FORUM
Academy of Medical Sciences

Pharmacogenomics, personalisation and public health

Summary report of the 2022 FORUM Sir Colin Dollery Lecture on 13 October 2022

Chaired by Professor Dame Anne Johnson DBE PMedSci, President, Academy of Medical Sciences. The panel discussion was chaired by Professor Sir Munir Pirmohamed FMedSci, David Weatherall Chair of Medicine, University of Liverpool

Keynote by Professor Dan Roden, Professor of Medicine and Pharmacology and Biomedical Informatics, Vanderbilt University

The Academy of Medical Sciences

The Academy of Medical Sciences is the independent body in the UK representing the diversity of medical science. Our mission is to promote medical science and its translation into benefits for society. The Academy's elected Fellows are the United Kingdom's leading medical scientists from hospitals, academia, industry and the public service. We work with them to promote excellence, influence policy to improve health and wealth, nurture the next generation of medical researchers, link academia, industry and the NHS, seize international opportunities and encourage dialogue about the medical sciences.

In 2022, the Academy launched its 10-year strategy, which focuses on making medical science work for everyone. In doing so, the goal is to bring many different disciplines together, working across the whole of the UK, with a diverse fellowship, engaging a diverse community, including patients and the public, and developing the next generation of researchers.

Opinions expressed in this report do not necessarily represent the views of all participants at the event, the Academy of Medical Sciences, or its Fellows.

This event was hybrid. In addition to in-person attendees (Annex III), over 150 people joined the Lecture online. The event was held in accordance with UK COVID-19 guidelines in place at the time.

All web references were accessed in April 2023.

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Executive summary

Pharmacogenomics is a field of medicine which combines pharmacology with genomics to study how a person's genes may affect their drug response. The field has exciting potential to deliver more tailored treatments and reduce serious side-effects from medicines, presenting benefits to the individual as well as to society by reducing pressure on the healthcare system. Yet, despite its potential, there has been limited adoption and implementation of pharmacogenomics in the healthcare system to date.

People respond to drugs differently. While a drug may have the desired effect in some, in others it may work less well than expected or cause unwanted side effects and, occasionally, a severe adverse drug reaction. In England alone, the NHS dispensed over 1 billion prescription drugs in 2015, 50% more than in 2005, and unwanted side effects from prescription drugs cost the NHS £530 million annually in hospital admissions.[1] A person's genomic make-up can play a significant role in their response to drugs. This is studied through pharmacogenomics, which combines pharmacology – the science of drugs – with genomics – the study of the genome and its functions. Pharmacogenomics aims to use information about a person's genome to identify the most effective treatment for them, to find the ideal dosage, and to minimise side effects from abnormal responses.

To explore the challenges and opportunities of pharmacogenomics in more detail, the Academy held the 2022 FORUM Sir Colin Dollery Lecture on 13 October 2022 in the Victoria Gallery & Museum in Liverpool. The keynote address was given by Professor Dan Roden, Professor of Medicine, Pharmacology and Biomedical Informatics, and Senior Vice President for Personalised Medicine at Vanderbilt University Medical Centre. His talk was then followed by a discussion with an expert, cross-sector panel.

The following key points emerged from the discussions at the Lecture:

- **Pharmacogenomic tests can help tailor treatments and ensure appropriate and effective prescribing of drugs to patients.** For example, the antibiotic gentamicin is not suitable for about 1 in 500 people who carry a particular mitochondrial genetic variant and are at risk of hearing loss if they use the treatment. A pharmacogenomic test can identify those who would be at risk.
- **Patient involvement is essential to ensure that the outcomes of pharmacogenomic research deliver the greatest health benefits.** Patient involvement can help identify and support those most at risk of adverse drug reactions, and aid in the development of pharmacogenomic tests.
- **Enhancing access to pharmacogenomic testing is important, particularly for under-served communities, but there are challenges to enabling widespread**

[1] Royal College of Physicians (2022). *Personalised prescribing: using pharmacogenomics to improve patient outcomes.* https://www.rcp.ac.uk/file/37911/download

implementation of pharmacogenomic testing in the healthcare system. To help overcome these challenges, the following suggestions were made:

- **Prioritising the most at-risk groups should be a key strategy for encouraging the incremental adoption of pharmacogenomic testing.** This could be achieved by focusing on certain disease groups where pharmacogenomic testing can have the largest effects.
- **The economic case for pharmacogenomics needs to be built.** Making the case for widespread procurement across healthcare will involve demonstrating how the upfront costs of implementation will be balanced out by the potential for long-term cost savings of reducing unnecessary and suboptimal treatments.
- **The acceptability of clinical use of pharmacogenomic testing should be improved.** Providing training for healthcare professionals on the safe and effective use of pharmacogenomics, as well as engaging with patients and the public as mentioned above, would help with the acceptance of clinical use.
- **The clinical use of pharmacogenomic testing should be made easier.** Pharmacogenomic assays should be simplified and pharmacogenomic information should be more effectively implemented in routine healthcare. Pharmacogenomic information should be integrated with systems that may already be in use, such as with electronic health records. High-throughput tests that require minimal interpretation by the clinician are also needed, so that clinicians understand – at the point of prescription – what that information provided by the test means and how it impacts treatment.
- **Increased diversity of participants needs to be embedded in pharmacogenomics research to ensure that pharmacogenomic tests are widely applicable to the population as a whole.** As different populations can have different genetic variants and variant frequencies, it is essential that pharmacogenomic research includes a diversity of participants. There should be a particular focus on groups that are traditionally underrepresented in research.

Pharmacogenomics has great potential to improve the safe and effective prescribing of medicines to patients and improve health. The challenge now is how it can be adopted and implemented in the healthcare system at scale. A continued focus on research is also important, as there is still much to be discovered in genome science and pharmacogenomics.

The FORUM Sir Colin Dollery Lecture

The Academy of Medical Science's FORUM was established in 2003 to catalyse connections across industry, academia and the NHS, and the charity, regulatory and wider healthcare sector. It provides an independent platform for national discussions on scientific opportunities, translational challenges and strategic choices in healthcare and the life science sector. The FORUM network helps address the Academy's strategic priority to support UK biomedical and health research to strengthen its global competitiveness and reputation, by championing transdisciplinary research across the health and care system, academia, charities and industry, as set out in our Strategy 2022–32.

The Academy's prestigious FORUM Lecture, now in its 20th year, provides an opportunity for FORUM member organisations, Academy Fellows, invited guests and members of the public to hear from key figures in biomedical science. Since 2021 the FORUM Lecture has been named in honour of **Sir Colin Dollery FMedSci** (1931–2020), one of the founders of clinical pharmacology, and we are most grateful to Sir Colin's family who have generously donated funds to support the delivery of the FORUM Lecture. The Academy's FORUM is the brainchild of Sir Colin, who was passionate about scientists working together, including with those outside their field, to discover the innovations that improve our health and wellbeing.

