**Vivienne: So for instance, I might have it on my NHS app, and when I go to a doctor and they prescribe something, I show my app to the GP, or something pops up on the GP’s screen, or maybe it’s something that pops up on the pharmacist’s screen.**

**Bill:** I think that’s right. I think that’s what we’re looking to get to that point. We know that colleagues in the Netherlands have made some great progress at developing pathways around that. There’s a lot of public support for that. And pharmacists are very engaged in that. In the UK, the pharmacists, over the last few years, have really taken a very active role to really push forward this area of medicine, and this should be seen as something that is relevant to all people, and all health professionals should be engaged with it.

**Vivienne: And on a scale of one to ten, how difficult is it going to be to implement in the NHS?**

**Bill:** So, that’s a difficult question. I think the first thing is identifying what the challenges are. So I have not given you a number, I’ve turned into a politician, not answered the question. So, I think what has happened over the last few years, and some of our work within the NHS Network of Excellence in pharmacogenetics and some of the other programmes of work that have been going on, is a really good, honest look at what it is we need to do to try to achieve pharmacogenetics implementation and routine use. I don’t think the challenge is going to be predominantly in the laboratory. I think we’ve got phenomenal laboratories. I think we’ve got great people doing great genetic testing. I think the biggest challenges are going to be about how you present the data, and that data is accessible. And then ensuring that health professionals really feel that this is information that isn’t getting in the way of their clinical practice, but really making a difference and enhancing it, and of benefit both to the healthcare system but more importantly to the patients.

**Vivienne: Now, when I hear you both talk, my mind turns to drug discovery and research, and Matt, I’m quite sure that that’s right at the top of your mind. Tell us how pharmacogenomics can help in drug discovery and research.**

**Matt:** So, pharmacogenomics, I think actually just genetic profiling of diseases in itself just to start off with is actually a really good way of identifying new potential therapeutic targets, and also from derisking drug development programmes by highlighting likely adverse drug reactions of medications that are being considered for therapeutic trials, or targets that are being considered for therapeutic development. Pharmacogenomics beyond that is actually largely about – well, it enables drug development programmes by enabling you to target people who are more likely to respond, and avoid people who are more likely to have adverse drug reactions. And so that therapeutic index of the balance between likely efficacy versus likely toxicity, genetics can really play into that and enable medications to be used where otherwise they might have failed.

This is most apparent I think in the cancer world. A classic example there, for example, is the development of a class of medications called EGFR inhibitors, which were developed for lung cancer, and in the initial cancer trials, actually were demonstrated to be ineffective, until people trialled them in East Asia and found that they were effective, and that that turns out to be because the type of cancers that respond to them are those that have mutations in the EGFR gene, and that that’s common in East Asians. We now know that, wherever you are in the world, whether you’re East Asian or European or whatever, if you have a lung adenocarcinoma with an EGFR mutation, you’re very likely to respond to these medications. And so that pharmacogenomic discovery basically rescued a class of medication which is now probably the most widely used medication for lung adenocarcinomas, so a huge beneficial effect. And that example is repeated across multiple different cancer types, cancer medication types, and I’m sure in other fields we’ll see that with expansive new medications coming in for molecularly targeted therapies in particular.

**Vivienne: So, smaller and more effective trials rather than larger trials that perhaps seem not to work but actually haven’t been tailored enough to the patients that are most likely to benefit.**

**Matt:** Yeah, well, particularly now that drug development programmes tend to be very targeted at specific genetic targets, pharmacogenetics is much more likely to play a role in identifying patients who are going to respond to those medications. So, I think many people in the drug development world would like to see that, for any significant drug development programme, there’s a proper associated pharmacogenomic programme to come up with molecular markers predicting a response.

**Vivienne: We’re going to wrap up there. Thank you so much to our guests, Bill Newman, Anita Hanson, Matt Brown, and our patient Jane Burns. Thank you so much for joining us today to discuss pharmacogenomics in personalised medicine, and the benefits, the challenges and the future prospects for integrating pharmacogenomics into healthcare systems. And if you’d like to hear more podcasts like this, please subscribe to Behind the Genes. It’s on your favourite podcast app. Thank you so much for listening. I’ve been your host, Vivienne Parry. This podcast was edited by Bill Griffin at Ventoux Digital and produced by the wonderful Naimah. Bye for now.**