Artificial intelligence and health

Summary report of a roundtable held on 16 January 2019

The Academy *of* Medical Sciences

MRC Medical Research Council

NIHR | National Institute for Health Research

The Academy of Medical Sciences
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The National Institute for Health Research (NIHR) is the nation's largest funder of health and care research. The NIHR:

- Funds, supports and delivers high quality research that benefits the NHS, public health and social care.
- Engages and involves patients, carers and the public in order to improve the reach, quality and impact of research.
- Attracts, trains and supports the best researchers to tackle the complex health and care challenges of the future.
- Invests in world-class infrastructure and a skilled delivery workforce to translate discoveries into improved treatments and services.
- Partners with other public funders, charities and industry to maximise the value of research to patients and the economy.

The NIHR was established in 2006 to improve the health and wealth of the nation through research, and is funded by the Department of Health and Social Care. In addition to its national role, the NIHR supports applied health research for the direct and primary benefit of people in low- and middle-income countries, using UK aid from the UK government.

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Executive summary

Artificial intelligence (AI) is likely to have a substantial and potentially transformative impact on biomedical research and the healthcare system. However, there is a risk that the benefits of AI in health are not fully realised if the environment for the development and implementation of these new technologies is not sufficiently enabling.

The Academy of Medical Sciences, in partnership with the Medical Research Council (MRC) and the National Institute for Health Research (NIHR), held a joint roundtable on 'AI and health' on 16 January 2019. The roundtable explored the challenges, opportunities and priorities for research and development of AI-driven data analytics. The following key themes emerged:

- **Data and computing technology:** The increase in data volume and complexity, in combination with cheaper and more powerful computational architectures, have been key drivers for the use of AI. To support the continued development of cutting-edge AI technologies and their use in healthcare and medical research, there is an increased need to support data stewardship, access, curation and standardisation activities, and underpinning infrastructure. It is also important to have access to the latest AI-supporting computing technology to enable the development and deployment of AI algorithms at pace and scale.
- **Evaluation and translational frameworks:** AI-driven health technologies, as evolving, dynamic, learning systems, present a regulatory challenge, especially where there is limited or no transparency around the processes by which they reach their output ('black box' systems). Researchers and developers need to engage with regulators throughout the research and development process, and methodologies should be developed to audit and evaluate AI-driven health technology. The generalisability (or applicability) of algorithms developed in 'clean' learning environments to 'messy' real life environments in diverse populations, as well as 'data outliers' and inherent biases in training data sets that can significantly skew AI algorithms, present key challenges to the development of new AI technologies. These are particularly important considerations in the healthcare space, where there are potentially serious implications for the health of patients and the public, and should be given due attention in the deployment of AI technologies.
- **Working across sectors and disciplines:** Reconciling the different drivers and ways of working that exist between the innovation/product-focused technology sector and the patient outcomes-focused healthcare sector will be necessary to realise the potential of AI. Greater permeability across sectors would be beneficial. To support this, the development of flexible funding streams, clearly articulated collaboration models, and cross-sectoral appointments that encourage collaboration between disciplines and sectors, are required.
- **Training and capacity building:** AI research often requires a collaborative, multidisciplinary team approach that current training provision does not address. Training programmes should be reviewed to provide researchers, developers and clinicians with the multidisciplinary networks and skills that are required to develop and/or use new AI technologies in health and social care. The social sciences should increasingly be involved in multidisciplinary teams developing AI technologies and emphasis should be placed on ethics training for data scientists to ensure that they are operating with high levels of research integrity.
- **Public/user engagement:** Ongoing engagement with patients, the public and healthcare professionals, including via co-creation, will be critical to ensuring that new AI technologies respond to clinical unmet need, are fit for purpose, and are successfully deployed, adopted and used. Research funders have an important role to play in driving these approaches. Without public use, trust and understanding, the potential of these new technologies is unlikely to be realised.

A number of future priority research areas for AI also emerged from the meeting. These ranged from supporting clinical decision-making (e.g. diagnosis); to facilitating operational improvements to allow clinicians to focus on care rather than administrative tasks; integrating multiple data modalities, including data from wearables; AI to support treatment strategies (e.g. in dementia and mental health); and 'explainable AI' (also known as 'forensic AI', interpretable decisions made by algorithms).

To create a catalyst for change, research funders should work with the wider UK community – including academia, industry, the NHS, public and private funders, regulators, and users and the public – to define and drive forward key research areas for AI and health. The roundtable provided a platform to initiate these conversations, which now need to be taken forward with this wider group of stakeholders to ensure the UK remains a world-leader in AI health research.

Introduction

The impact of AI on biomedical research and the healthcare system is likely to be substantial and potentially transformational. The increase in data volume and complexity, in combination with cheaper and more powerful computational architectures, and the need to integrate multiple data types for more precise healthcare decisions, have been key drivers for the use of AI and AI-driven data analytics.