The first FORUM Lecture – held on the occasion of the FORUM's launch in 2003 – was on the future promise of pharmacogenetics. In his talk, **Dr Allen Roses** shared his vision for single nucleotide polymorphism (SNP)-based pharmacogenetic testing to be standardised for the population, with the data routinely available in primary care for targeting an appropriate drug on the basis of sufficient efficacy and personalised safety. It is fitting therefore that the 20th FORUM Lecture should focus on the implementation of pharmacogenomics in the healthcare system and its potential to better tailor treatment strategies for patient benefit.

The 2022 FORUM Sir Colin Dollery Lecture was chaired by the President of the Academy of Medical Sciences, **Professor Dame Anne Johnson DBE PMedSci**. The keynote address was given by **Professor Dan Roden**, Professor of Medicine, Pharmacology and Biomedical

Informatics, and Senior Vice President for Personalised Medicine at Vanderbilt University Medical Centre.

A panel discussion chaired by **Professor Sir Munir Pirmohamed FMedSci**, David Weatherall Chair of Medicine at the University of Liverpool, then discussed the ethical, accessibility and economic impacts of pharmacogenomics. The following panellists joined **Professor Dan Roden** for these discussions:

- **Professor Bill Newman**, Professor of Translational Genomic Medicine, The University of Manchester, and Honorary Consultant in Genetic Medicine
- **Professor Katherine Payne**, Professor of Health Economics, The University of Manchester, and Fellow of the Royal Pharmaceutical Society
- **Dr Richard Turner**, Physician Director, Genomic Sciences, GSK

Introduction

Variable drug responses can lead to drugs working less well than expected or to serious adverse drug reactions. A prominent cause of these variable drug responses is genomic variation. Pharmacogenomics can help identify which patients are at risk of not responding optimally to a drug, benefitting the individual and reducing pressure on the healthcare system.

If a dose of a drug is given to a large population of patients, there is usually a normal distribution in the response. While most people's responses are at or near average, some people process or break down drugs more quickly ('fast metabolisers') or slowly ('slow metabolisers'). There are many reasons why people may respond differently to a drug. These include underlying diseases, drug–drug interactions, drug–food interactions, non-adherence to a treatment regimen, and genomic variation. Pharmacogenomics combines pharmacology – the science of drugs – with genomics – the study of the genome and its functions. Its aim is to use information about a person's genomic make-up to identify the most effective treatment for them, to find the ideal dosage, and to minimise side effects from abnormal drug responses.

In some cases, variable drug responses can lead to patients having very serious adverse drug reactions. An example is Stevens–Johnson Syndrome, a rare, potentially fatal blistering skin condition. Other organ systems can also be affected by serious adverse reactions, for example potentially fatal arrhythmias, and in some instances, multiple organ systems can be affected by the same drug. Adverse drug reactions are a significant health challenge affecting millions of people. A study published in 1998 estimated that 2.2 million adverse drug reactions in hospitalised patients led to 106,000 deaths in the US, making adverse drug reactions the fourth to sixth leading cause of death.[2] A 2004 analysis led by Professor Sir Munir Pirmohamed of 18,800 hospital patients in the UK found that 6.5% of admissions were caused by an adverse drug reactions.[3] A 2016 study summarised that little has changed, with research suggesting that between 5% and 10% of patients may suffer from an adverse drug reaction either at admission, during admission, or after discharge.[4]

Adverse drug reactions can be caused by different factors such as drug adherence and drug-food or drug-drug interactions, but a prominent component of a variability in response is genomic variation. If we can predict which patients are at risk due to this genetic component, there is an opportunity to intervene to prevent or avoid adverse drug reactions. Pharmacogenomics offers this opportunity, presenting benefits to both the individual and society, reducing pressure on the healthcare system and increasing long-term cost

[2] Lazarou J, *et al.* (1998). *Incidence of adverse drug reactions in hospitalized patients: a meta-analysis of prospective studies*. Journal of the American Medical Association **279 (15)**, 1200-5.
[3] Pirmohamed M, *et al.* (2004). *Adverse drug reactions as cause of admission to hospital: prospective analysis of 18,820 patients.* British Medical Journal **329 (7456)**, 15-9.
[4] Coleman JJ, *et al.* (2016). *Adverse drug reactions.* Clinical Medicine **16 (5)**, 481-5.

effectiveness of treatments. However, despite its potential, there has been limited adoption and implementation of pharmacogenomics in the healthcare system to date.

The 2022 FORUM Sir Colin Dollery Lecture, held on 13 October 2022 in the Victoria Gallery & Museum in Liverpool, aimed to explore the challenges and opportunities of pharmacogenomics in more detail. The main themes from the event, including the opportunities and challenges of pharmacogenomics, are summarised in this report. A recording of the Lecture is available on the Academy's YouTube channel.[5] A summary of interviews held with experts on the clinical implementation of pharmacogenomics can be found in Annex I. Opinions expressed in this report do not necessarily represent the views of all participants at the event, the Academy of Medical Sciences, or its Fellows.

[5] Please find Professor Dan Roden's talk here: https://www.youtube.com/watch?v=S-0Zo2J9m9g
Jane Burns' talk can be found here: https://www.youtube.com/watch?v=v4KJtDZJyaA

The impact of adverse drug reactions

Adverse drug reactions can have devastating effects on people's lives. Jane Burns gave a powerful account at the Lecture, describing how she was affected by Stevens–Johnson Syndrome, and why she is now an active member of the condition's patient involvement group.

Jane's experience of Stevens-Johnson syndrome

Jane was diagnosed with idiopathic generalised epilepsy in 1982 at the age of 11, and her seizures were well controlled with Epilim (sodium valproate). In 1991, at the age of 19, she attended a routine appointment about her epilepsy, and her consultant suggested changing her medication to Tegretol (carbamazepine). Less than 2 weeks into the process of decreasing her Epilim dosage and introducing Tegretol, she developed a cough and a slight fever. Five days later she had a rash of small red spots on her legs and body. And then, feeling hot and hallucinating, she was rushed to hospital with a temperature of 40°C.

The decision was made to discontinue the Tegretol, and she was kept in for observation.

Quite rapidly the rash was changing. Blisters were forming all over her body, her mouth was dry, her jaw ached, and her temperature remained high. At this point, the adverse drug reaction Stevens–Johnson Syndrome (SJS) was diagnosed. A rare, serious disorder of the skin and mucous membranes, SJS usually begins with flu-like symptoms, progresses to a painful rash that spreads and blisters, and then the top layer of affected skin dies and sheds. Toxic epidermal necrolysis (TEN) is a more severe form of the disorder, involving more than 30% of the skin surface and extensive damage to the mucous membranes.

