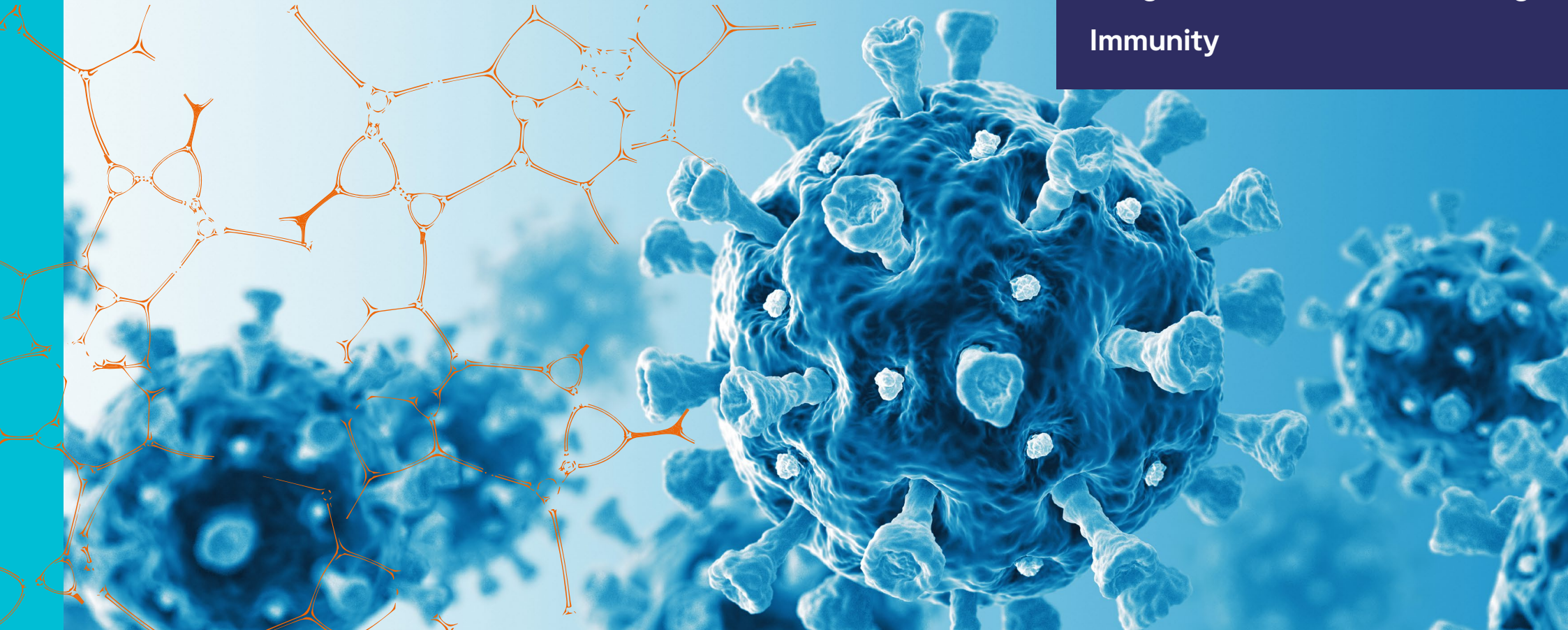
Medical Research Council

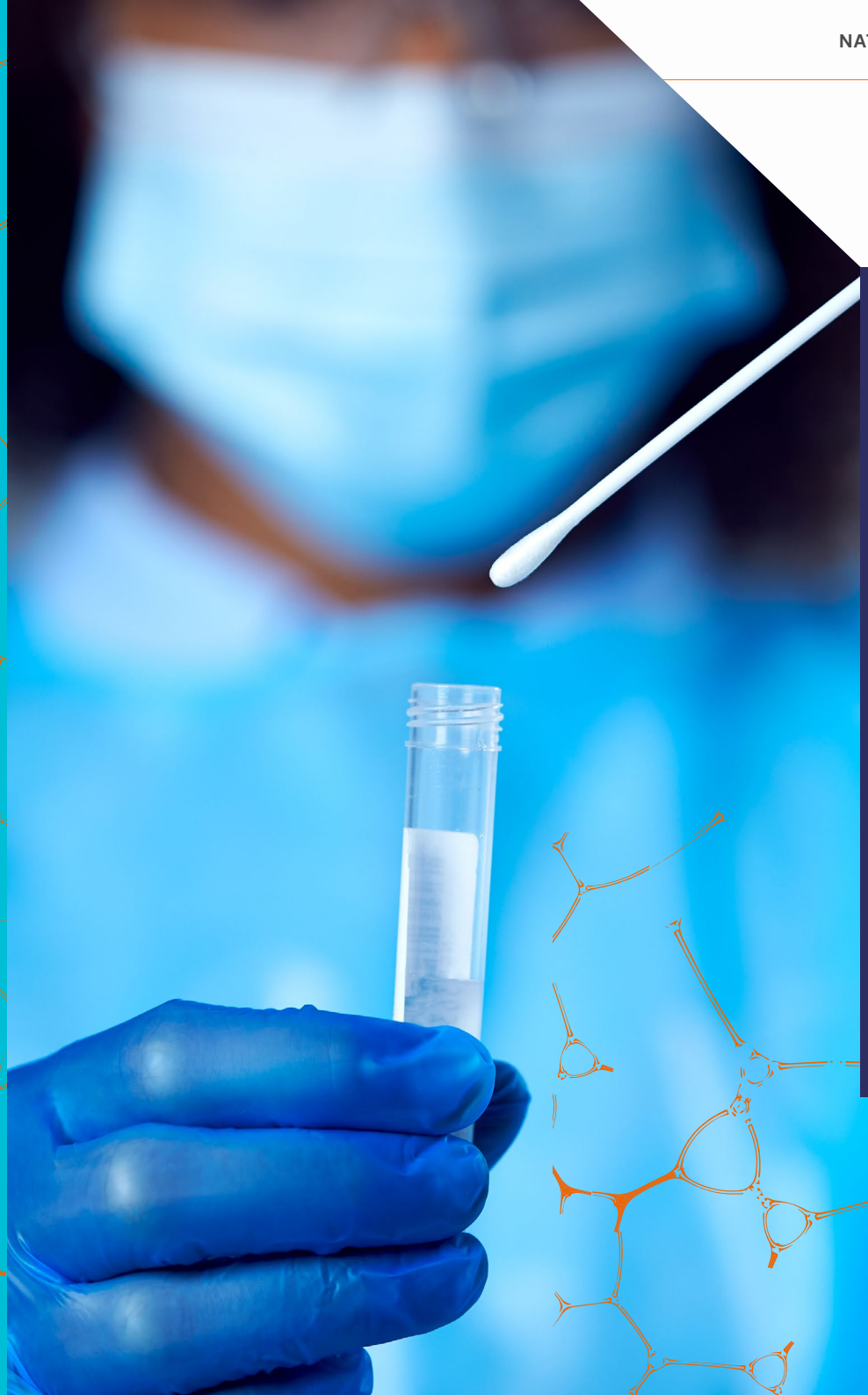
National Core Studies COVID-19 response:
Objectives, Impacts, and Legacy

Data & Connectivity

Longitudinal Health & Wellbeing

Immunity





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Introduction

The advent of the COVID-19 pandemic in winter of 2019/20 set in motion intensive efforts from the UK academic community and the Medical Research Council (MRC), part of UK Research and Innovation (UKRI) staff at all levels. With MRC and public sector support, the UK biomedical community quickly pivoted activities to address the global epidemic threat. Calls for research proposals and teams to establish and extend relevant research platforms were launched by February 2020, when the novel coronavirus began spreading globally.

Within months, more than 1000 COVID-19 targeted projects in all disciplines were funded by UKRI. While many of these projects delivered valuable information, government and funders recognised that there was a need for larger-scale coordinated and agile approaches. In summer 2020, assessment of the UK COVID-19 pandemic research portfolio by the Government's Chief Science Advisor, Patrick Vallance prompted the development of six National Core Studies (NCS) programmes. The aim was to increase research scale and provide infrastructure focussed on near term strategic, policy and operational needs.

The six NCS programmes were launched in October 2020. Three of these programmes came under the management and oversight of MRC (UKRI NCS):

- **NCS Data and Connectivity (D&C)**
- **NCS Longitudinal Health and Wellbeing (LH&W)**
- **NCS Immunity (Immunity)**

At this time, many highly impactful research programmes were underway and providing data, insight, and expertise to health and government policy makers. The UKRI NCS leads were already running relevant research programmes and had established communication links with policy makers. These relationships would be enhanced through the UKRI NCS programmes over 2020-2023.

The UKRI NCS programmes worked in a unique way to support the efforts of government and researchers nationally and globally to address the COVID-19 challenge. While regular monitoring of the progress was undertaken by oversight groups, the programmes acted independently to create the most effective way to approach the research. In addition to the expectations for research co-ordination, the programme remits required engagement with the public over the lifetime of the programme from planning to conclusions. The size and scope of this funding format was novel; it enabled a large cross-UK research response providing rapid, highly impactful knowledge, data, and analysis. This pan-UK connectivity was a key component of the success of these programmes.

Intent and objectives

The UKRI NCS programmes were designed to identify, compile, and deliver data to combat the present emergency. The required research demands to achieve this objective fell outside the usual practice of the funding remit and mechanisms that were familiar to the MRC biomedical research community.

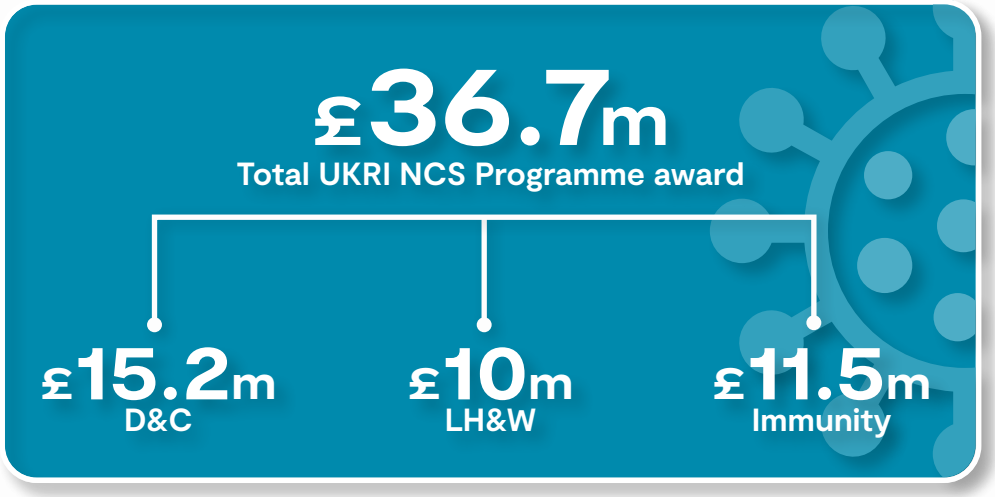
In contrast to normal research parameters, the COVID-19 research needed to provide understanding, insight and population data that was readily transferable to inform social and health policy, and to accomplish this in months rather than years.

