EIT Health

McKinsey & Company

Transforming healthcare with AI

The impact on the workforce and organisations

March 2020

EIT Health is supported by the EIT, a body of the European Union

Contents

Foreword

Artificial intelligence (AI) has the potential to transform how care is delivered. It can support improvements in care outcomes, patient experience and access to healthcare services. It can increase productivity and the efficiency of care delivery and allow healthcare systems to provide more and better care to more people. AI can help improve the experience of healthcare practitioners, enabling them to spend more time in direct patient care and reducing burnout. Finally, it can support the faster delivery of care, mainly by accelerating diagnosis time, and help healthcare systems manage population health more proactively, allocating resources to where they can have the largest impact.

The implications of introducing and scaling AI in healthcare have been much debated in recent years. The full potential of AI is still being discussed, but questions have been raised about its potential impact on practitioners and certain specialties, while issues around ethics, use of personal data and AI-related risks are also being debated. At the same time, healthcare investments in AI are increasing, creating or accentuating disparities in the adoption of innovation in healthcare, and raising questions around the role that health systems, public and private players and individual healthcare practitioners can, or should, play in ensuring citizens fully reap the benefits of AI.

This joint report between EIT Health and McKinsey & Company aims to build on the existing literature and thinking on the potential of AI in healthcare, going a step further in helping define the impact of AI on healthcare practitioners, and the implications of introducing and scaling AI for healthcare organisations and healthcare systems, with a particular focus on Europe and EU Member States. It does so by bringing together the McKinsey Global Institute's (MGI) research programme on the future of work with new analyses on the future of work in healthcare, focused on Europe. This is complemented by 62 interviews of public- and private-sector decision makers and thought leaders across Europe, North America and Asia, and an in-depth survey of 175 healthcare professionals, health investors and AI startup founders and other executives, conducted between December 2019 and January 2020.

The report aims to provide not only a comprehensive 'macro' perspective on AI in healthcare, but also ground this view in the reality of the people tasked with making AI happen in healthcare delivery today, listening to their voices, hopes, frustrations and suggestions. While recognising that it is still early days in terms of fully understanding the potential role of AI in healthcare, the report helps define the boundaries between aspiration, reality and hype, providing intriguing insights into how much of the AI in healthcare narrative is a reality and how healthcare professionals, startup executives and investors prioritise and navigate the choppy waters of innovation, in Europe and beyond.

The report is a collaboration between EIT Health and McKinsey & Company:

- EIT Health is a Knowledge and Innovation Community supported by the European Institute of Innovation and Technology (EIT), an EU body created to find solutions to pressing global challenges. EIT is an integral part of the European Union's Framework Programme for Research and Innovation. EIT Health brings together experts from business, research and education to form dynamic cross-border collaborations, helping create an optimal environment for healthcare innovation to flourish.
- The McKinsey Center for Government (MCG) is a global hub for research, collaboration and innovation in government productivity and performance, under the auspices of which this report is being published. Further analysis for this report came from QuantumBlack, McKinsey's advanced analytics firm; and McKinsey's Healthcare Systems and Services, and Pharmaceutical and Medical Products practices. The analyses also drew from research on the impact of automation on jobs by MGI, McKinsey's independent think tank, established in 1990 to develop a deeper understanding of the evolving global economy and cited as the world's leading private-sector think tank in the 2018 Global Go To Think Tank Index Report.

The research was led by Jorge Fernández García, Director of Innovation, EIT Health; Dr. Angela Spatharou, Partner, Healthcare Systems and Services, McKinsey & Company; Jonathan Jenkins, Senior Principal, QuantumBlack; and Solveigh Hieronimus, Partner, McKinsey & Company and co-leader of the MCG.

Steering group guidance was provided by Jan-Philipp Beck, CEO, EIT Health; and from McKinsey & Company, by Dr. Penny Dash, Senior Partner and leader of the Healthcare Systems and Services practice in Europe; Dr. Nicolaus Henke, Senior Partner and Chairman of QuantumBlack; Dr. Chris Llewellyn, Senior Partner and global leader of Digital and AI services, Pharmaceutical and Medical Products practice; and Dr. Jaana Remes, Partner, MGI.