Over the next few days, Jane's condition deteriorated rapidly: the rash became deeper in colour; some blisters burst while others enlarged, painful mouth ulcers developed, and she started to lose her hair and fingernails. As she had by now lost 65% of her skin, a diagnosis of TEN was made. She was moved to the acute renal unit, made a slow and steady recovery and, after 3 weeks, was discharged and continued her recovery at home.

Jane still has some physical scars on her body but, for her, the main scars are psychological, with the constant worry that SJS TEN may happen again.

Patient involvement in research

For more than 12 years, Jane has been part of the Patients and Public Involvement (PPI) Group for SJS, based at the Wolfson Centre for Personalised Medicine at the University of Liverpool, supporting and guiding its research. As part of the group, she is involved in staff training and team-building days, has received training on the Medicines and Healthcare product Regulatory Agency's Yellow Card Scheme to make medicines and medical devices

safer, and has connected with the SJS Awareness UK charity. The Group has been involved in producing awareness posters of SJS, and 'My SJS Passport' – a booklet that helps explain the condition, its management, and the long-term effects experienced by patients to healthcare professionals, friends, and family.

Jane's involvement in the research process means that her and her family now understand why her reaction may have happened, and that certain genes can affect how a person responds to a medicine. She feels that implementing pharmacogenomic testing more widely would take away her anxiety regarding taking new medications by reducing the risk of experiencing SJS, and enable safer drugs and drug dosages for future generations.

"I think involving patient voices and those with lived experience of health conditions in the research process is integral in ensuring the research benefits those who are impacted most."

Jane is a powerful voice as an advocate for research into pharmacogenomics, and for the development of tests to identify people who may be at risk of having an adverse drug reaction. Her involvement, alongside others with lived experiences of adverse drug reactions, helps ensure that research into adverse drug reactions stays relevant and impactful.

The biology and potential of pharmacogenomics

Scaling up the implementation of pre-emptive pharmacogenomic testing in healthcare could see more personalised treatment plans that account for the patient's genetic variants, increasing their effectiveness while minimising harms.

In his keynote address, **Professor Dan Roden**, Senior Vice President for Personalised Medicine at Vanderbilt University Medical Centre, explained how certain genes influence drug responses, which in some cases can lead to severe adverse reactions like Stevens–Johnson Syndrome (SJS), and provided a compelling account of the potential of pharmacogenomics to improve treatment strategies.

Gene influence on drug response

Gene variations can impact the way the body metabolises and responds to drugs. Professor Roden noted that the body's metabolism of a drug can inactivate it, breaking it down so that it can be excreted, or activate it if the drug is administered in a precursor form called a prodrug. There are a number of genes producing the enzymes that carry out this metabolism. The most important of these enzymes are the cytochrome P450 enzymes. The enzyme cytochrome P450 2D6, for example, is responsible for the biotransformation of about 25% of the drugs that are used chronically. However, the activity of this enzyme varies across populations. Encainide (an antiarrhythmic drug) was an early example of a compound that is metabolised by the enzyme cytochrome P450 2D6. Although encainide is effective in some patients, in others it has caused unwanted side effects including aggravated arrhythmia. Encainide has since been withdrawn.[6]

Variations in the genes that produce these enzymes – the CYP genes – can have profound influences on people's responses to drugs. Most people, with one or two wild-type ('normal') alleles of the *CYP2D6* gene that encodes the cytochrome P450 2D6 enzyme, metabolise drugs well. People with two mutant alleles are poor metabolisers, and a few people are ultra-rapid metabolisers as they have multiple copies of the functional gene and large quantities of the enzyme. More than 100 loss-of-function alleles of *CYP2D6* have been identified to date, some of which exist in some populations but not in others.

Variations in how drugs are metabolised by the body can risk health in different ways. For example:

1. **Where drugs are administered as precursor prodrugs that need to be converted to an active form to have a therapeutic effect:** if a patient is a poor metaboliser, then the active form of the drug is not produced and the drug does not

[6] Pool PE (1990). *Efficacy of encainide in supraventricular arrhythmias* Cardiovascular Drugs and Therapy **4**, 573-577.

have the desired effect. This is the case for drugs such as encainide, clopidogrel, tamoxifen and codeine.[7]

2. **Where a drug is administered in an active form and needs to be metabolised into an inactive form:** if the pathway is inhibited due to genetic factors or the coadministration of an inhibiting drug, the active drug can build up leading to more exaggerated effects than intended. This is the case for drugs such as debrisoquine, warfarin, irinotecan and azathioprine.[8]

Predicting drug responses with multiple genetic variants

An individual's drug response can be influenced by variations in the genes that produce the enzymes that carry out the metabolism of drugs. Professor Roden noted that for some treatments, where the response to a drug is influenced by a single genetic variant in one of these enzymes and this has a large effect on an individual's reaction to the drug, it is relatively straightforward to distinguish between normal, poor and rapid metabolisers in a population. But many drug responses are a continuum, with multiple genetic variants determining where somebody falls on that continuum.

Combining the effects of multiple genetic variants into a polygenic risk score can help overcome this complexity and predict a drug response to some extent. For example, combining the effects of 11 genetic variants that affect responses to clopidogrel (an antiplatelet medicine that helps to prevent blood clots) shows that the more risk alleles a person has, the higher the likelihood that they will experience an undesirable side effect.

Combining multiple genetic variants into a polygenic risk score can also be used to group people based on their level of risk of certain diseases. In some cases, this information about disease risk can in turn be used to predict the effect of a drug. For example, Professor Roden showed how the drug alirocumab (a PCSK9 inhibitor for coronary artery disease) has a larger effect in the group at high-risk for coronary heart disease. However, alirocumab, which lowers cholesterol, does not have a significant effect in the low-risk group. In this way, polygenic risk scores for disease appear to have potential to help guide treatment decisions and give treatments to those that are most likely to benefit from them.

Pharmacogenomics enables more personalised treatments

Research on variable drug responses, together with clinical bioinformatics, has enabled resources for personalised medicine to be created. At Vanderbilt University Medical Centre, a biobank called BioVU has enabled the case for pre-emptive pharmacogenomic testing to be examined. For example, a large study in BioVU that looked at 50,000 patients found that 65% had received at least one medicine with a recognised pharmacogenomic 'story' within the previous five years, and that an estimated 383 severe reactions could have been mitigated if pharmacogenomic information had been integrated appropriately into clinical decision-making. This led to a programme called PREDICT – the Pharmacogenomic Resource for Enhanced Decisions in Care and Treatment – which clinicians can use to check their patients' records for gene-drug interactions before prescribing medications (see Box 1).