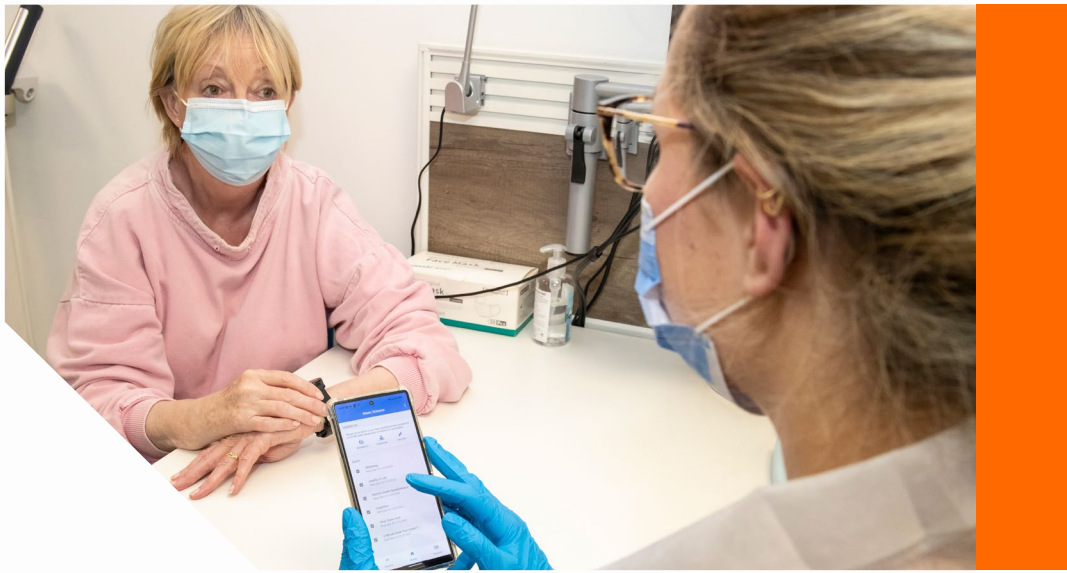
This required an immediate assessment of what information was most valuable and what was feasible to provide within the timescale set by the pandemic. This was in sharp contrast to academic's usual output of data for research publications that would contribute to a larger body of work addressing complex biological unknowns, often over decades. Additionally, researchers more commonly work in small groups, exploiting highly focused expertise.

To ensure the most efficient pandemic response, a collaborative effort was needed, drawing on a broad range of expertise, each focused on key areas of understanding. Therefore, *"in part, the value of the UKRI NCS programme is, undoubtedly, in the "how" as well as the "what" of the studies. The UKRI NCS funding mechanism has demonstrated efficiency and agility in mobilise, scaling, and pivoting research to meet an urgent need."**

The overarching intent of the UKRI NCS programmes was set out in an initial Business Case in September 2020 for a preparatory phase, and then detailed in the March 2021 Business Case for the three programmes, each of 18-month duration. A letter detailing the commencement of the NCS was sent in October 2020 to national senior clinical leads by Patrick Vallance.

The programmes were led by teams of investigators with diverse expertise within the given area of study (Annex for details).





Participant from TwinsUK cohort at the Convalescence Study Deep Phenotyping Clinic
Image credit: NCS LH&W Communications team

* Quote from the UKRI NCS Programme Benefits Realisation Report – April 2023 provided to the UKRI NCS Programme Board

There were four broad intentions in common for all NCS programmes:

1. Agility to rapidly respond to new priorities over the course of the pandemic

2. Address Government priority research needs and questions

To inform:

a) national policy for infection control measures: vaccines, lockdown, etc

b) effective health policies and interventions for the diversity of cultural and genetic population groups and health conditions

3. Streamlining accessibility to COVID-19 data

To support:

a) rapid COVID-19 research progress nationally and globally

4. Developing expertise and capacity building

To provide:

a) a legacy of expertise in data management and analysis, population studies and immunological population studies which will strengthen our ability to combat future pandemics

In addition, there were four more specific objectives for the NCS D&C, LH&W, and Immunity programmes:

5. Create advanced computer/analytics environments

To provide:

a) faster access to high priority data assets

b) a data infrastructure for the COVID-19 vaccine programme

c) cross-cohort/cross-platform collaborations across the broad diversity of four nations data sets

d) linkage of health with national administrative records

6. Immunological characterization of COVID-19 infection across populations and individuals

To inform effective interventions:

a) establish immune studies focused on the body's responses to COVID-19 infection (unique cohorts and collection of key sample sets)

b) identify differential susceptibility and vulnerability in population groups of common socio-demographics: ethnicity, cultural background, employment, existing health conditions etc.

7. Survey the near and long-term effects of the pandemic

To understand longer-term impacts:

a) identify health impact on individuals over the longer term

b) identify population impacts– economic, social impact, ethnicity

c) test the efficacy of shielding and other interventions

8. Monitor and assess the vaccination programme

To inform development of the vaccination programme in real time:

a) assess the sustainability of immune response to inform further vaccination policy

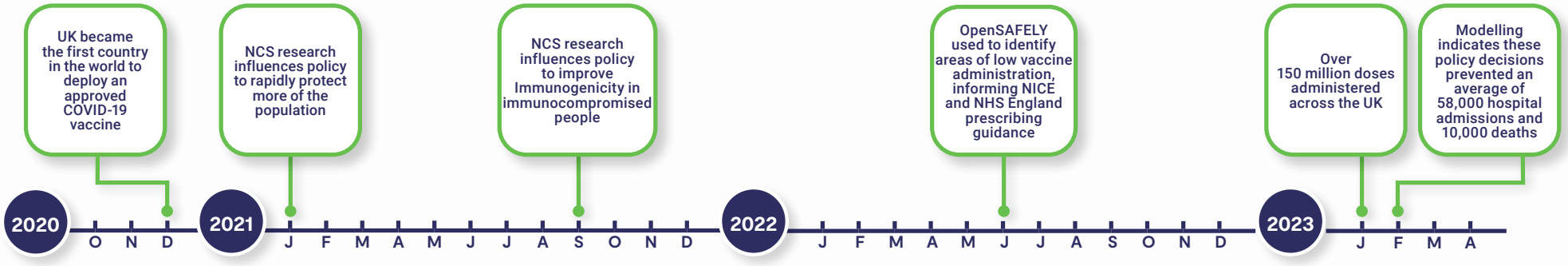
b) identify variability in response across population groups

Additionally, each of the separate programmes had tightly defined COVID-19 knowledge objectives which were identified in the initial business then modified or added to as government needs and shifts in the pandemic demanded.

Impact of UKRI NCS

In this section, we report on UKRI NCS impacts for each of the objectives. In the interest of brevity, we will not list all the projects that were initiated but instead we have selected examples of the resultant research that was undertaken and the impact. However, there is evidence that all COVID-19 specific research objectives listed in the Business Case were actively investigated through the UKRI NCS programmes and, in most cases, data was successfully provided to address the specific area of interest.

The UKRI NCS were established to address priority research questions and needs essential for pressing near-term UK government policy and operational responses to the COVID-19 pandemic. The successful completion of these intended outcomes is evidenced by key impacts achieved by NCS D&C, LH&W, and Immunity. They were often communicated directly to the appropriate government policy group and published as pre-prints in the first instance to enable rapid communication of results. A sample of these key impacts are detailed in this section.

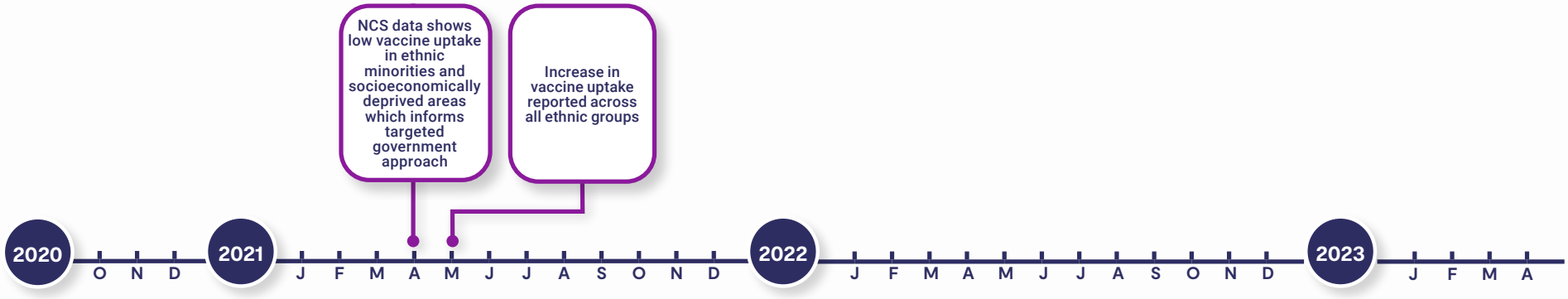


1. Agility to rapidly respond to new priorities over the course of the pandemic

By December 2020, the UK became the first country in the world to deploy an approved COVID-19 vaccine. The vaccination programme has been a phenomenal success with over 150 million doses administered across the UK by January 2023, saving countless lives, and reducing pressure on the NHS. However, the success of the vaccine roll-out depended on knowing and understanding its effect on protecting the population.

Immunological data following vaccine roll-out, provided by the NCS Immunity to government allowed key shifts in vaccine policy to prioritise emerging challenges over the course of the pandemic.