The team was comprised of Maria Fernández Albizuri, EIT Health and Dr. Mareike Herzog, Dr. Franziska Galiè and Will Taylor, McKinsey & Company; Gurneet Singh Dandona, Alok Singh, Shagun Narula and EB Armstrong, MGI; and Paul Mears, Senior Healthcare Advisor, McKinsey & Company.

This report contributes to the goal to help healthcare practitioners, public- and private-sector healthcare decision makers, policy makers, regulators, healthcare investors and innovators better understand the latest thinking on AI in healthcare, its potential impact on practitioners and healthcare systems and, in so doing, prioritise areas of focus in introducing or scaling AI in healthcare. As with all our research, this work is independent and has not been commissioned or sponsored in any way by external parties. While we are grateful for all the input we have received, the report and the views expressed here reflect the outcome of the EIT Health and McKinsey & Company collaboration alone.

Jorge Fernández García
Director of Innovation,
EIT Health

Dr. Angela Spatharou
Partner,
McKinsey & Company

Solveigh Hieronimus
Partner,
McKinsey & Company,
co-leader, MCG

Jan-Philipp Beck
CEO,
EIT Health

Jonathan Jenkins
Senior Principal,
QuantumBlack

Acknowledgements

The authors would like to express their gratitude to those colleagues who gave their time and advice graciously and made a significant contribution to this work, each with a distinct perspective.

We are grateful to the following McKinsey & Company colleagues from around the world, who provided valuable insights into various aspects of this research: Axel Baur, Alex Beauvais, Niklas Berglind, Dr. Mercedes Blasi, Deepesh Chandra, Bo Chen, David Chinn, Alex Davidson, Martin Dewhurst, Grail Dorling, Pia Hardy, Caroline Henricson, Christian Harbo Madsen, James Manyika, Dr. Kristin-Anne Rutter, Yaron Savoray (alum). and Carlos Trascasa.

EIT Health would specifically like to thank the expert members in its partnership who have shared their knowledge in the report.

The report received significant input and support from members of EIT Health, EIT, the European Commission Directorates General (DGs) and the European Medicines Agency (EMA). EIT Health would like to express its thanks for the insightful input provided by the members of the EIT Health network, who are at the forefront of the application of AI in healthcare; in particular, Paul Timmers, Chief Advisor, EIT Health, and Research Associate, University of Oxford, for his extensive feedback on content.

Very special thanks are due to Jonathan Turton, our editor, Rich Nunn, Senior Media Designer, Adam Richardson-Foster, Senior Media Designer and Marie Neuhoff, for her support throughout this process.

Finally, we would like to extend our deep gratitude to all our interviewees and survey respondents, without whose commitment to share their insights and help shape this important topic, this report would not have been possible. Thank you all.

Abbreviations

A&E	Accident and Emergency
AI	Artificial Intelligence
AHA	American Hospital Association
CDS	Clinical Decision Support
CT	Computed Tomography
DG	Directorate General
EC	European Commission
EHR	Electronic Health Record
EMA	European Medicines Agency
EIT	European Institute of Innovation and Technology
EU	European Union
FDA	Food and Drug Administration
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GP	General Practitioner
HMA	Heads of Medicines Agencies
HMO	Health Maintenance Organisation
IT	Information Technology
JRC	Joint Research Centre
M&A	Mergers & Acquisitions
MGI	McKinsey Global Institute
MCG	McKinsey Center for Government
NHS	National Health Service (UK)
NLP	Natural Language Processing
R&D	Research and Development
SaMD	Software as a Medical Device
VC	Venture Capital
WHO	World Health Organization

Executive summary

Healthcare is one of the major success stories of our times. Medical science has improved rapidly, raising life expectancy around the world, but as longevity increases, healthcare systems face growing demand for their services, rising costs and a workforce that is struggling to meet the needs of its patients.

Demand is driven by a combination of unstoppable forces: population ageing, changing patient expectations, a shift in lifestyle choices, and the neverending cycle of innovation being but a few. Of these, the implications from an ageing population stand out. By 2050, one in four people in Europe and North America will be over the age of 65 – this means the health systems will have to deal with more patients with complex needs. Managing such patients is expensive and requires systems to shift from an episodic care-based philosophy to one that is much more proactive and focused on long-term care management.