[7] Encainide is a class IC antiarrhythmic agent, which is no longer used due to its potential side effect of aggravating arrhythmia. Clopidogrel is an antiplatelet medicine used to prevent major problems in those at high-risk of heart disease and stroke. Tamoxifen is a selective oestrogen receptor modulator used for treating breast cancer. Codeine is a prescription-only opiate used to relieve pain and suppress coughing.

[8] Debrisoquine is an adrenergic neuron-blocking drug formerly used to treat hypertension, and a *CYP2D6* substrate. Warfarin is an anticoagulant that works by blocking the enzyme VKOR, preventing it from reactivating vitamin K1. Irinotecan is a type of chemotherapy and an antineoplastic enzyme inhibitor used to treat colon cancer and small cell lung cancer. Azathioprine is an immunosuppressant used to treat rheumatoid arthritis, Crohn's disease, ulcerative colitis, and to prevent the rejection of a renal transplant.

Box 1: PREDICT – the Pharmacogenomic Resource for Enhanced Decisions in Care and Treatment

PREDICT, Vanderbilt University Medical Center's Pharmacogenomic Resource for Enhanced Decisions in Care and Treatment, helps physicians predict, through genetic testing, how their patients will respond to commonly prescribed medications.[9]

Candidate drugs are identified by reviewing evidence from the academic literature, looking at guidance from professional societies and the US Food and Drug Administration (FDA), and then replicating and validating known pharmacogenomic findings using BioVU. The evidence is then reviewed by the Clinical Pharmacogenetics Implementation Consortium. Once implemented in the system, clinicians can check their patients' records for gene-drug interactions before prescribing medications for them.

They first began by implementing testing for the *CYP2C19* gene for patients who might be given clopidogrel (an antiplatelet drug that prevents blood clots) to identify poor metabolisers at a higher risk of thrombosis in a stent; other drug–gene pairs have been added subsequently.

Clinical implementation of pharmacogenomics

For many diseases, the clinical options are well developed, there are clear services and plans available to healthcare professionals, and patients are given multiple treatment choices. Professor Roden described how, in principle, expanding the implementation of pre-emptive pharmacogenomic testing from speciality sites more widely into clinical practice should be straightforward. Pharmacogenomic research has identified a number of genetic alleles that are common, have large effects on drug response when present, and can be linked to electronic record systems. Although conversations around genomic make-up require a careful and sensitive approach, none of the variants identified so far have links to susceptibility for underlying diseases or cancers, which could otherwise be distressing and require additional support.

Yet, while developments such as PREDICT (Box 1) demonstrate how pharmacogenomic testing systems can be established, there are still challenges that need to be overcome before pharmacogenomics is scaled-up and used routinely in healthcare systems, including:

[9] https://mydruggenome.org/

- Training of and engaging healthcare professionals in the use of pharmacogenomic data.
- The complexity of some pharmacogenomic assays, which makes their widespread use difficult.
- The need for further research to determine the function of many variants in pharmacogenes.

Despite the challenges discussed below, understanding the biology and genetics of variable drug responses has already helped avoid severe adverse drug reactions by implementing pharmacogenomics in the clinic (see Box 2 as an example).

Box 2: The Pharmacogenetics to Avoid Loss of Hearing (PALOH) Trial

The antibiotic gentamicin, an aminoglycoside, is generally safe and is effective against a broad range of bacteria. It is commonly used in intensive care units for babies affected by serious bacterial infections, who often need immediate treatment. However, gentamicin is not suitable for about 1 in 500 people who carry the mitochondrial genetic variant MT-RNR1 as they are at risk of severe hearing loss (aminoglycoside-induced ototoxicity, AIO).

The Pharmacogenetics to Avoid Loss of Hearing (PALOH) trial examined the use of a new rapid point-of-care test for MT-RNR1. Recruiting neonates admitted to neonatal intensive care units across two participating hospitals in the UK, the trial found that clinicians were able to integrate the 30-minute test into existing clinical pathways to guide antibiotic therapy and avoid AIO in the acute neonatal setting.[10]

To build the evidence base to support the implementation of pharmacogenomic testing in healthcare, trials are required to determine which groups of patients may benefit. The clinical decision influenced may be more nuanced than a simple 'prescribe or do not prescribe' decision, and could help guide the dose of drug that should be given. Indeed, a 2015 study investigated the effect of variants in a gene called TPMT (thiopurine methyltransferase), on the response to different doses of azathioprine, a drug that is used in the treatment of inflammatory bowel disease.[11] Results showed that while pre-treatment genotyping should not be used instead of blood safety monitoring, TPMT screening and personalised dosing of

[10] McDermott JH, *et al*. (2022). *Rapid Point-of-Care Genotyping to Avoid Aminoglycoside-Induced Ototoxicity in Neonatal Intensive Care*. JAMA Pediatr. **176(5)**, 486–492.
[11] Coenen MJH, *et al.* (2015). *Identification of Patients With Variants in TPMT and Dose Reduction Reduces Hematologic Events During Thiopurine Treatment of Inflammatory Bowel Disease.* Gastroenterology **149 (4)**, 907-917.

azathioprine reduced the risk of leukopenia in those patients who had variants in the TPMT gene. The study concluded that pharmacogenomic testing should become standard care for inflammatory bowel disease patients taking thiopurine treatment.

Professor Roden introduced a larger trial – PREPARE (Preemptive Pharmacogenomic Testing for Preventing Adverse Drug Reactions), run by the Ubiquitous Pharmacogenomics Group – that has examined whether pharmacogenomic testing makes a difference in patient outcomes. The study was conducted in seven sites across seven European countries (with Liverpool as the UK site), with the sites randomised to provide either prescriptions adjusted based on pharmacogenomic testing (using a 12 gene pharmacogenomic panel) or standard treatment.[12]

After 18 months, the sites switched over to the other arm. The study started in 2017 and lasted for three years, recruiting 6,944 participants. Every participant was provided with a card that lists their metaboliser status and whether there are drugs that they should or should not be prescribed.

The results of the study, published in February 2023 (following the Lecture), showed that genotype-guided treatment using the 12-gene pharmacogenomic panel significantly reduced the incidence of clinically relevant adverse drug reactions by 30% and was feasible across diverse European healthcare system organisations and settings.[13]

[12] Genomics Education Programme (2023). *A 'world first' in pre-emptive pharmacogenomic testing.* Genomics Education Programme blog, March 10. https://www.genomicseducation.hee.nhs.uk/blog/a-world-first-in-pre-emptive-pharmacogenomic-testing/

[13] Swen JJ, *et al.* (2023). *A 12-gene pharmacogenetic panel to prevent adverse drug reactions: an open-label, multicentre, controlled, cluster-randomised crossover implementation study.* The Lancet **401 (10374)**, 347-356.

Challenges for the implementation of pharmacogenomics

Before the scale-up and implementation of pharmacogenomic testing can be realised, several challenges will need to be addressed. Overcoming these research-based and systemic challenges will be vital to realising the potential of pharmacogenomics in improving the safe and effective use of drugs.