- The Pfizer vaccine was originally authorised for a three-week interval between doses; however, the UK decided in January 2021 to optimise the vaccination programme by vaccinating a greater number of people with a single dose. Data published as a pre-print in May 2021 by NCS Immunity showed that the antibody response in people aged over 80 is 3.5x greater in those who have the second dose of the Pfizer COVID-19 vaccine after 12 weeks, compared to those who have it at a three-week interval, validating the effectiveness of this approach. An analysis published by MRC GIDA researchers in February 2023 showed that this approach of rapidly providing partial (single-dose) vaccine-induced protection to a larger proportion of the population may have prevented an average of 58,000 hospital admissions and 10,000 deaths between 8th December 2020 and 13th September 2021, successfully reducing the burden of COVID-19 hospitalisations and deaths overall.
- The OCTAVE study evaluated the immune responses following COVID-19 vaccination in immunocompromised patients. The data, published as a pre-print by August 2021 showed a low serological immune response after two SARS-CoV-2 vaccines in 40% of people in these patient groups. The data also showed that approximately 1 in 10 immunocompromised patients fail to generate any antibodies four weeks after two vaccines. As a result, the UK government responded in September 2021 by recommending a third dose of COVID-19 vaccine be offered to severely immunocompromised people to improve immunogenicity.
- Following the emergence of new treatments for COVID-19, by June 2022 NCS LH&W were quickly able to link data on who received such treatments into OpenSAFELY, a national electronic health record platform. The data showed large regional variation, with particularly low administration in socioeconomically deprived areas and care homes. This data has been used to inform NICE, NHS England prescribing guidance and is being reviewed by the WHO as part of their review of the recent guidance.

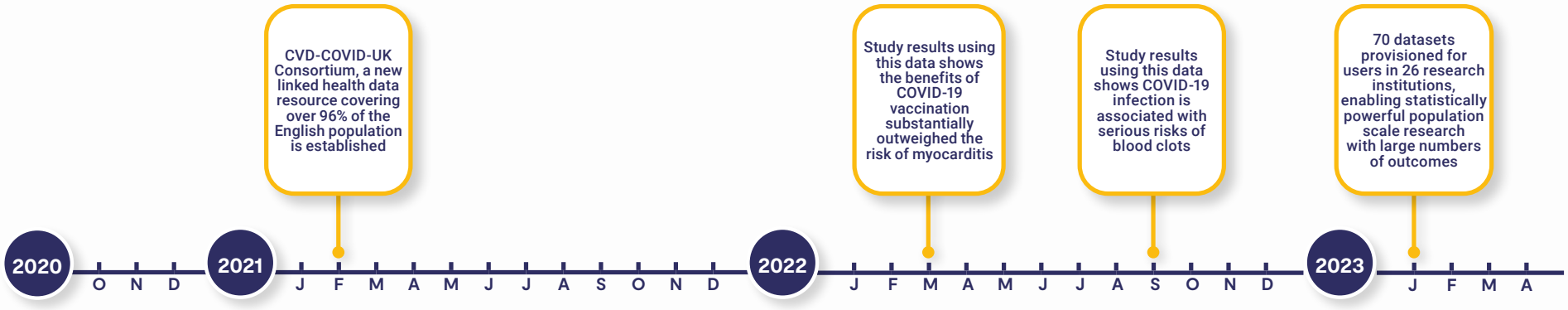


2. Address Government priority research needs and questions

By early 2021, the UK had one of the fastest population-wide vaccination roll-out programmes in the world. The early COVID mortality risk stratification work was critical for creating prioritisation groups for vaccinations. As the pandemic progressed and evolved, several urgent research questions were identified by governments and public health bodies across the world. Responding to these research priorities depended on the rapid identification of adverse events and behaviours that could potentially impact on the UK's vaccine roll-out, and subsequently the UK's pandemic recovery plan.

The ongoing routine surveillance of the real-world impact of the vaccines was facilitated by linked electronic health records. In the UK, data from NCS LH&W, which provided electronic health records linked to vaccine status, informed national policy for infection control and public health measures, helping to provide effective health policies and interventions for all.

- Results from a study of 46 million adults in England, published as a pre-print by August 2021 confirmed that the risk of blood clots with COVID-19 vaccines was very low. However, the data showed that in people under 70, an extremely small number of people (an extra 1–3 people per million) had an intracranial venous thrombosis after the Oxford-AstraZeneca vaccine, but not the Pfizer vaccine. This provided further validation for the precautionary government recommendation in May 2021 that adults aged 18 to 39 years with no underlying health conditions are offered an alternative to the Oxford-AstraZeneca vaccine, where available.
- A study analysing 57.9 million patient records in England, published as a pre-print in April 2021 identified that ethnic minorities were substantially less likely to be vaccinated, and those living in more socioeconomically deprived areas generally had lower vaccine uptake. The study was the first to describe in detail the demographic and clinical features of those who have been vaccinated by the NHS England COVID-19 vaccination campaign. As a result, the NHS, government and communities themselves introduced targeted activities to address this, including vaccination at places of worship and webinars led by community leaders to tackle misinformation. By the end of May 2021, these initiatives had led to an increase in vaccine uptake across all ethnic groups.



3. Streamlining accessibility to COVID-19 data

During the pandemic, policymakers needed timely information on health service burden, potential impact of vaccines and treatments, and the effects of new variants of concern from across the four nations of the UK. To enable this, they would need to streamline access to high priority health, administrative, molecular, and behavioural data assets for researchers working on COVID-19. At the outset of the pandemic researchers had no access to linked health data across the whole UK population.

The NCS D&C CVD-COVID-UK/COVID-IMPACT consortium established May 2020, made its data available to all researchers in February 2021. They worked in partnership with NHS Digital to bring together routinely collected, de-identified, linked health data. This data includes primary and secondary care, registered deaths, medication data, COVID-19 laboratory and vaccination data and cardiovascular specialist audits. Remote secure access is provided in a new NHS Digital Trusted Research Environment (TRE) for England. This dataset holds about 4.9 billion records and covers 96% of the population of England (>54m people), with similar linked data made available in TREs for Scotland and Wales (>8m people). As of January 2023, 70 datasets have been provisioned for users in 26 research institutions, enabling COVID-19 researchers to conduct statistically powerful population scale research with large numbers of outcomes.

- Results from a study of 46 million adults in England, published in March 2022 demonstrated evidence for a lower incidence of myocarditis after COVID-19 vaccination. The study contrasted with previous reports emerging from the United States of America and Israel in which small numbers of patients reported these adverse events following vaccination. The large dataset enabled population-scale research, showing that the benefits of COVID-19 vaccination outweighed the risk of myocarditis.
- A study of 48 million adults in England published in September 2022 September 2022 identified that COVID-19 infection is associated with a serious risk of blood clots, even after 49 weeks following infection. The results provided clear support for policies to prevent severe COVID-19 by means of vaccines, and use of secondary preventive agents in high-risk patients.

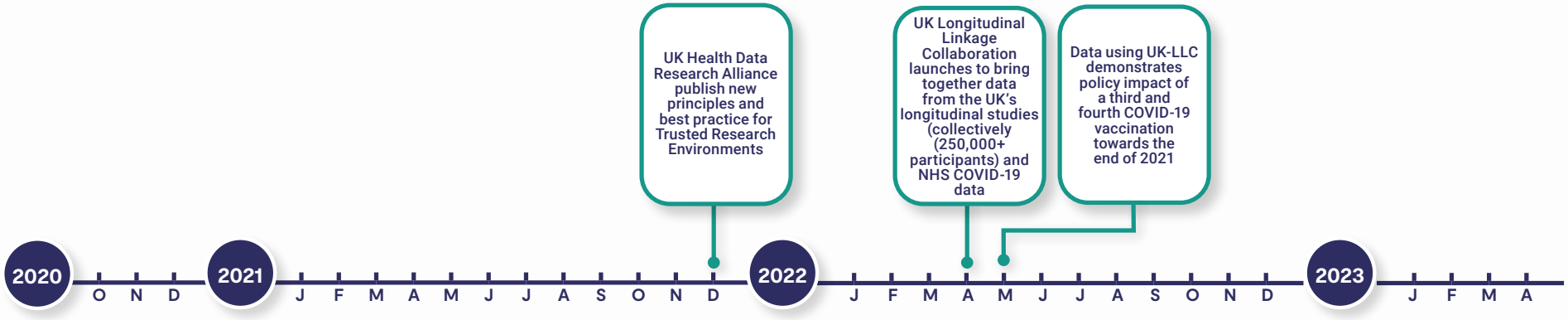
'Developing expertise and capacity building' was a constant thread running through the NCS timeline with active training carried on through every month

4. Developing expertise and capacity building

Before the pandemic, the UK supported an unparalleled collection of large and long-term Longitudinal Population Studies (LPS) that provide a wealth of information from their participants, describing both them and the society and environment in which they live. Since the pandemic, the NCS have been instrumental in establishing the UK as a world leader in harnessing the power of national electronic health record platforms. Together, these factors have provided new opportunities for research that improves population health, and a legacy of expertise in data management and analysis.

- The NCS LH&W, D&C and Immunity have aligned complementary resources and brought together linkage of electronic health records and cohorts at an unprecedented scale. Early career researchers have been given the opportunity to lead areas of research and gain valuable experience working in large collaborative research consortia. NCS LH&W has also trained a new generation of data scientists, both from within the collaborating institutions, and secondees across the country, in the use of these unique, complex, and highly informative datasets.

Secondees from the MRC NCS LH&W programme
Image credit: NCS LH&W Communications team



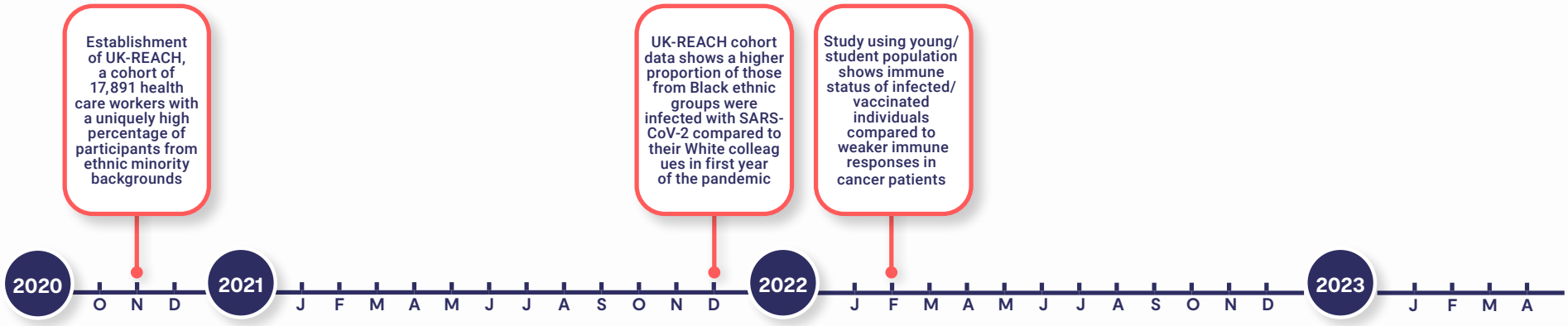
5. Create advanced computer/analytics environments

The establishment of TREs, which are highly secure computing environments that provide remote access to health data for approved researchers, underlie much of the impacts of the UKRI NCSs. By December 2021, the UK Health Data Research Alliance had published new principles and best practice for TREs, following extensive consultation and consensus building with key stakeholders and patient/public representatives. The principles provide a guide for UK data custodians and other organisations involved in data sharing and information governance.