Benefits could include: improved efficiency of research and development processes; new methods of healthcare delivery; more informed clinical decision-making; faster, more efficient clinical trials; and empowerment of patients in managing their health. AI has already begun to be used in each of these areas and, as technology develops to further analyse complex datasets, so too will its scale of use. AI has the potential to accelerate diagnoses (and potentially improve their accuracy and range, for example new types of diagnoses from real-time monitoring using wearable devices), as well as alleviate some of the pressures on the healthcare system by introducing system efficiencies, such as online booking systems or chatbots. By using AI as a complementary tool, healthcare practitioners may be able to free up valuable time to focus on care.

AI is now being used in many different industries and the scale and pace of its use is anticipated to increase in the future.[1]

To discuss this increasingly important area, the Academy of Medical Sciences, the MRC and the NIHR convened a roundtable on 16 January 2019, chaired by Professor Jacqueline Hunter CBE FMedSci, Chief Executive of Benevolent Bio. Participants were drawn from across the life sciences and AI landscape, with expertise from industry, the National Health Service (NHS), academia and funding bodies. The meeting aimed to explore the challenges and opportunities in AI-driven data analytics for health, in particular to:

- Assess future research areas for AI-driven data analytics that capture the value of biomedical and healthcare data.
- Explore the function and wider implications of current collaboration models for the development and application of AI-driven data analytic tools in healthcare and the medical sciences.
- Consider the development of skills for AI-driven data analytics and aspects related to research quality, software/algorithm transparency and standards.

The discussions focused on data and computing technology; evaluation and translational frameworks; cross-sectoral and interdisciplinary working; training and capacity building; public, patient and user involvement; and priority research areas.

This report provides a summary of the discussions that took place at the meeting. It does not necessarily represent the views of all participants at the event, the Academy of Medical Sciences or its Fellows, the MRC or the NIHR.

References

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AI in health: overview of future technology advancements and strategic investments

During the roundtable, speakers offered insight into future AI-driven technology developments across health and biomedical research, and provided an overview of strategic investments within the field. The presentations delivered over the course of the meeting are summarised in this chapter.

Professor Jaqueline Hunter CBE FMedSci, Chief Executive of Benevolent Bio and Chair of the roundtable, opened by highlighting the timely nature of the meeting given the extent of interest in and activity surrounding the use of AI in health ecosystems. She stressed that while much of the technology already exists, the adoption and implementation of this technology for healthcare uses needs to be further examined.

Future AI-driven data analytics that will have a transformational effect across biomedical research and health care delivery

Professor Chris Holmes, Professor in Biostatistics at the University of Oxford and Programme Director for Health and Medical Sciences at The Alan Turing Institute (a joint appointment with Health Data Research UK [HDR UK]), gave an overview of AI, its potential transformational role in medicine, and areas of particular interest to health sciences. He defined AI as computer systems that can learn a task by exposure to examples of that task. That is, learning by data rather than traditional human coding of rules. The overarching area of AI includes machine learning, computational statistics and inductive (probabilistic) logic.[2]

In conjunction with other tools, AI has the potential to transform medicine. First, driven by advances in digital measurement technologies, data generation and acquisition are becoming much cheaper, including data from genomes, images, wearables and electronic health records. For example, sequencing the first human genome originally cost about $2.7 billion, whereas it now costs under $1,000[3]. In addition, increases in raw computing power are facilitating the development of AI algorithms that utilise increased processing power, and enhanced connectivity across data environments has enabled the development of better algorithm-learning environments.

While the actual methods of AI have not changed a great deal since the 1980s, it is the coupling of these methods with the increased availability of data and raw computing power that are set to be transformative.

Professor Holmes noted that AI can add substantial value to learning systems that have any of the following characteristics:

- Systems that are typified by large quantities of data in a stable learning environment with clearly defined objective functions.
- Systems that have cryptic hard to define features (such as those found in images, free text or video footage). For example, AI could help with difficult image diagnostics through learning from vast quantities of data.
- Systems that integrate multiple data modalities at scale. For instance, combining images, genomic data and electronic health records.

In terms of future application areas, there has been a lot of interest in the area of image analytics, defined by Professor Holmes as 'the poster child of AI'. The current priority is to move from a bench to bedside approach, although issues of accommodating heterogeneity in images across sites will need to be addressed. Synthetic data approaches, where an artificial set of data is created based on the original files, could be used for data sharing where there are concerns about patient confidentiality and data privacy. Professor Holmes highlighted the potential of AI to assist with the improvement of the evidence base from clinical trials, including: recruitment of patients; adaptation of trials and data analysis; and the power of combining clinical trial data with other 'real world' data. He also noted the potential of AI to assist healthcare delivery and operational research. Other application areas that could contribute to advancement in AI include wearables for the ageing population and for wellbeing, and the use of electronic health records to better understand drug-drug efficacy or adverse reactions and co-morbidities.