There are still many challenges to overcome if health systems are to uniformly implement pharmacogenomic testing and take best advantage of the opportunities of pharmacogenomics. Some of the challenges are research-based – understanding how multiple genetic variants influence drug responses and building the evidence base to support implementation – while others involve developing the systems to support implementation, raising awareness and engaging with physicians and the public on the benefits of pharmacogenomics, and ensuring that the tests are accessible.

During his keynote address, Professor Roden began to explore the challenges of integrating pharmacogenomic testing from speciality sites into clinical practice and prescribing decisions. These challenges were then discussed in more depth with an expert panel, chaired by **Professor Sir Munir Pirmohamed FMedSci**, David Weatherall Chair of Medicine at the University of Liverpool. During this session, **Professor Roden** was joined by the following experts to discuss the ethical, accessibility and economic impacts of pharmacogenomics:

- **Professor Bill Newman**, Professor of Translational Genomic Medicine, The University of Manchester, and Honorary Consultant in Genetic Medicine
- **Professor Katherine Payne**, Professor of Health Economics, The University of Manchester, and Fellow of the Royal Pharmaceutical Society
- **Dr Richard Turner**, Physician Director, Genomic Sciences, GSK

Acceptance and clinical use of pharmacogenomic testing

Even when the benefits of a pharmacogenomic test are clear, it can still take time for it to become accepted by healthcare professionals, and there is a need to engage and communicate about pharmacogenomics carefully to avoid unintentional harms. For example, Professor Roden highlighted in his Lecture a trial of a pharmacogenetic test for *HLA-B*15:02* – a susceptibility allele for Stevens–Johnson Syndrome that is particularly prevalent in South East Asia – that had an unexpected outcome. In a study, which was conducted in Hong Kong, the plan was that everybody who would normally be prescribed carbamazepine (Tegretol) would be genotyped before they received the drug; if they had the HLA variant, they would be prescribed a different drug. The researchers found that new prescriptions for Tegretol fell from 16% to 2% as doctors did not use the genotyping approach, instead prescribing other drugs straightaway. And while the incidence of Stevens–Johnson Syndrome due to

carbamazepine fell to zero, the incidence of adverse reactions (including new cases of Stevens-Johnson Syndrome) induced by alternative antiepileptic drugs increased.

Sir Munir highlighted that one barrier to implementation is bridging the knowledge gap so that healthcare professionals become more aware and accepting of pharmacogenomics. Professor Roden described how this will take time, and that building an evidence-base for evaluating pharmacogenomic testing and its outcomes was a challenge. Further research also needs to be done to determine the function of many variants in pharmacogenes, to understand drug responses and ensure that pharmacogenomic testing can have widespread benefits.

To increase acceptance, healthcare professionals need to be trained and engaged on the use of pharmacogenomic data. Further complications arise from the complexity of some pharmacogenomic assays, which can make their widespread use difficult. Professor Roden reflected on the initial resistance by some healthcare professionals when the PREDICT system (Box 1) was rolled out 10–12 years ago. He suggested that, at the time of the Lecture, there was more acceptance of the system, in particular from healthcare professionals who had become experienced with its use, an acceptance which could then spread to other healthcare professionals.

Alongside this, the information provision for carers and patients also needs to be considered. While there can be a nervousness about how genetic information is used, Professor Newman reflected that in his experience this tends not to be the case when discussing drug safety and drug efficacy. Professor Newman noted that in his experience people are, in general, supportive of science and health data use that can make prescriptions safer and more effective. He explained that to ensure people are comfortable with the implementation of pharmacogenomics, there needed to be more evidence-based conversations and transparent plans for how people's genetic information is being used.

Professor Payne also emphasised the need for public engagement on the topic of pharmacogenomics to raise awareness and increase the acceptability of its use.

As well as outlining the health benefits, the economic case for pharmacogenomic testing also needs to be developed, to produce evidence to support widespread procurement across the healthcare system. Procurement and widespread adoption can also be facilitated by considering integrating pharmacogenomic data with the existing online systems and tools used by prescribers, allowing for better ease of use.

The importance of diversity in pharmacogenomics research

In his Lecture, Professor Roden showed that ongoing research into pharmacogenomics has uncovered striking differences in allele frequencies between populations, with differences particularly notable among variants in the *CYP2C19* gene (Box 1). Research has also identified ancestry-based susceptibility for SJS. For example, as noted above, the genetic variant *HLA-B*15:02*, a susceptibility allele for SJS, is particularly prevalent in South East Asia. Such findings illustrate the importance of diversity in pharmacogenomics research.

Professor Roden also highlighted that the All of Us health research programme in the USA has an emphasis on recruiting people who are traditionally underrepresented in biomedical research and reflected on Our Future Health as a similar initiative in the UK.[14,15] The goal of

[14] https://allofus.nih.gov/
[15] https://ourfuturehealth.org.uk/

the All of Us programme is to recruit and involve at least a million people from diverse backgrounds. The programme returns data to participants and informs them if they have any of the 59 genes with actionable variants that increase risk for certain hereditary diseases. The programme is also informing participants on whether they have any pharmacogenomic variants, returning information about variants in seven genes. Extensive genetic counselling support is being provided.

Improving access to pharmacogenomic testing

The panel discussed how barriers to accessing healthcare services faced by underserved communities extend to genetic or potentially pharmacogenomic services. In the panel discussion, Professor Newman noted how, to help improve accessibility to such services, the NHS Genomic Medicine Service (GMS) has established seven laboratory hubs across England. These hubs are working with the seven regional GMS Alliances to look at how to implement pharmacogenomic testing more widely in the NHS.[16] Clinical pharmacologists or clinical geneticists may not themselves be able to reach out to every community, as this would not be scalable. Instead, the GMS plans to reach more people by engaging with the primary and community care systems, including GPs – where 90% of all medications are prescribed. They are starting an implementation study called PROGRESS to assess the feasibility of routine pharmacogenetics testing in primary care.[17] Also, they are connecting with community pharmacists and practice pharmacists. Professor Newman described how the North-West region's GMS Alliance is working closely with other GMS Alliances to consider the role of community pharmacists. This exercise will explore the appetite for pharmacogenomic testing, what it would mean in practice for pharmacists to be involved and investigate how pharmacogenomic testing could be rolled out. This kind of engagement with key stakeholders is and will continue to be essential for the effective implementation of pharmacogenomics in health systems.

[16] Hill S (2020). *NHS Genomic Medicine Service Alliances to help embed genomics into patient care pathways.* NHS England Blog, December 23. https://www.england.nhs.uk/blog/nhs-genomic-medicine-service-alliances-to-help-embed-genomics-into-patient-care-pathways/
[17] https://www.nw-gmsa.nhs.uk/about-us/our-projects/spotlight

The future of pharmacogenomics

Overcoming the challenges of implementing pharmacogenomics could transform the way in which medicines are prescribed and limit the incidence of suboptimal drug response. Increasing access to pharmacogenomic testing will involve a continued focus on discovery, and a strategy to prioritise the most at-risk groups.