By using an agile, collaborative approach, the TREs have provided faster access to high priority data assets and helped establish cross-cohort collaborations on datasets held across the four UK nations. TREs have also established the linkage of health with national administrative records, together providing the tools and data needed for researchers to perform analyses on a variety of linked, pseudonymised data sources. Previously there was difficulty linking administrative data to the UK health data resources. The Administrative Data Research UK (ADR UK) programme (funded by ESRC UKRI) exists to provide safe access to good quality, de-identified data held by various parts of government to support policy-focused research. With funding from MRC and ESRC, collaborative working between UKRI NCS, ADR UK, Office of National Statistics and UK Longitudinal Linkage Collaboration (UK LLC) has for the first time created systematic linkages within a TRE between non-health administrative records (employment, earnings, social benefits, pensions, and education) and wider determinants of health data. This is key to understanding what works in public policy, and was vital during the pandemic to enable health, economic and social science research to save and improve lives.

- The UK LLC is a unique TRE set up to bring together study data from the UK's top longitudinal studies (collectively more than 250,000 participants) and link it with NHS COVID-19 data; education data; occupation data and information related to where people live. These longitudinal studies have detailed information about study participants' lives, both before and during the pandemic. Through a single application, the UK LLC TRE offers pre-pandemic and pandemic data from more than 20 longitudinal population studies linked with health data. This allows approved researchers the opportunity to examine the wider impact on health and wellbeing of lockdown measures, and the disruption to our health, financial and social systems. These findings will provide insights for policy makers and support changes to public health for years to come.

- Results from a study published as a pre-print by May 2022 demonstrated that the booster COVID-19 vaccine programme led to a large increase in the antibodies, associated with a lower risk of severe infection. Researchers analysed blood samples from 9,361 participants from two UK population cohorts (Twins UK and Children of the 90s). The findings demonstrated the policy impact of a third and fourth COVID-19 vaccination towards the end of 2021, to boost antibodies and protect against COVID-19.



6. Immunological characterisation of COVID-19 infection across populations and individuals

As the novel SARS-CoV-2 virus rapidly spread through the population in 2020, it was vital to establish studies to characterise the immune response to COVID-19. This was especially important given the key role of asymptomatic infection in the early months of the pandemic, and observations by June 2020 that the virus may affect ethnic minority groups more severely than those of White ethnicity. As the pandemic progressed and the vaccine roll-out began, it was also essential to understand how vulnerable immunocompromised patients would respond to COVID-19 infection and vaccination.

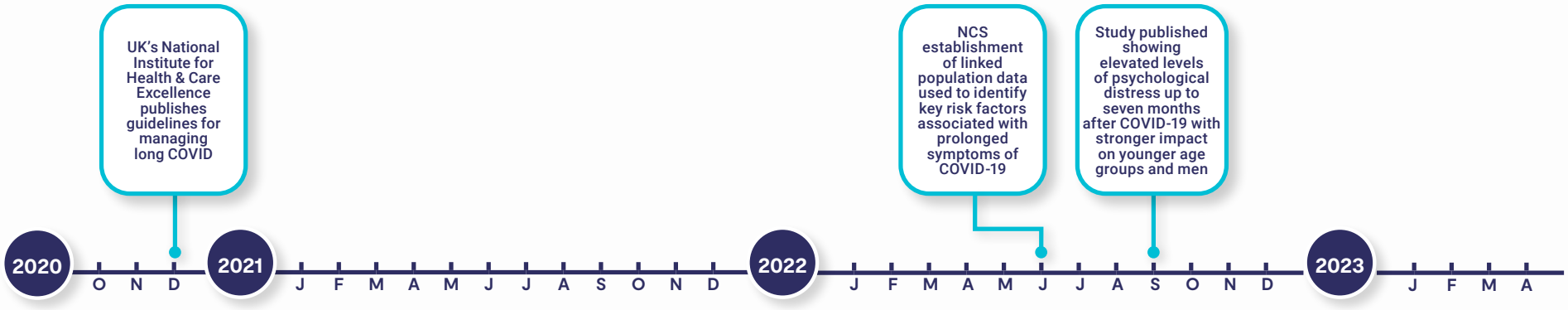
NCS Immunity set up several key studies that expanded our understanding of the immune response to COVID-19 infection and provided valuable information and evidence to policymakers.

- UK-REACH, a prospective cohort was established in November 2020 to understand why ethnic minority healthcare workers are at risk of poorer outcomes from COVID-19 when compared with their White ethnic counterparts in the UK. A total of 17,891 health care workers were recruited from across the UK, with a uniquely high percentage of participants from ethnic minority backgrounds about whom a wide range of qualitative and quantitative data were collected. The UK-REACH cohort has provided useful insights into COVID-19 infection and its effects. For example, a December 2021 publication indicated that a quarter of participants reported having been infected with SARS-CoV-2 within the first year of the pandemic, with seroprevalence showing a higher proportion of those from Black ethnic groups having been infected with SARS-CoV-2 compared to their White colleagues.

NCS LH&W serology analysis published in May 2022 using cross-sectional antibody testing from two UK population-based longitudinal studies quantified the association between antibody level and risk of subsequent infection, supporting a policy of triple vaccination for the generation of protective antibodies.

- A study published as a pre-print in March 2021 analysed serial samples from 207 SARS-CoV-2 infected individuals with a range of disease severities over 12 weeks from symptom onset. The results showed that individuals who have asymptomatic or mild disease show a robust immune response early on during infection. The findings also indicate that patients requiring admission to hospital have impaired immune responses and systemic inflammation.

- A study published in February 2022 using samples collected from 231 healthy donors describes an immunoassay that accurately and rapidly identifies the presence of SARS-CoV-2-specific T-cell responses, both helping to elucidate the adaptive immune status of previously infected and/or vaccinated individuals and diagnosing previously unsuspected past infection. It is one of the largest global studies of young/student populations and will help to determine the quality and longevity of immune protection in people who have mild or asymptomatic clinical infection. The study also compared the immune responses in healthy subjects against immunocompromised cancer patients, showing a significantly weaker induction of immunity, providing further support for cancer patients to be closely monitored for longer-term immunity and prioritised for booster vaccines.

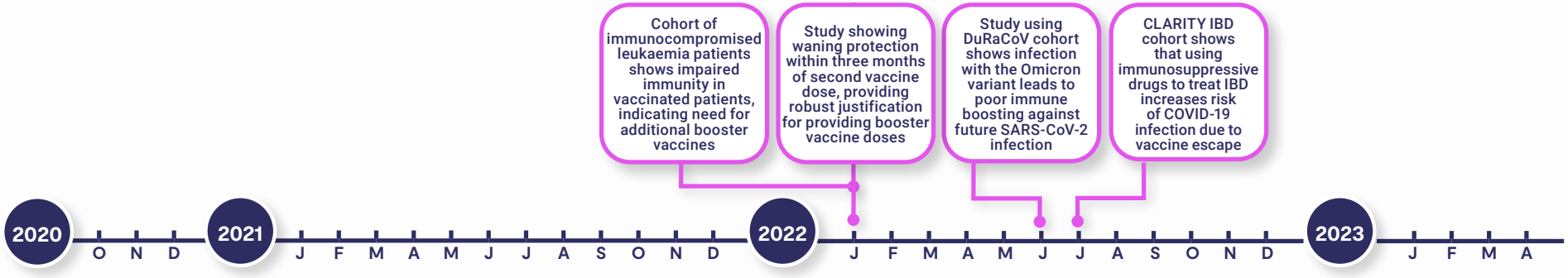


7. Survey the near and long-term effects of the pandemic

Towards the beginning of 2021, it was clear that the pandemic would have long-term effects on a large segment of the population, despite the rapid roll-out of the COVID-19 vaccination programme. By December 2020, the UK's National Institute for Health and Care Excellence (NICE) had published guidelines on managing the long-term effects of COVID-19, to address increasing reports of symptoms that develop during or after COVID-19 infection and continue for more than 12 weeks. There was an urgent need to identify and understand the longer term physical and mental health consequences of COVID-19 infection.

NCS LH&W helped combine data from multiple UK population-based longitudinal studies and electronic health records to respond to these questions. The rich dataset allowed researchers to identify the health impact on individuals over the longer term and identify population risk factors. It also helped understand the efficacy of interventions such as shielding and the furlough scheme, to examine the wider impact of the pandemic on societal health and wellbeing.

- A study published in June 2022 used survey data from 6907 individuals with COVID-19 from 10 UK population-based longitudinal study samples and 1.1 million individuals with COVID-19 diagnostic codes in electronic healthcare records collected by spring 2021. The study showed that increasing age, female sex, White ethnicity, poor pre-pandemic general and mental health, overweight/obesity, and asthma were associated with prolonged symptoms of COVID-19.
- Data from the UK Household Longitudinal Study, published as a pre-print in March 2021, showed elevated levels of psychological distress up to seven months after probable COVID-19 infection, compared to participants with no infection. These associations were stronger among younger age groups and men. By April 2022, further collaborative work using 11 well-established longitudinal studies showed the long-term impact of COVID-19 infection on mental health, even when lockdown was lifted in summer 2020 (in contrary to evidence from online convenience samples).
- A study protocol published in September 2022 by NCS Immunity funded researchers provide an outline for evaluating the effects and costs of shielding. Given that shielding is a new intervention, used in the UK during the pandemic without prior evidence of effects on health outcomes or behaviour, it is important to understand its effectiveness to inform policy development and delivery during future pandemics. This is particularly key as evidence is now emerging of effects of shielding on: physical and mental health; well-being and quality of life including social isolation, loneliness, and anxiety; access to medical care.
- NCS LH&W investigated the impact that furlough had on mental health and health behaviours. A study published in September 2022 showed that that furlough occupies an intermediate position between employment and unemployment. Furlough had a protective effect for those who were at risk of losing their job but was not as beneficial as remaining at work.