Finally, Professor Holmes described a number of potential future technical advances that could be of value to the health sector. These consisted of:

- Deep learning, including the critical evaluation and appreciation of when and where this technique could be applied, transfer learning,[4] domain adaptation,[5] and sensitivity analysis.[6]
- Causal inference and how this can be useful for predicting the effects of interventions.
- Data sharing under privacy constraints, for example with synthetic data.
- Coping with missing data under highly-structured missingness.[7]
- Multi-view learning through the combination of different types of data (also known as data modalities) at and across scales.

Overview of strategic investments for AI-driven data analytics

UK Research & Innovation (UKRI) perspective

Dr Claire Newland, Head of Data Science at the MRC, described UKRI's current strategic investments for the field of AI. She emphasised that the formation of UKRI, which brings together the seven research councils (including the MRC), Research England, and Innovate UK, presents a unique opportunity for supporting multi-disciplinary research and innovation. Together with this renewed invigoration for collaboration, there is heightened impetus from the government to invest in research and innovation, for example through the Industrial Strategy Challenge Fund (ISCF), which has specific allocations for AI. Dr Newland noted that there is a keen interest across UKRI to invest more in this area, and that input from the relevant sectors and communities would be invaluable in informing and shaping UKRI activities, both as individual councils and collectively. For example, a UKRI review of AI had recently been initiated, convened by Professor Tom Rodden, Deputy Executive Chair of the Engineering and Physical Sciences Research Council (EPSRC).

Dr Newland highlighted existing investments and initiatives by UKRI to support AI. MRC investments to date have been both through their normal grant routes to support innovative research, and through flagship programmes in conjunction with a number of partners. Notable flagship investments across UKRI and partners include the Alan Turing Institute and HDR UK. AI-driven analytics are becoming increasingly ubiquitous tools for research right across the (MRC) portfolio, for instance in imaging,[8] precision medicine, and biomarker discovery. These are example areas demonstrating the need and value of multidisciplinary cross-sectoral approaches. As a more specific example, Dr Newland also described a stratified medicine consortium that is using AI to gain maximum insight from multiple, diverse, complex, and large data sets for the early diagnosis of prostate cancer.[9] Dr Newland concluded by highlighting that there are opportunities for investments to support and enable AI research and innovation across UKRI. A notable example is the £210 million ISCF 'from data to early diagnosis and precision medicine',[10] to support a range of projects and activities to better harness data assets to drive innovation in early diagnosis and precision treatments, with particular focus on genomics, health data and digital pathology.

NIHR perspective

Martin Hunt, Director of the Invention for Innovation Programme at the NIHR, indicated that the NIHR has a budget of £1.3 billion and, despite having no overarching strategy for investing in AI research, 13 of their 20 Biomedical Research Centres are involved in AI projects, some in collaboration with industry. NIHR is enthusiastic about the potential of AI and its ability to offer patient benefit, and would like to learn about the experiences of other funding bodies and grant recipients to inform their future strategy. Mr Hunt noted that out of NIHR's Invention for Innovation £120 million portfolio, £7-8 million was allocated to projects that are specifically focused on AI, with an additional £20 million allocated to projects using sophisticated digital analysis or machine learning.

Mr Hunt described how the NIHR can allocate funding in a 'response mode', where it considers application of all kinds, but also in a 'themed mode', which is used to actively promote a programme of work. The NIHR would be receptive to input from the sector to help shape a potential future AI-themed funding call, particularly in terms of what should be within remit. He noted that NIHR already funds AI in many areas of research, including ischemic stroke, lung cancer diagnostics and diagnostics of language disorders, but that there are many other areas of potential interest. The NIHR has collaborative projects involving the NHS, the Alan Turing Institute and industry. He stressed the importance of harnessing the potential of the 3,500 small and medium-sized enterprises in the UK that have a key role to play in this area and in the delivery of the Life Sciences Industrial Strategy.

Mr Hunt noted some of the remaining barriers to the full scale and system-wide deployment of AI, including:

- The introduction of innovation into the NHS, which is an issue in terms of affordability, how the research community develops AI and how funders operate in this space. A risk averse culture in the NHS poses an additional barrier to uptake of these new technologies.
- The regulatory environment, where early conversations with regulators are likely to facilitate the approval process.
- The industrialisation and commercialisation of AI.

Given the current enthusiasm for AI and new digital technologies, careful management of funding is required so that funding strategies result in meaningful outcomes – beyond publications.

Industry perspective

Pamela Spence, Global Health Sciences and Wellness Industry Leader and Life Sciences Industry Leader at Ernst & Young, introduced the area from an industry perspective. She observed that medicine is moving from a clinical science supported by data to a data science that will be supported by clinicians.