The field of pharmacogenomics has advanced significantly over recent years. These advances have been helped by considering the many different elements involved in delivering pharmacogenomics at scale: from routine diagnostic laboratory testing; to informatics for analysing data; the implementation of information into clinical systems to allow rapid, clear decision making; and the training of healthcare professionals on this topic. The process needs to involve clinicians, pharmacists and other healthcare professionals, and patients and the public working together as a team.

Building the economic case for pharmacogenomics

During the panel discussion, Professor Payne noted that there needs to be careful thought about how healthcare systems can use pharmacogenomics to its best advantage. Rather than rushing the implementation of pharmacogenomic testing into the NHS, she proposed that an iterative approach should be taken. Professor Payne indicated that **the development of an economic case to understand and measure the potential value of pharmacogenomic testing could aid with procurement. Short-term and long-term benefits for patient populations need to be measured alongside the costs to healthcare systems associated with the implementation of pharmacogenomic testing.**

Encouraging the incremental adoption of pharmacogenomic testing by prioritising the most at-risk groups

Dr Turner posited that, in the future, pharmacogenomic information may be used in a similar way to how renal function testing is currently used routinely to guide prescribing decisions, although barriers around education and the integration of pharmacogenomic information into prescribing decision-support systems will have to be navigated. Dr Turner noted that stepwise incremental adoption is one pragmatic approach to feasibly implement pharmacogenomics into healthcare systems. This approach would initially **prioritise tests and clinical settings where pharmacogenomic testing would be expected to convey the largest benefits**. This stepwise incremental implementation of drug-gene pairs could consider, for example, the strength of evidence underpinning different drug-gene associations, the severity of their associated adverse reactions, the merits of alternative treatments available, the ease of incorporating testing into existing patient pathways, the numbers of individuals eligible for testing, and how many individuals would be helped.

Facilitating the adoption of pharmacogenomic testing

Alongside these developments, Professor Newman highlighted that complexity is a challenge, and that **high-throughput tests that require minimal interpretation** are needed. It will be essential for clinicians to know – at the point of prescription – what that information means and how it impacts treatment. Similarly, finding straightforward ways to analyse and use genetic information will be important if routine whole genome sequencing is being used for pharmacogenomics.

Professor Newman noted that introducing **whole genome sequencing at scale across a population** may happen as the costs of this technology fall and as our understanding of how to analyse the data improves. However, even for clinical geneticists, who spend time looking at genomic information from patients, a whole genome sequence will provide information on specific variants that are sometimes very complex and difficult to interpret. The diagnostic process can be challenging, as can the ethical questions associated with the interpretation of that information (including the incidental findings).

Finally, Professor Roden highlighted in his Lecture the importance of coherent national programmes, education and communication. In particular, he supported a **national programme with support teams**, and **clear communication to patients including diverse groups, the public, and the media,** to ensure that pharmacogenomic testing can be smoothly scaled-up and that the benefits of implementation are trusted by healthcare professionals and the public.

Supporting research on pharmacogenomics to improve its use in clinical settings

A **continued focus on discovery** is important, ensuring that genome science continually informs pharmacogenomics. Through this, Professor Roden's view was that, in 10–15 years' time, polygenic risk scores are likely to be available for many drugs, which combined with electronic records will help patients and clinicians determine the suitability of drugs based on not just single genetic variants, but many variants.

Concluding remarks

Reflecting on the future of pharmacogenomics, many panellists felt that although pharmacogenomic tests are already helping ensure appropriate and effective prescribing of certain drugs to patients, **there is the potential for pharmacogenomics to be used far more widely and routinely in healthcare**. Implementing pharmacogenomic testing would not only improve patient safety and the health of patients but may also reduce healthcare costs. And while several challenges were raised during the meeting – including building the evidence base, embedding diversity into pharmacogenomics research, improving access to pharmacogenomics testing, increasing its acceptance and clinical use, better engaging with clinicians and the public, and integrating pharmacogenomics with healthcare systems – there was optimism and enthusiasm about the future use of pharmacogenomics in better tailoring treatments to patients, ensuring they are safe and effective and avoiding adverse drug reactions.

Annex I Interviews

The first FORUM Annual Lecture took place in 2003. Entitled 'Pharmacogenetics: Personalised Safety and Segmented Efficacy', the Lecture discussed the exciting potential of pharmacogenetics to revolutionise personal medicine. Twenty years on, pharmacogenomics is starting to be clinically implemented, and it was timely to further explore the challenges and opportunities associated with its adoption in the healthcare system through the 2022 FORUM Sir Colin Dollery Lecture on 'Pharmacogenomics, personalisation and public health'. At the Lecture, pre-recorded interviews with relevant clinical experts were screened providing attendees with a broader set of perspectives on this important topic.

Interviews were held with the following experts:

- **Dr Judith Hayward**, GP with a Special Interest (GPwSI) in Clinical Genetics, Yorkshire Regional Genetics Service
- **Professor Sandosh Padmanabhan**, Professor of Cardiovascular Genomics and Therapeutics, University of Glasgow
- **Dr Imran Rafi**, General Practitioner and Reader in Primary Care and Genomics, St George's, University of London
- **Dr Videha Sharma**, Lecturer in Health Informatics, The University of Manchester, and National Medical Director's Fellow, Faculty of Medical Leadership and Management

These individuals were asked to comment on a range of topics pertaining to the utility, applications, and implementation of pharmacogenomics within health and social care settings.

The benefits of pharmacogenomics

The inefficiencies of the prevailing model of pharmacotherapy were likened by Professor Padmanabhan to a 'fishing exercise', in which patients are prescribed drugs according to standard recommendations, with limited regard for the individual characteristics of the specific patient. Pharmacogenomics was highlighted as a critical tool moving forward – supporting therapy choice, dosage and dosing schedule. Professor Padmanabhan also highlighted the wider public health benefits of the adoption of pharmacogenomics in practice, particularly its potential to minimise the challenge of polypharmacy in primary care. Dr Hayward and Dr Rafi echoed these sentiments, agreeing that there is great potential for pharmacogenomics to help address challenges associated with multiple long-term conditions.

Barriers to implementation and adoption of pharmacogenomics in health and social care settings

However, interviewees suggested that the widespread implementation and adoption of pharmacogenomics within the health and social care settings faced many barriers. Dr Sharma grouped these challenges into two categories: technical and social.