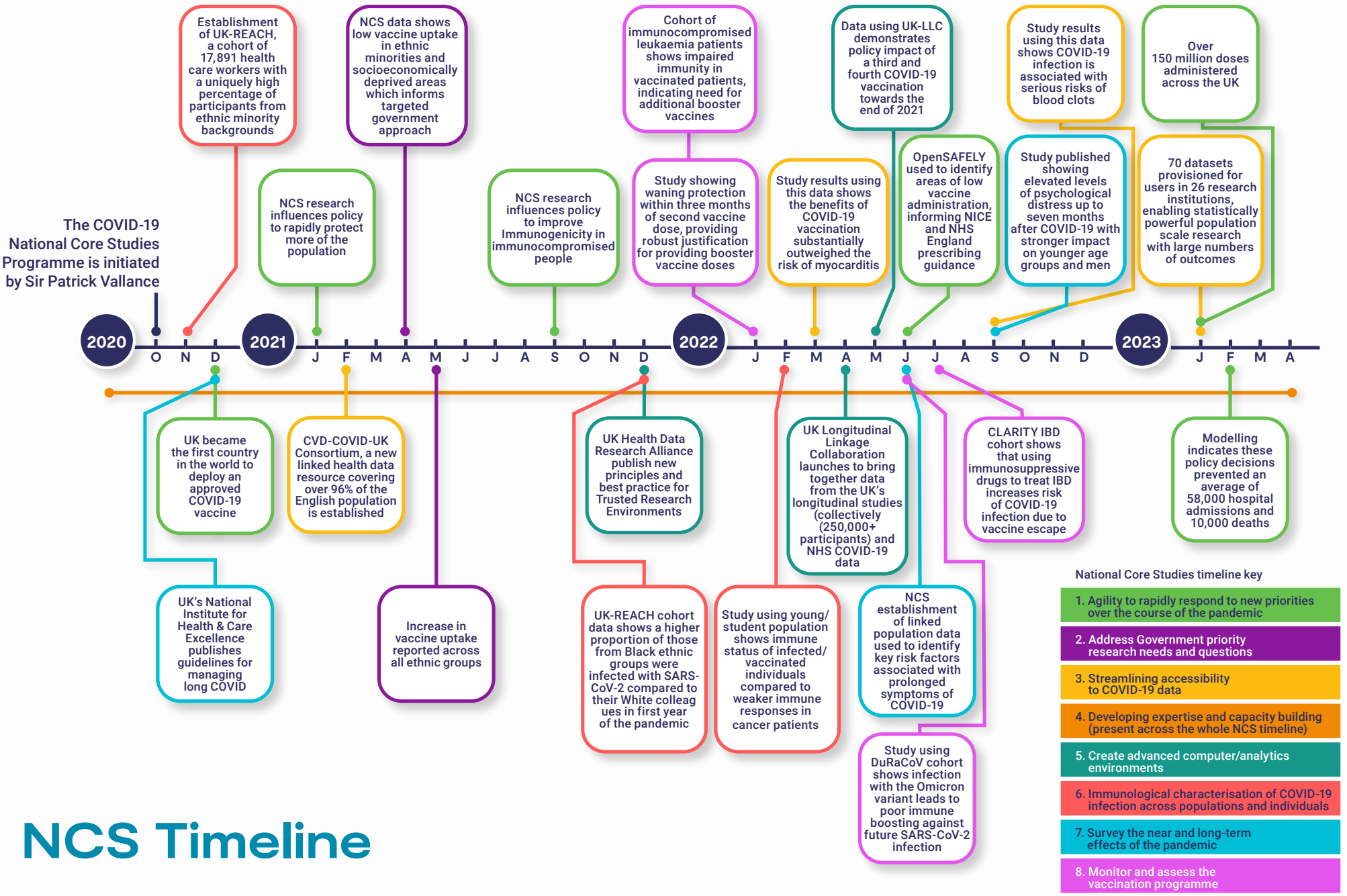
8. Monitor and assess the vaccination programme

By spring 2022, testing and infection control guidance remained in place for adult social care homes. However, for most of the public, the COVID-19 vaccination programme was the only line of defence against SARS-CoV-2 as the UK government published its Living with COVID-19 strategy. It was therefore vital to assess the sustainability of the immune response to inform further vaccination policy and identify any variability in the immune response across population groups. This was particularly important with the evolution of SARS-CoV-2 variants such as Delta and Omicron in the latter half of 2021. These variants were more transmissible and becoming increasingly adept at avoiding vaccine-derived immunity.

NCS Immunity and NCS D&C produced key insights relevant to these issues, providing recommendations for protecting vulnerable segments of the population and detailed information for the development of the COVID-19 booster programme.

- NCS D&C used information from the EAVE II data cohort (which brings together data from 5·4 million people in Scotland, covering around 99% of the population) to study the Oxford-Astra Zeneca vaccine's protection against COVID-19. The results published in January 2022 showed waning protection within three months of second vaccine doses, providing robust justification for employing booster vaccine doses for the population.
- The CLL-VR cohort, established by NCS Immunity has provided valuable insights into how immunocompromised chronic lymphocytic leukaemia patients respond to COVID-19 vaccines. The cohort was instrumental for showing in January 2022 that vaccine-derived immunity is impaired in vaccinated patients who were exposed to the SARS-CoV-2 Delta variant, indicating the need for additional booster vaccines. In addition, results published in June 2022 using CLL-VR confirmed that COVID-19 vaccines provide robust immunity and clinical protection but approximately 20% of patients do not produce any antibodies and are at increased risk of infection. These results validate the September 2021 UK Joint Committee for Vaccination and Immunisation (JCVI) recommendation for a 3rd primary vaccine dose for immunocompromised patients.
- The DuRaCoV cohort established by NCS Immunity showed in a study published in June 2022 that infection with the Omicron variant leads to poor immune boosting against future SARS-CoV-2 infection. It meant that re-infection with Omicron itself, even in people who are triple-vaccinated, provided no extra immunity – something that would be normally seen in the immune response to infection. In another study published in July 2022, the CLARITY IBD cohort showed that using immunosuppressive drugs to treat inflammatory bowel disease (IBD) increases risk of COVID-19 infection due to vaccine escape. These studies highlight the nature and durability of the immune response against SARS-CoV-2 following infection and 1-4 doses of COVID-19 vaccines, in the context of Alpha, Delta and Omicron waves in 2021.

NCS Timeline



UKRI NCS Outputs

The NCS programmes developed extensive outputs over their total 30 month lifespan (includes the start up phase and a six month extension of the programmes from September 2022). These outputs gave rise to the impacts previously described and many provide a legacy which will contribute to knowledge growth and societal impact in the decades to come.

An assurance panel was established to run in parallel with the UKRI NCS programmes. They provided oversight and advice monthly during the initial set-up phase and quarterly during the research progress phase. They reviewed UKRI NCS output reports and discussed new approaches to emerging pandemic challenges.

At the midpoint of the programmes, December 2021, an independent expert review panel was convened to assess research outputs and impacts and advise on future direction.

The Review Panel consisted of:

Professor David Crossman CSO Scotland and University of St Andrews (Chair)

Ms Tricia Dodd Independent, Freelance Statistical Consultant (Panel Member)

Professor Jennifer Dowd University of Oxford (Panel Member)

Professor Tracy Hussell University of Manchester (Panel Member)

Professor Paul Kaye University of York (Panel Member)

Dr Andrew Roddam Our Future Health (Panel Member)

Professor Nick Wareham University of Cambridge (Panel Member)

Their review stated:

The Review Panel agreed that the UKRI NCS Programme has been an outstanding success with many world-leading and positive attributes. Each of the three Study Areas has risen to the challenge, galvanising researchers across multiple disciplines to tackle the challenges of the pandemic. The three Study Areas assessed have delivered an impressive breadth of infrastructure, tools, knowledge, and data assets.

This has enabled government, researchers and policy makers to pose and rapidly answer strategic, policy and operational questions regarding COVID-19.

The Study Areas continue to provide impactful outputs and are on course to complete the objectives originally prescribed and those that have evolved and required adaptation alongside the pandemic.

The Review Panel made the following comments about the three specific programmes:

NCS immunity

- *"has been critical in driving vaccine policy and the use of antivirals in immunosuppressed individuals."*
- *"has successfully achieved a balance between understanding mechanism and broad surveillance. The programme represented an exemplar for Patient and Public Involvement and Engagement (PPIE)."*

They also noted the programmes agility in modifying research plans to address the prevalent variant: Omicron.

D&C

- *"Professor Morris had shown significant leadership, building relationships and networks with a diverse range of stakeholders across the UK."*
- *"The cross-nation approach has created a step-change in the use of electronic data at scale and at speed, which would not have been achieved in isolation."*
- *"The Panel highlighted that whilst this review has focused on the application to the pandemic, the legacy of this work goes way beyond COVID-19 to other chronic and acute conditions setting the UK as a world leader in this area."*

LHW

- *"NCS LH&W has delivered very important insights."*
- *"The high value in leveraging pre-pandemic data is demonstrated in the current obesity work which is contributing to the understanding of how pre-existing conditions impact the effects of the pandemic."*
- *"the Panel recognised the challenges and value of linking EHRs with LPS" "would provide important outputs that will contribute to our understanding of the enduring effects of the pandemic."*

Following on from their mid-term review, the UKRI NCS programmes continue to be highly effective at communicating their research objectives and acting in their convening role, bringing together expertise and database accessibility.

Dissemination of research outputs

Strong data dissemination links to policy makers were established early in the pandemic and strengthened with the UKRI NCS programmes. The UKRI NCS Programme leads were members of or invited to report to various government COVID-19 groups throughout the pandemic.

These links supported many policy decisions (some of which are detailed in the Impact of UKRI NCS section above). Both organised and informal UK academic networking supported rapid data and methodology sharing with other researchers. While not the primary focus for NCS programmes, scientific publication was an additional dissemination pathway; it was particularly valuable to the global COVID-19 research effort.

Publications require more time to develop, and to have impact on, other research. However, accelerated publication times and the increased use of preprints during the pandemic allowed more rapid release of data than was usual.

Time to dissemination analysis provides evidence for the speed with which information was shared across the global academic community; a greater proportion of publications produced by the NCS were released earlier (0-6 months from award start) than MRC awards from 'business as usual' funding mechanisms (40% vs 23%, respectively). Time to data release through preprint or publication was compared between NCS programmes and a comparable portfolio of non-COVID-19 programmes funded by the MRC over the same time period.