Behaviour change is an area where AI and new digital technologies may be transformative. Many smaller companies are generating apps focussed on behaviour change, rather than medical interventions. For example, Welldoc has developed BlueStar, a diabetes app aiming to help manage diabetes through behaviour change.[11] By encouraging small interventions on a more frequent personalised basis, this app has been successful in reducing a diabetic marker, HbA1c levels, in patients by two points, which goes beyond the US Food and Drug Administration's benchmark of half a point. The whole spectrum of medical practice is likely to be affected by AI-driven technology, so a key aim will be to personalise interventions before and/or during disease. 'Sensors' on the body will be fundamental to getting better data capture and feedback loops.

The pharmaceutical industry is particularly interested in new digital technologies and has the capacity to invest heavily in this area. A recent example is the partnership between GlaxoSmithKline (GSK) and 23&me, which saw the pharmaceutical giant invest $300 million in the smaller biotechnology company, a sum that was transformative to its activities.[12] Big technology companies such as Google also have a strong interest in healthcare and are keen to invest. Ms Pence noted that there is, however, a cultural barrier between the healthcare and technology sectors, with the former being relatively slow to act and fearful of the regulators, whereas the latter is much more nimble and fearless, and the pace at which they make decisions is foreign to the health industry. The capital of such companies that sit outside of the traditional life sciences sector presents a significant opportunity for investment. Their outlook is a quality that the life sciences sector needs to embrace, though there are questions as to how these alliances with external players can be married up at scale, and how the cultural differences can be overcome.

References

2. De Raedt L & Kersting K (2008). *Probabilistic Inductive Logic Programming*. In De Raedt L, *et al*. eds. (2008) Probabilistic Inductive Logic Programming. Lecture Notes in Computer Science, **4911**. Springer, Berlin, Heidelberg.
3. National Institutes of Health (2016). *The Cost of Sequencing a Human Genome*. https://www.genome.gov/27565109/the-cost-of-sequencing-a-human-genome/
4. Transfer learning is an area of AI that focuses on the ability for a machine learning algorithm to improve learning capacities on one given dataset through the previous exposure to a different one. https://medium.com/owkin/transfer-learning-and-the-rise-of-collaborative-artificial-intelligence-41f9e2950657
5. Domain adaptation concerns the generalisability of the AI algorithm from the data training environment to the deployment domain.
6. Sensitivity analysis characterises the influence of training data observations on the shape of the AI predictions, as well as the monitoring of how the model predictions are influenced by small changes to the input data (for example, detecting whether a model is unduly influenced by atypical input data, or whether small changes to the input data result in disproportionately large changes to the outputs).
7. When training algorithms on data captured from multiple studies, highly-structured, or systematic, missingness refers to the property that all studies might not have measured all modalities. For instance, one study may have captured imaging and genetic data, while another study might have only captured imaging data.
8. https://www.kcl.ac.uk/news/news-article?id=1d945f60-f586-400d-9514-5df7dfb09300
9. https://www.ukri.org/news/researchers-to-investigate-screening-for-prostate-cancer-using-mri/
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Challenges and opportunities

Building on the speakers' presentations, participants were asked to consider the major challenges and opportunities to enable research into AI-driven data analytics to reach its maximum potential and help transform healthcare provision. They were also asked to reflect on the current and future research areas for AI-driven data analytics with the most potential to transform healthcare, as well as the most pressing research priorities. This chapter provides a summary of the discussions at the meeting.

Data and computing technology

Data access

Challenges around data access and governance were highlighted as priority areas to be addressed. Participants stressed the need for better access to high quality, large-scale standardised datasets that are routinely collected, annotated and linkable. In particular, participants highlighted the need to improve access to data generated in the NHS, which should be better collected and utilised, and suggested that a unified data access agreement across the NHS would be valuable. It was suggested that HDR UK has an important role in improving access to data and that lessons could be learnt from how this has been achieved in other sectors, such as the intelligence sector. Participants felt there was an opportunity to create systems that provide fair access and value for all participants, including the public. For example, it was suggested that a federated model of accessing data with centralised regional nodes would be valuable. Participants stressed the need for appropriate investment in the infrastructure to support research into AI-driven data analytics and questioned whether at present this was recognised by funders.

Data sharing

The development of AI algorithms relies on large data sets from which they can learn to ensure both effectiveness and robustness. In many instances, data sharing is critical to establishing these data sets. Issues exist around exporting data into a format that can be linked with other datasets, although HDR UK is playing an important role in seeking to address them. Participants suggested that funding should be provided to support data curation, a task that is undervalued yet critical to the sharing and interoperability of data.