The issue of interoperability – the ability of computer systems or software to exchange and make use of information – was seen by Dr Sharma, Dr Hayward and Dr Rafi as the critical technical barrier to the implementation of pharmacogenomics in primary care. There is a need to ensure that different forms of data, as well as different operational systems, can be linked. Prevailing modes of drug prescribing have been hospital/pharmacy-centric, resulting in siloing of data and operating procedures. Interviewees described a need to ensure that appropriate digital infrastructure is in place to make data access and sharing possible, such that integration of novel tools is minimally disruptive.

Dr Hayward, Dr Rafi and Dr Sharma also all highlighted the need to ensure that pharmacogenomic datasets are representative of the populations they are attempting to serve – for example, many existing data sets are poorly representative of many ethnic groups. Spanning both the technical and social challenges to implementation of pharmacogenomic workflows, representation of a diversity of patient populations in datasets is essential to minimise bias in suggested outcomes on which pharmacogenomic prescription decision-making is based. Dr Sharma also emphasised the need to ensure that data is captured in an agnostic way, suggesting that open standards could help the entire healthcare system benefit from pharmacogenomics.

Social barriers, identified by multiple video interviewees, pertained to the engagement of clinicians and professionals in the design and adoption of pharmacogenomic workflows. Alongside patients, GPs, pharmacists, and other allied health professionals, all represent 'end-users', who should be consulted during process design. It was highlighted that the adoption and implementation of tools would be facilitated if these could be relatively seamlessly integrated into existing systems already employing Electronic Health Records. All interviewees also emphasised the need for education and upskilling of the workforce to support the use of these tools in daily practice.

Professor Padmanabhan additionally stressed the possible role of policymakers in supporting cultural change through the dissemination and promotion of the benefits of pharmacogenomic-supported decision making, including the economic benefit to all stakeholders, including physicians, pharmacists, policymakers, and patients. It was noted that it is important to communicate to policymakers, as well as primary care general practitioners, specialists, and pharmacists, that despite the relatively high upfront cost of widely implementing pharmacogenomics, eliminating the unnecessary and suboptimal treatments associated with current prescription models will see greater economic and societal benefits in the long-term. Whilst stakeholders, such as commissioners, will be explicitly interested in the economic value associated with clinical implementation of pharmacogenomic workflows, policymakers will also have a role in communicating the wider health and monetary benefits to clinicians and other health professionals, in addition to patients and the public.

The importance of patient involvement

The involvement and support of patients is a fundamentally important consideration in the implementation of pharmacogenomics, as stressed by Dr Hayward and Dr Rafi. Patient relationships are critical in healthcare, particularly in the context of shared decision-making. Professor Padmanabhan, reflecting upon previous patient engagement, spoke to the general positivity of patient attitudes regarding pharmacogenomics. In his experience, patients were keen to reduce polypharmacy, but wanted more information about the other benefits and drawbacks of pharmacogenomic tools for prescribing. Professor Padmanabhan also raised that patients may be concerned about how their genetic data is used, stored and shared, with particular concerns regarding benefit/risk trade-offs when private companies may be involved. Establishing and maintaining a dialogue with patients will be important to ensure wider public acceptability of these novel workflows into routine practice.

Future considerations

Finally, all video interviewees discussed considerations for the implementation of pharmacogenomics moving forward. Dr Hayward and Dr Rafi discussed the ongoing development of clinical decision support tools, and integration of education into tool

interfaces as GPs begin to access and use genomic information at the point of care. Also raised was the need for multi-disciplinary approaches to the development of pharmacogenomic tools, a sentiment echoed by Dr Sharma. Furthermore, all experts emphasised the need for clear evidence of clinical benefit in driving adoption and uptake moving forward, and the requirement for widespread communication to stakeholders including patients, the public, physicians, pharmacists, and policymakers of the benefit to individuals and society.

Annex II Agenda

13.00 – 14.00	**Lunch & learn session** *Video presentations from:* • **Dr Judith Hayward,** GP with a Special Interest (GPwSI) in Clinical Genetics, Yorkshire Regional Genetics Service • **Professor Sandosh Padmanabhan**, Professor of Cardiovascular Genomics and Therapeutics, University of Glasgow • **Dr Imran Rafi,** General Practitioner and Reader in Primary Care and Genomics, St George's, University of London • **Dr Videha Sharma,** Lecturer in Health Informatics, The University of Manchester, and National Medical Director's Fellow, Faculty of Medical Leadership and Management
14.00 – 14.05	**Welcome and introduction** Professor Dame Anne Johnson DBE PMedSci
14.05 – 15.00	**Keynote Lecture** Professor Dan Mark Roden, Professor of Medicine, Pharmacology and Biomedical Informatics, and Senior Vice President for Personalised Medicine, Vanderbilt University Medical Centre
15.00 – 15.15	**Patient perspective** Jane Burns, Member of the Drug Safety Patient & Public Involvement Group, Wolfson Centre for Personalised Medicine
15.30 – 16.25	**Panel discussion** *Chaired by Professor Sir Munir Pirmohamed FMedSci, David Weatherall Chair of Medicine, University of Liverpool* • **Professor Dan Mark Roden**, Professor of Medicine, Pharmacology, and Biomedical Informatics and Senior Vice President for Personalised Medicine, Vanderbilt University Medical Centre • **Professor Bill Newman,** Professor of Translational Genomic Medicine, The University of Manchester, and Honorary Consultant in Genetic Medicine • **Professor Katherine Payne,** Professor of Health Economics, The University of Manchester, and Fellow of the Royal Pharmaceutical Society • **Dr Richard Turner,** Physician Director, Genomic Sciences, GSK
16.25 – 16.30	**Closing remarks**
16.30 – 18.00	**Drinks reception**

Annex III Attendee list

Please note that this event was a hybrid event. In addition to the in-person attendees listed here, over 150 people joined the event online.

Chairs

Professor Dame Anne Johnson DBE PMedSci, President, Academy of Medical Sciences
Professor Sir Munir Pirmohamed FMedSci, David Weatherall Chair of Medicine, University of Liverpool

Speakers and panellists

Professor Dan Roden (keynote speaker), Professor of Medicine, Pharmacology, and Biomedical Informatics and Senior Vice President for Personalised Medicine, Vanderbilt University Medical Centre
Jane Burns, Member of the Drug Safety Patient & Public Involvement Group, Wolfson Centre for Personalised Medicine
Professor Bill Newman, Professor of Translational Genomic Medicine, The University of Manchester, and Honorary Consultant in Genetic Medicine
Professor Katherine Payne, Professor of Health Economics, The University of Manchester, and Fellow of the Royal Pharmaceutical Society
Dr Richard Turner, Physician Director, Genomic Sciences, GSK