The results (Figure 1) demonstrate that the NCS programmes more rapidly produced publication output than "non COVID-19 relevant" research grants. These publications have not been available long enough for analysis to be possible on potential indicators of uptake e.g. a citation impact factor. However, one indication of global engagement with the published data is seen in the rapid citation of UKRI NCS publications by an international audience.

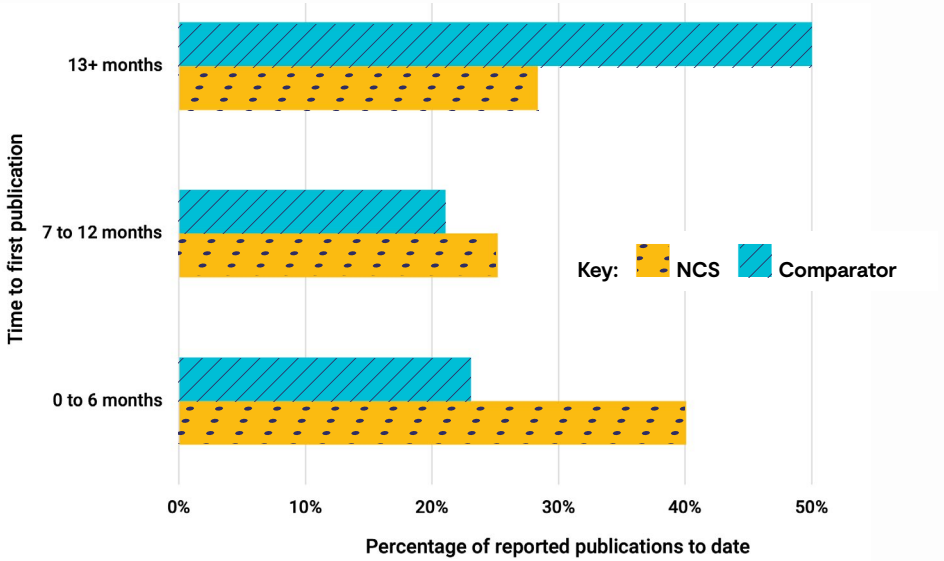


Figure 1 (above): Comparison of time to publication for NCS versus comparator MRC awards (All awards started between 1 March 2020 and 31 March 2021; the comparator portfolio (n=243) excludes all new COVID-19 funding awards)

All three studies generated outputs that secured a high number of international citations; the proportion of international citations, by both number of NCS publications and as a proportion of total citations is on a par with the comparator portfolio of MRC awards (Figure 2). Publications will continue to arise from the UKRI NCS work and their contribution to our understanding of infection and pandemics will be additional legacy of the UKRI NCS programmes.

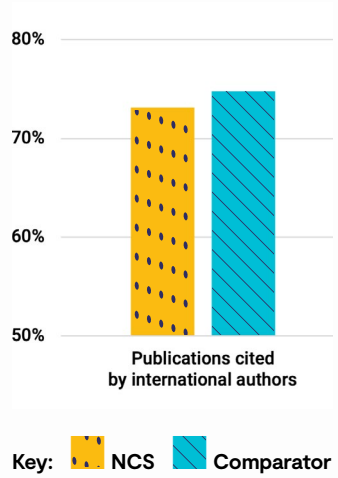


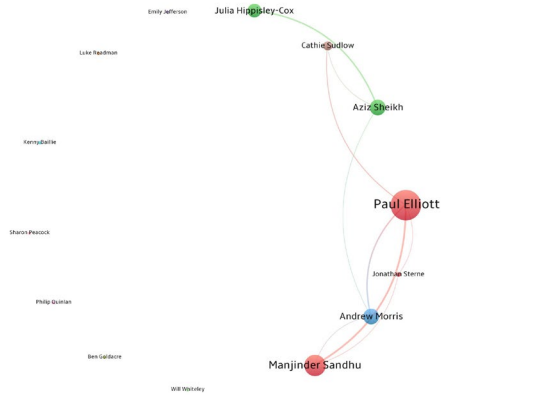
Figure 2 (right): Proportion of UKRI NCS publications cited by international researchers

Collaboration

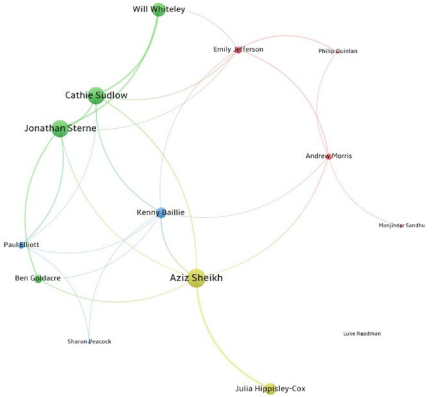
UKRI NCS programmes brought together senior researchers with a diverse range of expertise. They formed the executive group for the programmes and led individual projects. The interactions and collaboration of these researchers is evident in the data on co-authorship before and during the UKRI NCS programmes (see Figures 3-8).

Collaboration and networking are also seen in the development of database linkages such as the UK LLC, the TREs and the population cohort studies (e.g. LPS). Through the NCS, UK LLC has pooled data on around 250,000 participants from 20 major interdisciplinary LPSs and has systematically linked these to participant NHS records and environmental exposure data. This work has brought together existing epidemiologists and data scientists from the four nations of the UK and provided training for a new generation of researchers.

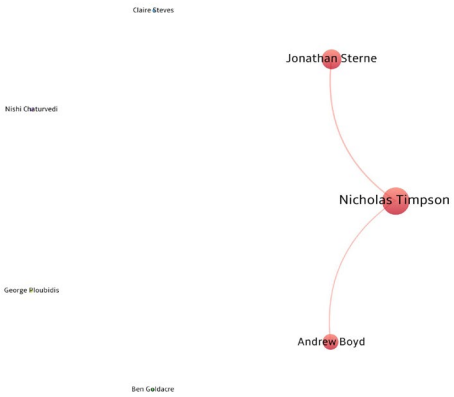
Figures 3: NCS Data and Connectivity pre-2020



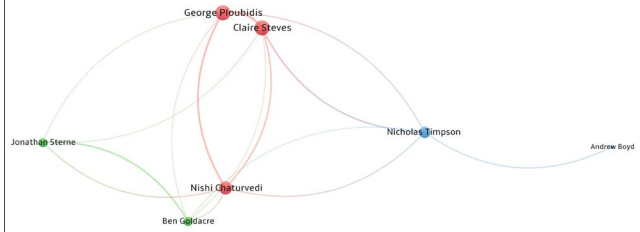
Figures 4: NCS Data and Connectivity 2020-2022



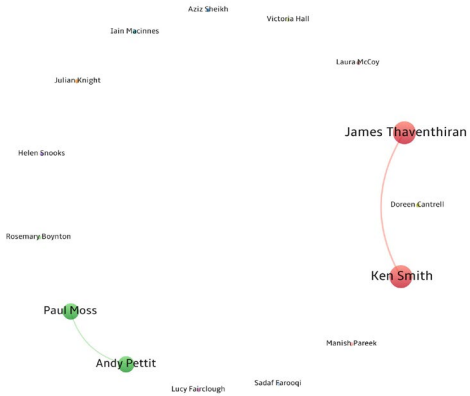
Figures 5: NCS Longitudinal Health and Wellbeing pre-2020



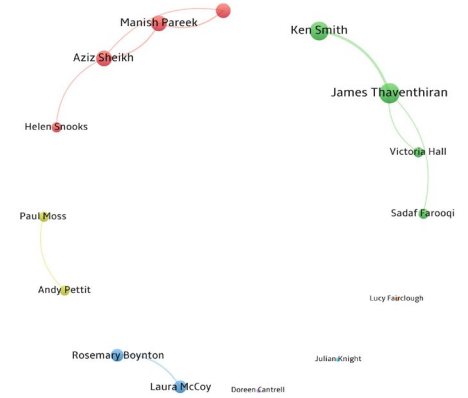
Figures 6: NCS Longitudinal Health and Wellbeing 2020-2022



Figures 7: NCS Immunity pre-2020



Figures 8: NCS Immunity 2020-2022



Population cohorts integrated into NCS LH&W

CHILDREN OF THE 90S

generation scotland

MRC NSHD

BCS70 1970 British Cohort Study 50 YEARS OF LIFE & SCIENCE

CHILD OF THE NEW CENTURY

sabre Southall and Brent Revisited Diabetes & Heart Disease Research Study

We are family BORNINBRADFORD

ncds National Child Development Study

twinsUK

ELSA English Longitudinal Study of Ageing

NEXT STEPS LEARNING FROM YOUR GENERATION

Understanding Society

Databases

The UK has high quality population cohorts, health records, microbial bioinformatic data, tissue and genetic biobanks and population demographic data.

However, it has been recognised that this data is siloed, often poorly documented, difficult to link data between datasets, and difficult to access. It was therefore a fundamental objective for all three UKRI NCS programmes to address these challenges, to improve data linkage, findability, and access. The data infrastructure developed by the NCS programmes would support all UK research to understand and tackle the pandemic through more efficient harnessing of UK strengths in health research data. Since 2020, this data infrastructure has expanded to collect some of the richest health, biomedical and cross-sectoral COVID-19 related datasets in the world.

These include:

- COVID-19 specific datasets
  - PCR and antibody testing data, viral genomic data
  - ZOE App (live COVID-19 symptom tracking) data
  - COVID-19 research cohorts
- data held within NHS systems (e.g. primary care data, hospital Electronic Health Records (EHRs)
- cross-sectoral datasets (e.g. census, administrative, behavioural and industry data)
- existing research datasets that have been augmented for COVID-19 research (e.g. the UK Biobank).

On the HDR UK innovation gateway, NCS D&C has made available 116 COVID -19 datasets with 8 tools to facilitate use; this has supported 316 research publications by early 2023.

The UK's advantages of integrated data environments were limited by constraints in accessibility and disparity of format at the outbreak of COVID-19. Advances in legal agreements, governance arrangements and collaborative working, facilitated by UKRI NCS, have dramatically improved accessibility for researchers.

During 2020 and 2021, NCS D&C held iterative meetings and workshops with the UK data science community: NCS programmes and other UK database holders. This community engagement has supported the development of common best-practice, analytical tools, and COVID-19 focused databases. This work has transformed linkage and accessibility of these datasets to create a world leading data infrastructure.

Participants of the National Survey of Health and Development cohort (1946 cohort)
Image credit: MRC Unit for Lifelong Health and Ageing

Legacy of UKRI NCS

As we transition to SARS-CoV-2 endemicity, there is a continued need for coordinated research to understand the longer-term impact of the COVID-19 pandemic, to prepare for future waves and to identify new threats.