Sharing personal data requires particularly careful consideration to ensure that data privacy and confidentiality are safeguarded.[13] One innovative solution to re-use and share sensitive data is the use of synthetic data. This entails producing synthetic versions of the data, rather than sharing the actual raw data. Participants noted that this could be used to share medical images and that such methods are already being used in some parts of the NHS to share codified data with trusted parties.

However, there is a danger that the algorithms responsible for generating the synthetic data set do not replicate all of the features of the original data. This could result in important elements or features being lost, or biases being introduced, especially if these do not appear to be of value to the programme that is generating them. It was stressed that this is an emerging area, and its uses and limitations are still being explored.

Raw computing power

In order to safeguard data privacy and confidentiality, certain data are kept behind firewalls. Participants noted that one of the major challenges in using such data is the lack of raw computing power (including Graphic Processing Units – GPUs) available in these environments. Insufficient computing power can prevent the development or running of algorithms, particularly in instances where a large number of deep learning models would need to be run simultaneously, and can lead to delays in model development. Participants agreed that even with computing capacity that would be considered to be substantial in most hospitals and academic settings (e.g. 500 GPUs), the analysis demands of some AI algorithms still cannot always be met.

Further investment in infrastructure to support the increased requirements for computing power is needed to support research and development in this field. One solution put forward by participants was to establish a cloud-based system for GPUs, which would enable an increased number of algorithms to run concomitantly.

Evaluation and translational frameworks

Participants discussed the opportunity presented by AI to close the loop between the healthcare system, and patients and the care they receive in a direct responsive fashion. This will require leveraging data in hospitals in a much more efficient way, but could support a learning system where the AI technology – and therefore healthcare delivery – could improve by learning as further data are gathered.[14]

Learning systems pose a challenge to regulatory bodies, such as the Medicines and Healthcare products Regulatory Agency (MHRA), which are currently exploring how best to regulate such evolving systems. There are particular challenges around so-called 'black box' systems that use complex and dynamic algorithms resulting in limited or no transparency around the processes by which they reach their output (also known as 'explainability').[15] There is a need for a clear pathway for regulatory approval. Researchers and developers need to engage with regulators throughout the research and development process, and methodologies need to be developed to audit and evaluate AI-driven health technology.

To improve research quality and enhance the usability of AI, greater transparency of algorithms and data standards are needed. Reporting guidelines such as those listed on the EQUATOR network could help,[16] as could the development of frameworks for the implementation and evaluation of AI.[17] Participants indicated that there is opportunity to build best practice for open and transparent data standards that are both appropriate and proportionate.[18,19]

Generalisability of AI algorithms

Robust AI algorithms are produced in stable learning environments, which allow the finding of patterns in training data sets. Participants discussed the challenges of generalising findings once the algorithm is taken out of such 'clean' learning environments into 'messy' real life environments (a process also known as generalisation or industrialisation). An example of this is using data from clinical trials obtained from a relatively homogenous group of individuals that has been carefully selected, which may not be representative of the wider population. Participants highlighted the critical need to capture and evaluate data in a continuous manner to mitigate issues of data representativeness. Moreover, most examples of AI health interventions to date have been developed in the leading research labs with access to the best measurement technologies – a degradation in performance when they are deployed in application sites with older technologies or less rigorous study protocols might therefore be expected.

Participants also noted the challenges associated with data outliers, which can have a significant impact on deep learning algorithms. The consequence of error was highlighted as a key determinant in how much resource should be dedicated to mitigating problems associated with outliers – if the consequence is negligible, then efforts may not be justified, whereas efforts should be concentrated on resolving such issues for algorithms where the consequences are severe (e.g. death). Participants agreed that this is a real consideration in healthcare, where there is significant potential for harm if algorithms do not consistently perform as designed or indeed anticipated.

The generalisability of algorithms is particularly important in terms of fairness and equity of access to new medical technologies. It should be a key consideration in the development of AI algorithms.

Cross-sectoral collaboration

Partnership working

Meeting participants recognised that the different drivers and ways of working between the patient outcomes-focused healthcare sector (including the scientific community, the healthcare system and the pharmaceutical industry) and the innovation/product-focused technology sector can present a challenge to the development and widespread use of AI technologies in health and social care. It was felt that both sectors could learn from one another: the healthcare sector would benefit from the speed and scale at which technology companies operate; whereas technology companies need to be cognisant of the potential for harm when developing new technologies for the healthcare sector, which necessitates a more measured approach. While participants appreciated the 'fail fast' culture in the technology sector, such an approach can have harmful consequences in the healthcare sector. In addition, institutional buy-in and leadership from senior management will be required to support the deployment of AI in the healthcare sector.

Participants acknowledged the current limited funds that are available for research into AI and the need to prioritise specific research areas. Collaboration with the private sector presents opportunities for further investment, particularly where there is a potential for commercialisation.