In-person attendees

Dr Muhammad Ahmed, Junior Doctor in Infectious Diseases and Clinical Pharmacology, Royal Liverpool University Hospital
Mark Bartlett, CEO, StoreGene
Amy Beanlands, Student, University of Newcastle
Gruffydd Behnan, Student in Pharmacology, University of Liverpool
Dr John Blaikley, Senior Lecturer in Immunology and Respiratory Medicine, The University of Manchester
Dr Thomas Blair, Senior Medical Science Liaison (Haemoglobinopathies), Vertex Pharmaceuticals
Daniel Bond, Student, University of Liverpool
Sir Robert Boyd FMedSci, Visiting Professor in Child Health, The University of Manchester
Professor Ed Bullmore FMedSci, Professor of Psychiatry and Deputy Head of the School of Clinical Medicine, University of Cambridge
Professor Peter Calverley FMedSci, Emeritus Professor of Respiratory Medicine, University of Liverpool
Dr Dan Carr, Lecturer in Pharmacology and Therapeutics, University of Liverpool
Dr Julian Chan, Postdoctoral Researcher, University of Liverpool
Sophie Crawford, Student, University of Liverpool
Sian Cunningham, Communications Officer NIHR-ARC-NWC, University of Liverpool
Professor David Denning FMedSci, Professor of Infectious Diseases in Global Health, The University of Manchester

Dr Rina Dutta, Clinical Senior Lecturer, King's College London
Gail Fitzgerald, Research Nurse, Royal Liverpool & Broadgreen University Hospitals NHS Trust, Wolfson Centre for personalised Medicine, University of Liverpool
Dr Anna Auer-Fowler, Lecturer in Health Data Science, University of Liverpool
Dr Flic Gabbay FMedSci, President, Faculty of Pharmaceutical Medicine and Managing Partner, Transcrip Partners
Lisa Gaskell, Royal Liverpool & Broadgreen University Hospitals NHS Trust
Dr Georgina Gregory, Royal Society Dorothy Hodgkin Fellow, University of Oxford
Sam Hamlett, Executive Territory Account Manager, Illumina
Professor Dharani Hapangama, Professor of Gynaecology, University of Liverpool
Professor Michael Hanna FMedSci, Director, UCL Institute of Neurology; Director, UCL MRC Centre for Neuromuscular Diseases; Professor in Clinical Neurology, University College London
Anita Hanson, Lead Research Nurse, University of Liverpool
Maria Imran, Student, University of Bristol
Dr Surabhi Kandaswamy, Lecturer in Clinical Genetics, University of Central Lancashire
Jessica Keen, Pharmacy Lead, NHS North West Genomic Medicine Service Alliance
Professor Henry Kitchener FMedSci, Professor of Gynaecological Oncology, The University of Manchester
Dr Valeria Lascano, Real World Evidence Principal (Director), IQVIA
Professor Mandy MacLean FMedSci, Professor of Pulmonary Pharmacology, University of Strathclyde
Professor Michael Malim FRS FMedSci, Head of School of Immunology & Microbial Sciences, King's College London
Dr Geraldine McCaffrey, Principal Pharmacist for Research and Development, Betsi Cadwaladr Health Board
Dr John McDermott, NIHR Doctoral Research Fellow at the Manchester Centre for Genomic Medicine, The University of Manchester
Laurence McEvoy, Research Technician and PhD Student in Pharmacology, University of Liverpool
Oliver Moore, Student, University of Liverpool
Dr Tiffany Morris, Staff Market Development Manager Precision Health & Pharmacogenomics, Europe, Illumina
Vala Parpala, University of Liverpool
Anastasia Pavlovets, Senior Scientist in Human Genomics, C4X Discovery Ltd
Mathew Peters, Senior Professional Services Manager, National Pharmacy Association (NPA)
Dr Vivien Price, Clinical Research Fellow, University of Liverpool
Clare Prince, Research Nurse, Royal Liverpool & Broadgreen University Hospitals NHS Trust, Wolfson Centre for Personalised Medicine, University of Liverpool
Dr Judith Richardson, Programme Director – Health and Social Care, National Institute for Health and Care Excellence (NICE)
Professor Eleanor Riley FMedSci, Professor of Infectious Disease Immunology, London School of Hygiene and Tropical Medicine
Clare Roberts, University of Liverpool
Professor Amin Rostami-Hodjegan, Professor of Systems Pharmacology, The University of Manchester
Tazim Samad, Student, University of Liverpool

Professor Calum Semple, Professor of Child Health and Outbreak Medicine, University of Liverpool
Dr Videha Sharma, Honorary Lecturer in Informatics, Imaging and Data Sciences, The University of Manchester
Professor Sally Sheard, Executive Dean, Institute of Population Health & Andrew Geddes and John Rankin Professor of Modern History, University of Liverpool
Professor Reecha Sofat, Breckenridge Chair of Clinical Pharmacology and Head of the Department of Pharmacology and Therapeutics, University of Liverpool
Professor Tom Solomon CBE FMedSci, Director of the Pandemic Institute, Director of the NIHR HPRU in Emerging and Zoonotic Infections; Chair of Neurology, University of Liverpool
Dr James Squires, Policy and Public Affairs Manager, The Health Foundation
Professor Paul Stewart FMedSci, Dean of Medicine, Faculty Dean of Medicine & Health, University of Leeds
Dr Sarah Trenfield, Strategic Stakeholder Engagement Manager, Medical Research Council
Dr Dorothy Tse, Senior Lecturer in Psychology, Edge Hill University
Dr David Twesigomwe, Postdoctoral Research Fellow, University of the Witwatersrand
Promise Vanderboom, University of Liverpool
Ruth Westhead, Royal Liverpool & Broadgreen University Hospitals NHS Trust, University of Liverpool
Professor Dame Margaret Whitehead FMedSci, WH Duncan Professor of Public Health and Head, World Health Organisation Collaborating Centre for Policy Research on Social Determinants of Health, University of Liverpool
Professor Wiebke Arlt FMedSci, William Withering Chair of Medicine, Director of the IMSR, University of Birmingham
Simon Wilson, Medical Science Liaison, Vertex Pharmaceuticals
Dr Eunice Zhang, Postdoctoral Researcher in Pharmacology and Therapeutics, University of Liverpool

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Alex Straw, Senior Programme Officer, Academy of Medical Sciences
Julia Turan, Digital Communications Manager, Academy of Medical Sciences

Interviewees

We are also grateful to the following interviewees for sharing their experience and expertise ahead of the Lecture:

Dr Judith Hayward, GP with a Special Interest (GPwSI) in Clinical Genetics, Yorkshire Regional Genetics Service
Professor Sandosh Padmanabhan, Professor of Cardiovascular Genomics and Therapeutics, University of Glasgow
Dr Imran Rafi, General Practitioner and Reader in Primary Care and Genomics, St George's, University of London
Dr Videha Sharma, Lecturer in Health Informatics, The University of Manchester, and National Medical Director's Fellow, Faculty of Medical Leadership and Management

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