The use of the infrastructure, networks, increased expertise, data assets and biological samples created/collected by UKRI NCS will be key to this continuing research response. The current generation of trained data analysts are crucial to address key policy questions, using these resources and national datasets while also training future analysts and continuing to develop data assets. Together this places the UK in a unique global position to address continuing and emerging pandemic-related questions and the population health threats of the future.

The expert review panel identified key areas of UKRI NCS potential legacy at the midpoint of the programmes. These and other long-term benefits have now been realised and are part of a continuing plan for infrastructure improvement: for example, the TRE network, facilitated by HDR UK, will continue to develop and share bast practice and improve accessibility The long term benefits identified include not only newly created or enhanced infrastructure but also ways of working, such as four-nations networking and collaborative working with policy makers, that will be of great benefit to the UK biomedical community's future investigations in population health.

Some of the benefits arising from UKRI NCS programmes that support on-going research and approaches to future health threats are listed.

1. For the first time, a considerable proportion of the interdisciplinary UK longitudinal health data community have committed to a new way-of-working based on a centralised TRE: the UK LLC. The linkage of existing population cohorts and other population health data will continue to inform our understanding and treatment of the health implications of having had the COVID infection, Long- COVID, and of future waves and/or mutations of COVID-19 virus. It also provides a unique and rich data legacy. This will combine with the power of national electronic health record platforms, such as OpenSAFELY and the NHS Digital TRE established in the BHF Data Science Centre. This infrastructure, relationships, and ways of working which were built within the NCS D&C and LH&W study areas can now be efficiently applied to understanding the impact and reach of pandemics and other health conditions.

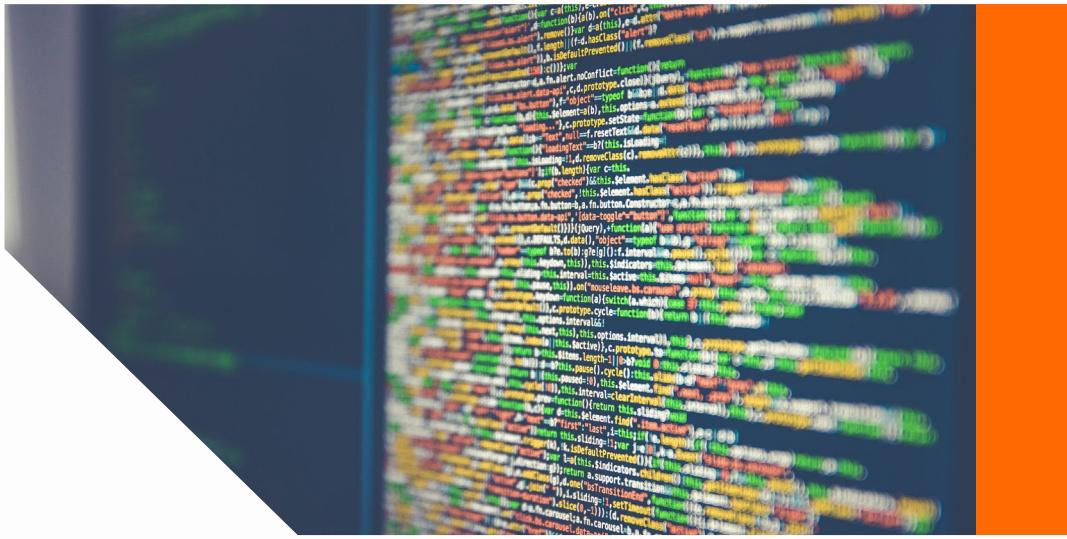
2. Data scientists of UKRI NCS and other research centres developed new methods for preserving patients' privacy which allowed an unprecedented scale of data access - using 58 million patients' full GP records in research for the first time ever. During the pandemic there was a major shift in the public acceptance of the use and linkage of health and personal data, and the collection and use of biological samples for research and disease surveillance. There is immense value in the ability to access health data at scale and at speed under COPI (Control of Patient Information) notices. The maintenance of these capabilities with continuing engagement and public trust will maximise knowledge gained from existing data and samples, and enable rapid scale up of targeted research, treatments, and interventions in response to new threats.

3. NCS Immunity established new biobanking resources of biological samples which have the potential to be attractive to the pharmaceutical industry, thereby supporting the British economy. Additionally, integration between large scale surveillance and analysis, and small-scale discovery research has ensured that research fuels both policy and discovery science agendas and that patient samples are used to greatest effect.

4. By working with the diversity of government stakeholders such as National Institute for Health Research (NIHR), UK Health Security Agency UK HAS), Vaccine Task Force, Joint committee of Vaccination and Immunisation (JVCI), and the UK devolved administrations, UKRI NCS has strengthened the underpinning infrastructure and quality for challenge-led science research to support government and health policy decisions rapidly and effectively. The "clearing house model", established to enhance communication links, enables rapid transfer of policy relevant science directly to policymakers and also empowers policy makers to approach the team with questions.

5. Collaborative working over the past three years has firmly established a genuine four nation approach to data linkage and research objectives and collaboration.

6. The expert review panel stated, *"The pan-UK data scientists working with NCS D&C have embraced, modern open approaches to data science: sharing code openly to the whole community, as the bedrock of deep technical collaboration; working closely with research software engineers alongside traditional domain experts with research knowledge; and moving away from "manual labour" on datasets towards "reproducible analytic pathways", with well tested and re-executable code, in line with best practice in data science."*



7. The NCS D&C convened, for the first time, a 'National TRE Network' with ONS, NHS Digital, SAIL Databank (Wales), Scottish National Data Safe Haven, the Northern Ireland Honest Broker Service (and later OpenSAFELY) as TRE delivery partners for the programme. These TREs enabled access and linkage to 116 UK priority datasets, enhanced the data infrastructure and services across the UK, and improved user experience.This legacy was in use by 270 research teams with 1534 million recorded views through 2022. Evidence of continuing value by the research community is indicated by 303 users in the first 5 days of January 2023. While the HDR UK Gateway is heavily used by academic researchers, during the pandemic this data was sought after by many different types communities to serve their data needs: along with University based researchers, there users from the Bank of England, Greater London Authority, Competition and Markets Authority, Department of Health and Social Care, Sagacity Research, National Institute for Health Research Bioresource, NHS England, Nuffield Trust, Medicines and Healthcare Products Regulatory Agency, NHS Blood and Transplant, Sanofi Pasteur, the Office for National Statistics (ONS), Novax, Inc., Firmly Health NHS Foundation Trust, Liverpool Womens NHS Foundation Trust, Ministry of Defence, Dorset Council, Royal Bournemouth and Christchurch Hospitals, Public Health Wales, NHS Tower Hamlets CCG, Food Standards Agency, Joint Biosecurity Centre, Islington Public Health, Kirklees, Calderdale Council, UK Government Department of Education, Government Cabinet Office, Welsh Government, Makere University (Uganda).

HDRUK
Health Data Research UK

8. CVD-COVID-IMPACT/COVID-UK Consortium (led by the British Heart Foundation Data Science Centre) provides a list and classification of the available (or soon to be available) datasets across TREs via the Consortium (see table on page 26).

CVD COVID UK/COVID IMPACT TRE Dataset Provisioning Dashboard - 09/02/2023 release - for the latest Dashboard, please visit here

Innovation Gateway TRE Dataset/Access Request Innovation Gateway Collection GitHub Paper on the power of data linkage

Nation / Population size	ENGLAND / 57 million	SCOTLAND / 5.5 million	WALES / 3.2 million
TRE	NHS England's TRE service for England	National Data Safe Haven	SAIL Databank
Users / Institutions	85 users / 13 institutions	18 users / 5 institutions	32 users / 11 institutions
Datasets	32 requested / 29 provisioned	18 requested / 16 provisioned	34 requested / 30 provisioned
Comments		▪ SMR02 to be requested	▪ ONS COVID-19 Infection Survey and Census 2021 available, subject to approval
Primary Care	▪ GDPPR	▪ Primary Care	▪ General Practice Monthly/Daily COVID
Secondary Care	▪ HES (Admitted Patient Care, Outpatient, Critical Care, Accident & Emergency) ▪ SUS ▪ Uncurated Low Latency Hospital Data ▪ Emergency Care Data Set"	▪ Outpatient Appointments / Attendances - Scottish Morbidity Record (SMR00) ▪ General Acute Inpatient and Day Case - Scottish Morbidity Record (SMR01) ▪ Accident & Emergency"	▪ Critical Care Dataset ▪ Emergency Department Daily/Monthly ▪ Outpatient Dataset for Wales ▪ Outpatient Referral Dataset ▪ Patient Episode Dataset"
Covid 19 Lab Tests	▪ SGSS (Pillar 1, 2 – positive results only) ▪ Pillar 2 Antigen (positive and negative) ▪ Pillar 3 Antibody (positive and negative) ▪ COVID Tests (lab/lighthouse testing) ▪ (ECOSS) ▪ Variant strain data (COG-UK)	▪ COVID Tests (lab/lighthouse testing) ▪ (ECOSS) ▪ Variant strain data (COG-UK)	▪ LIMS (Pillar 1, 2, 3) ▪ ONS COVID-19 Infection Survey* ▪ Test, Trace & Protect ▪ Shielded People ▪ Variant strain data (COG-UK)*
Covid 19 Vaccinations	▪ Covid 19 vaccination events ▪ Covid 19 vaccination adverse reactions	▪ Vaccination Data	▪ Covid Vaccination Dataset
Deaths	▪ Civil Registry Deaths	▪ Deaths	▪ Annual District Death Daily/Monthly ▪ Consolidated Death Data Source
ITU	▪ ICNARC COVID	▪ SICSAG Daily, Episodes	▪ ICNARC Quarterly/Weekly COVID
ITU/HDU Admissions	▪ (COVID 19 SARI Watch formerly CHESS)	▪ N/A	▪ N/A
Prescribing/Dispensing	▪ NHS BSA Dispensed Medicines ▪ Secondary care prescribed medicines	▪ PIS: Dispensed, Prescribed, Paid ▪ ePrescribing	▪ Wales Dispensing Dataset
NICOR CVD Audits	▪ PCI, MINAP, NHFA, NCHDA, NACRM, NACSA, TAVI	▪ N/A	▪ NICOR Audits and Registers (pending approvals)
Stroke Audit	▪ SSNAP	▪ Scottish Stroke Care Audit (SSCA)	▪ HQIP Stroke Audit (pending approvals)
National Vascular Registry	▪ NVR	▪ N/A (not currently requested)	▪ NVR (pending approvals)
Other	▪ Improving Access to Psychological Therapies (IAPT v2.0 / v2.1) ▪ Mental Health Services Dataset (MHSDS) ▪ Maternity Services Dataset (MSDS) ▪ Patient Reported Outcome Measures	▪ Diabetes Covariates ▪ Scottish Renal Registry ▪ Maternity Inpatient and Day Case – Scottish Morbidity Record (SMR02)	▪ Annual District Birth Extract ▪ Care Homes Index ▪ Maternity Indicators Dataset ▪ Congenital Anomaly Register (CARIS) ▪ National Community Child Health ▪ ONS Census (2011) & (2021)* ▪ Referral to Treatment Times ▪ SAIL Dementia e-Cohort ▪ Welsh Ambulance Service Dataset ▪ Wales Results Reporting Service ▪ Welsh Demographic Service