Cross-sector mobility

Participants indicated that greater permeability across sectors would help to address some of the challenges to partnership working. Greater freedom to move or collaborate across traditional sector boundaries would provide researchers with a better understanding of the challenges that each sector faces, as well as a broader perspective on how the community can better work together. Participants discussed the need for retention of skills in academia and agreed that researchers moving between academia and industry is largely positive, especially when links are maintained with academia. The lack of a clear career pathway and lower salaries in academia were cited as two of the main reasons for leaving academic research, though this is often at the expense of scholarly and intellectual freedom.

Joint appointments between academia and industry could be a mechanism to enable cross-sectoral mobility, and provide links between the sectors while helping to retain talent in academia. These opportunities are highly valued by the industry and it was agreed that funders could play a role in recognising the value of such cross-sectoral appointments. A clearer articulation of the current collaboration models would also help to support cross-fertilisation of ideas across sectors. It was suggested that collaborations across the NHS and technology companies should be supported and promoted more widely. Exemplars or best practice for partnerships would be valuable.

Training and capacity building

Training provision

Participants indicated that the current training provision is not fit for purpose. AI research often requires a collaborative multidisciplinary approach, unlike the current dichotomic system where the clinical and scientific routes operate in relative silos.

In an attempt to address this, HDR UK is partnering with the NIHR to create more training opportunities via establishing a NIHR/HDR UK Incubator in Health Data Science.[20] This programme supports a mix of clinical and non-clinical researchers in developing a career in health data science. Participants also suggested that big data and bioinformatics should become a core part of clinician training, and that opportunities, including protected time, for clinicians to participate in AI research should be provided.

The social sciences were highlighted as an important partner in this field of research, offering a unique and complementary perspective. Participants felt that they should increasingly be included in multidisciplinary teams developing AI and in conversations around the development of AI technologies. The need for ethics training for data scientists was also highlighted to ensure that they are operating with the high levels of research integrity required.

Funding for training

Participants suggested that research funders should develop flexible funding streams that encourage collaboration between disciplines within large doctoral centres. The Alan Turing Enrichment Scheme was highlighted as a good example, allowing PhD students in a variety of disciplines across the UK to enhance and broaden their research by joining the Turing Institute for up to 12 months.[21] The scheme is set up to provide new opportunities for collaboration and to enrich students' research by learning new techniques while working alongside a range of researchers and industry partners.

Importance of public/user engagement

Participants stressed that ongoing engagement of patients, the public and healthcare professionals is paramount in informing the priority focus areas for AI. Co-creation of new AI technologies with patients, the public and users in the healthcare system is also critical to ensure that new AI technologies respond to clinical unmet need, are fit for purpose, and are successfully deployed, adopted and used. Without public use, trust and understanding, the potential of these new technologies is unlikely to be realised. It is important that the healthcare sector is prepared for and understands the value in adopting these new technologies, and efforts should focus on raising awareness and understanding of this emerging area, both in the sector itself and more broadly at a societal level. Further, it was emphasised that AI should deliver a service that is outcomes-focused, delivering transformative change for patients.

Given the level of public trust in the NHS, participants felt the NHS could play a key role in building public confidence as implementation continues to be rolled out. The recent Topol Review (in preparation at the time of the meeting) makes a series of recommendations aimed at supporting NHS staff to embrace innovative technologies, such as genomics, digital medicine, artificial intelligence and robotics, to improve services.[22] Buy-in by senior management would help to create a culture that embraces new technologies that permeates through all layers of the organisation.

Participants felt that research funders also have an important role to play in driving public-patient involvement and user-led design. By setting high standards for public, patient and user engagement, there is an opportunity for the UK to lead the way in ethical research into AI.

Future research areas for AI-driven data analytics

Future important research areas suggested by participants ranged from the use of AI to support end-to-end care, the detection of rare disease cases (e.g. to assist rapid cancer diagnosis), and indirect care, which could complement direct care provision by healthcare professionals and lead to efficiency savings for the workforce (see **Box 1**).

Participants noted that AI could also have a transformative effect on the healthcare system itself, for example by allowing healthcare practitioners to focus on care by removing – or at least significantly reducing – administrative tasks. Its potential has already been seen in the area of radiology where rapid uptake of algorithms has led to improved accuracy of diagnosis.[23] There is also a lot of interest in how AI could help with managing the increasing prevalence of dementia and the rise in poor mental health, especially given the current pressures on the health system. Wearables have the potential to help accelerate and improve accuracy of diagnosis; however, participants warned that this form of 'monitoring' should be carefully deployed to mitigate any undue stress that it may cause by patients constantly being reminded of their health status.

Box 1 Future research areas for AI-driven analytics identified by participants

- Supporting-end to-end and indirect care
- Predicting drug-drug and drug-environment interactions
- Facilitating operational improvement in the healthcare setting
- Supporting clinical decision-making (e.g. disease prevention, diagnostic accuracy, rare case detection)
- Tackling multimorbidity
- Dealing with problems associated with data quality
- Generalisability of AI algorithms across a range of inputs and applications (e.g. using transfer learning or reinforcement learning)[24]
- Tailoring prevention schemes (precision prevention)
- Optimising treatment allocation (precision medicine)
- Integrating data from multiple modalities (e.g. imaging; genomic, transcriptomic and proteomic data; and data from wearables and electronic healthcare records)
- Supporting treatment strategies (e.g. cognitive behavioural therapy)
- 'Explainable AI' (also known as 'forensic AI', understanding how models come to their conclusions)
- Evaluation and auditing tools

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17. Vollmer S, *et al.* (2018). *Machine learning and AI research for Patient Benefit: 20 Critical Questions on Transparency, Replicability, Ethics and Effectiveness.* arXiv:1812.10404. https://www.turing.ac.uk/research/publications/machine-learning-and-ai-research-patient-benefit

18. Shortly after the meeting, the Department of Health and Social Care published a Code of conduct for data-driven health and care technology: https://www.gov.uk/government/publications/code-of-conduct-for-data-driven-health-and-care-technology.

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20. https://www.hdruk.ac.uk/news/nihr-and-health-data-research-uk-join-forces/

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22. NHS (2019). *The Topol Review: Preparing the healthcare workforce to deliver the digital future.* https://topol.hee.nhs.uk/wp-content/uploads/HEE-Topol-Review-2019.pdf

23. De Fauw J, *et al.* (2018). *Clinically applicable deep learning for diagnosis and referral in retinal disease.* Nature Medicine **24**, 1342–1350.

24. Transfer learning is a machine learning method where a model developed for a task is reused as the beginning point for a model on the next task. Reinforced learning is a type of machine learning that enables an agent to learn in an interactive environment by trial and error using feedback from its own actions and experiences.

Issues to be addressed

From the discussions around current and future challenges, and opportunities to creating a framework for the development, implementation and evaluation of AI, participants suggested a series of potential next steps as the use of AI in health and social care progresses.

Next steps highlighted by participants in the shorter-term included:

- Ensuring that implementation plans are developed for AI technologies. These should be included in funding applications so that sufficient resources can be dedicated from the inception of the project through to implementation and adoption, and should involve all relevant stakeholders.
- Discussions with the NHS about the speed of uptake, which could be accelerated, with lessons to be learnt from other industries.
- A need for flexibility in funding streams; in particular, mechanisms to bring multiple disciplines together needs greater consideration within and across research funders.
- Investment in the data infrastructure to support the development of new AI technologies; specifically, investment in data curation and standardisation to enable greater interoperability between data sets.
- Greater clarity of the regulation and governance frameworks for the development and deployment of AI technologies. This includes better understanding of the governance issues that are created by AI algorithms supporting decision-making.
- Increased transparency, robustness and feedback on new AI technologies, and the need for openness around their development, evaluation and utilisation.[25] These factors will be critical in improving the robustness of AI research and building trust in these new technologies, both within the healthcare system and more broadly by the public.
- Greater engagement with users, including patients, healthcare professionals and the public, to ensure new AI technologies respond to a clinical need and are fit for purpose. Engagement of these communities will help to build the trust in these emerging technologies that will be required for their successful implementation and adoption in the healthcare system.

A number of further steps to realise the potential of AI in health were recognised. Reconciling the different drivers and ways of working across the fast paced, risk-taking technology sector and the slower, risk averse nature of the healthcare sector, where the primary concern is patient safety, will be important. Greater fluidity in working and/or moving across sectors would help, as would greater flexibility in funding across disciplines. There is also a need to review training programmes to provide researchers and clinicians with the multidisciplinary skills that will be required to develop and/or use new AI technologies. Participants noted the need for a clear translation pathway for AI technologies, from algorithm development to implementation and adoption in the healthcare system, and the need for researchers to engage with the regulators throughout to accelerate and streamline the process.

In addition, participants felt that funders should identify and prioritise five key research areas for AI and health, and drive these forward to create a real catalyst for change. Participants agreed that funders should work in concert with the wider community, including the wider investment community, to define these priorities. Going forward, it will be important to engage a wider group of stakeholders that are involved with the use of AI in health, including the pharmaceutical industry, small and medium-sized enterprises, regulators, the social sciences and humanities, a broader range of funding bodies, representatives from the devolved nations, and importantly users and the public. There was a real appetite for follow-up and participants were keen to make use of the forum provided by the roundtable to take discussions forward.