NORTHERN IRELAND Access to corresponding datasets to follow

KEY:

- Dataset available and actively being used for research purposes
- Dataset requested, but not yet available/pending approvals
- Dataset not requested
  * Additional approvals required

DATASET ACRONYMS:

- **CHESS:** COVID-19 Hospitalisation in England Surveillance System
- **ECOSS:** Electronic Communication of Surveillance in Scotland
- **GDPPR:** General Practice Extraction Service (GPES)Data for Pandemic Planning and Research
- **HES:** Hospital Episode Statistics
- **HQIP:** Healthcare Quality Improvement Partnership
- **ICNARC:** Intensive Care National Audit and Research Centre
- **LIMS:** Laboratory Information Management System
- **MINAP:** Myocardial Ischaemia National Audit Project
- **NACRM:** National Audit of Cardiac Rhythm Management
- **NACSA:** National Adult Cardiac Surgery Audit
- **NCHDA:** National Congenital Heart Disease Audit
- **NHFA:** National Heart Failure Audit
- **NICOR:** National Institute for Cardiovascular Outcomes Research
- **NIMS:** National Immunisation Management System
- **NVR:** National Vascular Registry
- **PCI:** Percutaneous Coronary Interventions
- **SGSS:** Second Generation Surveillance System
- **SICSAG:** Scottish Intensive Care Society Audit Group
- **SSNAP:** Sentinel Stroke National Audit Programme
- **SUS:** Secondary Uses Service
- **TAVI:** Transcatheter Aortic Valve Implantation

British Heart Foundation Data Science Centre
Led by Health Data Research UK

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Finally, we are immensely grateful to the UK biomedical research community that stepped up during an unprecedented global emergency to contribute to a collective effort that supported the pandemic response. None of this would have been possible without their commitment and dedication.

Annex

National Core Studies Leads and project leads

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Lead: Professor Andrew Morris HDR UK Director

Professor Sir Ian Diamond National Statistician

Professor Cathie Sudlow Chief Scientist and Deputy Director of HDR UK and Director of the BHF Data Science Centre

Professor Sir Aziz Sheikh University of Edinburgh and BREATHE Health Data Research Lab Professor of Primary Care Research

Professor Phil Quinlan University of Nottingham Head of Digital Research Service

Professor Paul Elliott Imperial College London Chair Epidemiology and Public Health Medicine

Professor Sharon Peacock University of Cambridge Professor of Public Health and Microbiology

Professor Ben Goldacre Bennett Institute for Applied Data Science Director Professor of Evidence Based Medicine

Professor Emily Jefferson University of Dundee Chair of Health Data Science

Luke Readman NHS England, London Director of Digital Transformation

Professor Julia Hippisley-Cox University of Oxford Professor of Epidemiology and General Practice

Professor Kenny Baillie University of Edinburgh Professor of Experimental Medicine

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Professor William Whiteley University of Edinburgh Centre for Clinical Brain Science

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Co-Lead: Professor Jonathan Sterne University of Bristol Professor of Medical Statistics and Epidemiology

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Professor Ben Goldacre Bennett Institute for Applied Data Science Director Professor of Evidence Based Medicine

Professor George Ploubidis University College London Professor of Population Health and Statistics Director 1958 National Child Development Study

Professor Claire Steves King's College London Professor of Ageing and Health Director of Twins UK

Professor Nicholas Timpson University of Bristol Professor of Genetic Epidemiology

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Deputy Lead: Professor Doreen Cantrell University of Dundee Professor of Cellular Immunology

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Professor Lucy Fairclough University of Nottingham Professor of Immunology

Professor Andy Pettitt University of Liverpool Professor of Haematology

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Professor Julian Knight Oxford University Professor of Genomic Medicne

Professor Aziz Sheikh University of Edinburgh and BREATHE Health Data Research Lab Professor of Primary Care Research

Dr Victoria Hall Brighton and Sussex Medical School Researcher in global health and infection

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Pre-prints and peer reviewed academic publications

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   Authors: Parry H, Bruton R, Stephens C, et al.
   Journal: NPJ Vaccines
   Publication date: 27 January 2022 (pre-print available 17 May 2021)
   URL(s): https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8795435/ and https://www.medrxiv.org/content/10.1101/2021.05.15.21257017v1

2. Quantifying the effect of delaying the second COVID-19 vaccine dose in England: a mathematical modelling study
   Authors: Imai N, Rawson T, Knock ES, et al.
   Journal: Lancet Public Health
   Publication date: 9 February 2023
   URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9910835/

3 Examining the Immunological Effects of COVID-19 Vaccination in Patients with Conditions Potentially Leading to Diminished Immune Response Capacity – The OCTAVE Trial
   Authors: Kearns P, Siebert S, Willicombe M, et al.
   Journal: The Lancet preprint (SSRN)
   Publication date: 23 August 2021
   URL: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3910058

4. Covid-19: How the UK vaccine rollout delivered success, so far
   Authors: Baraniuk C.
   Journal: British Medical Journal
   Publication date: 18 February 2021
   URL: https://pubmed.ncbi.nlm.nih.gov/33602672/

5. Association of COVID-19 vaccines ChAdOx1 and BNT162b2 with major venous, arterial, and thrombocytopenic events: whole population cohort study in 46 million adults in England
   Authors: Whiteley WN, Ip S, Cooper JA, et al.
   Journal: PLoS Medicine
   Publication date: 22 February 2022 (pre-print available 23 August 2021)
   URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8863280/ and https://www.medrxiv.org/content/10.1101/2021.08.18.21262222v1

6. Trends and clinical characteristics of COVID-19 vaccine recipients: a federated analysis of 57.9 million patients' primary care records in situ using OpenSAFELY
   Authors: Curtis HJ, Inglesby P, Morton CE, et al.
   Journal: British Journal of General Practice
   Publication date: 31 December 2021 (pre-print available 9 April 2021)
   URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8589463/ and https://www.medrxiv.org/content/10.1101/2021.01.25.21250356v3.full

7. Linked electronic health records for research on a nationwide cohort of more than 54 million people in England: data resource
   Authors: Wood A, Denholm R, Hollings S, et al.
   Journal: British Medical Journal
   Publication date: 7 April 2021
   URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8413899/

8. Risk of myocarditis and pericarditis following BNT162b2 and ChAdOx1 COVID-19 vaccinations
   Authors: Ip S, Torabi F, Denaxas S, et al.
   Journal: medRxiv preprint
   Publication date: 8 March 2022
   URL: https://www.medrxiv.org/content/10.1101/2022.03.06.21267462v1.full

9. Association of COVID-19 With Major Arterial and Venous Thrombotic Diseases: A Population-Wide Cohort Study of 48 Million Adults in England and Wales
   Authors: Knight R, Walker V, Ip S, et al.
   Journal: Circulation
   Publication date: 19 September 2022 (pre-print available 24 November 2021)
   URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9484653/

10. Antibody levels following vaccination against SARS-CoV-2: associations with post-vaccination infection and risk factors in two UK longitudinal studies
    Authors: Cheetham NJ, Kibble M, Wong A, et al.
    Journal: eLife
    Publication date: 24 January 2023 (pre-print available 22 May 2022)
    URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9940912/

11. The immunology of asymptomatic SARS-CoV-2 infection: what are the key questions?
Authors: Boyton RJ, Altmann DM.
Journal: Nature Reviews Immunology
Publication date: 19 October 2021
URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8525456/

12. The impact of ethnicity on clinical outcomes in COVID-19: A systematic review
Authors: Pan D, Sze S, Minhas JS, et al.
Journal: E Clinical Medicine.
Publication date: 3 June 2020
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13. The United Kingdom Research study into Ethnicity And COVID-19 outcomes in Healthcare workers (UK-REACH): protocol for a prospective longitudinal cohort study of healthcare and ancillary workers in UK healthcare settings
Authors: Woolf K, Melbourne C, Bryant L, et al.
Journal: BMJ Open
Publication date: 17 September 2021
URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8450967/

14. Predictors of SARS-CoV-2 infection in a multi-ethnic cohort of United Kingdom healthcare workers: a prospective nationwide cohort study (UK-REACH)
Authors: Martin CA, Pan D, Melbourne C, et al.
Journal: PLoS Medicine
Publication date: 26 May 2022 (pre-print available 17 December 2021)
URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9187071/ and https://www.medrxiv.org/content/10.1101/2021.12.16.21267934v1.full

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Authors: Bergamaschi L, Mescia F, Turner L, et al.
Journal: Immunity
Publication date: 8 June 2021 (pre-print available 26 March 2021)
URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8125900/ and https://www.medrxiv.org/content/10.1101/2021.01.11.20248765v2

16. Whole blood-based measurement of SARS-CoV-2-specific T cells reveals asymptomatic infection and vaccine immunogenicity in healthy subjects and patients with solid-organ cancers
Authors: Scurr MJ, Zelek WM, Lippiatt G, et al.
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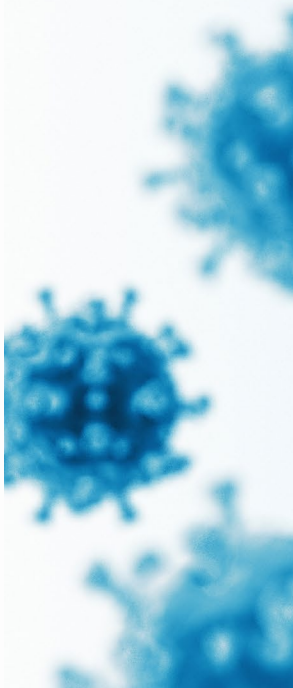

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