References

25. Robust machine learning is a key theme for the newly established European Laboratory for Learning and Intelligent Systems. https://ellis.eu/

Annex 1: Programme

09.30 – 10.00	Registration and refreshments
10.00 – 10.05	Welcome and introduction Professor Jacqueline Hunter FMedSci, Chief Executive, Benevolent Bio
Session 1: Cutting-edge advances in AI-based data analytics	
10.05 – 10.30	Future AI-enabled/-powered data analytics that will have a transformational effect across biomedical research and health care delivery Professor Chris Holmes, Professor in Biostatistics, University of Oxford; Programme Director for Health and Medical Sciences, The Alan Turing Institute (joint appointment with Health Data Research UK)
10.30 – 12.00	Group discussion Facilitated by Professor Jacqueline Hunter FMedSci *Possible discussion topics:* • What are the future research areas for AI-based data analytics that capture the value of biomedical and healthcare data for both novel and existing applications? • Which current/future research areas for AI-based data analytics have the most potential to transform healthcare? • What are the most pressing research priorities in this area?
12.00 – 13.00	Lunch and networking
Session 2: Challenges, priorities and next steps	
13.00 – 13.25	Overview of strategic investments for AI-enabled/-powered data analytics *Speakers:* • Dr Claire Newland, Head of Data Science, Medical Research Council (UKRI perspective) • Martin Hunt, Director of Invention for Innovation Programme, National Institute for Health Research (NIHR perspective) • Pamela Spence, Global Health Sciences and Wellness Industry Leader and Life Sciences Industry Leader, Ernst & Young (industry perspective)
13.25 – 14.50	Group discussion Facilitated by Professor Jacqueline Hunter FMedSci *Possible discussion topics:* • What are the major challenges and opportunities to enable research into AI-enabled/-powered data analytics to reach its maximum potential and help transform healthcare provision? • Should research quality, software/algorithm transparency and standards (including of publication) be improved? And if so, how? • What is the function of the current collaboration models, including public-private partnerships and NHS partnerships, for the development and application of AI-based data analytic tools in healthcare and the medical sciences? What are the implications for the funding sector?

	• How can skills for AI-based data analytics be developed and retained within academia?
14.50 – 15.00	**Closing remarks** Professor Jacqueline Hunter FMedSci
15.00	**Close**

Annex 2: Attendee List

Dr Craig Buckley, Head of Research and Scientific Collaborations, Siemens
Neil Chue Hong, Director, Software Sustainability Institute
Dr Alex Cuenat, Expert in residence, Wellcome Trust
Dr Mark Davies, Chief Medical Officer, IBM Watson Health
Professor Alastair Denniston, Consultant Ophthalmologist, University Hospitals Birmingham NHS Foundation Trust; Honorary Professor, University of Birmingham
Dr Aldo Faisal, Reader in Neurotechnology, Imperial College London
Professor Anthony Gordon, Professor of Anaesthesia and Critical Care, Imperial College London
Dr Keith Grimes, Clinical Innovation Director, Babylon Health
Professor Chris Holmes, Professor in Biostatistics, University of Oxford; Programme Director for Health and Medical Sciences, The Alan Turing Institute (joint appointment with Health Data Research UK)
Martin Hunt, Director for Invention for Innovation Programme, National Institute for Health Research
Professor Jacqueline Hunter CBE FMedSci (Chair), Chief Executive, Benevolent Bio
Dr Pearse Keane, NIHR Clinician Scientist, Moorfields Eye Hospital
Professor Andrew Morris CBE FRSE FMedSci, Director, Health Data Research UK
Dr Declan Mulkeen, Chief of Strategy, Medical Research Council
Dr Claire Newland, Head of Data Science, Medical Research Council
Dr Daniel Ray, Director of Data, NHS Digital
Melissa Ream, Adviser, Kent Surrey Sussex AHSN and AHSN Network AI initiative
Professor Geraint Rees FMedSci, Professor of Cognitive Neurology, University College London
Pamela Spence, Global Health Sciences and Wellness Industry Leader and Life Sciences Industry Leader, Ernst & Young
Dr Adam Steventon, Director of Data Analytics, The Health Foundation
Professor Cathie Sudlow FRSE, Director, Health Data Research UK Scotland
Dr Mark Toal, Deputy Director, Research Systems, Science, Research and Evidence Directorate, Department of Health and Social Care
Professor Mike Trenell, Director, NIHR Innovation Observatory

Secretariat
Dr Ekaterini Blaveri, Programme Manager, Data Science, Medical Research Council
Dr Claire Cope, Policy Manager, Academy of Medical Sciences
Dr Shaun Griffin, Interim Head of Policy, Academy of Medical Sciences
Sophia McCully, Policy Officer, Academy of Medical Sciences
Dr Inesa Thomsen, Acting Head of Systems and Information (Research), Science, Research and Evidence Directorate, Department of Health and Social Care

The **Academy** *of*
Medical Sciences

Academy of Medical Sciences
41 Portland Place
London, W1B 1QH
+44(0)20 3141 3200

info@acmedsci.ac.uk
www.acmedsci.ac.uk

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