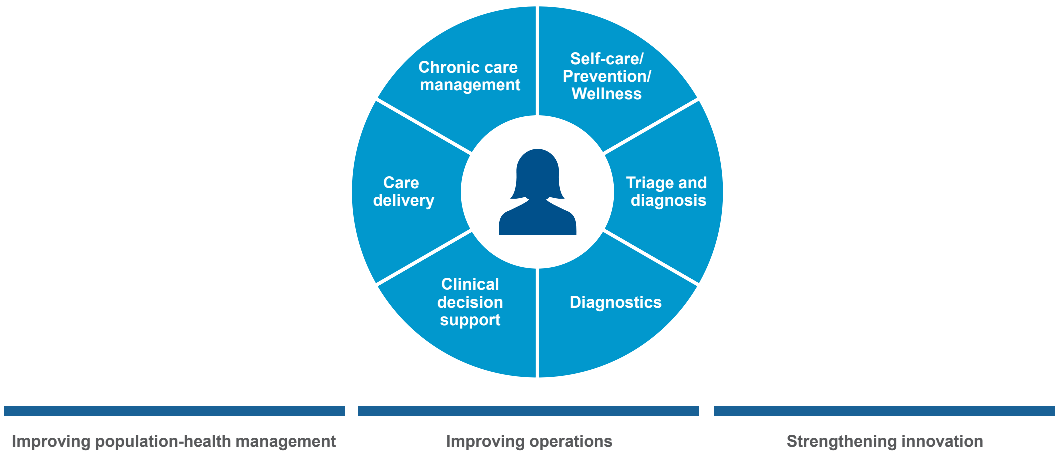
Healthcare spending is simply not keeping up. Without major structural and transformational change, healthcare systems will struggle to remain sustainable. Health systems also need a larger workforce, but although the global economy could create 40 million new health-sector jobs by 2030, there is still a projected shortfall of 9.9 million physicians, nurses and midwives globally over the same period, according to the World Health Organization.[1] We need not only to attract, train and retain more healthcare professionals, but we also need to ensure their time is used where it adds most value – caring for patients.

Building on automation, artificial intelligence (AI) has the potential to revolutionise healthcare and help address some of the challenges set out above. There are several definitions of AI, but this report draws from a concise and helpful definition used by the European Parliament, "AI is the capability of a computer program to perform tasks or reasoning processes that we usually associate with intelligence in a human being."[2] AI can lead to better care outcomes and improve the productivity and efficiency of care delivery. It can also improve the day-to-day life of healthcare practitioners, letting them spend more time looking after patients and in so doing, raise staff morale and improve retention. It can even get life-saving treatments to market faster. At the same time, questions have been raised about the impact AI could have on patients, practitioners and health systems, and about its potential risks; there are ethical debates around how AI and the data that underpins it should be used.

This EIT Health and McKinsey & Company report aims to contribute to the debate surrounding AI in healthcare, specifically looking at how practitioners and organisations will be affected. It aims to cast light on the priorities and trade-offs for different parts of the healthcare system in Europe and beyond. The report draws on proprietary research and analyses undertaken by EIT Health and McKinsey & Company. This includes work by the McKinsey Global Institute (MGI) on the future of work in the era of automation and AI,[3] analysing the impact on healthcare practitioners in Europe; a series of one-to-one interviews with 62 healthcare and other leaders with experience in AI and digital health, and an online survey of 175 healthcare professionals, healthcare investors and AI startup founders and other executives. AI in healthcare being a fast-moving field, the report provides a unique vantage point from the frontline of healthcare delivery and innovation today and the latest view from a wide array of stakeholders on AI's potential, the real state of play today, and what is holding us back.

Last, to highlight where AI is already having an impact in healthcare, the report also looks at detailed examples of existing AI solutions in six core areas where AI has a direct impact on the patient and three areas of the healthcare value chain that could benefit from further scaling of AI (Exhibit 1).

Exhibit 1 – Areas of impact for AI in healthcare



In doing so, the report provides a unique contribution to the debate on the impact of AI in healthcare in four ways: 1) decision makers' view of the state-of-play in this fast-moving field, where developments from just 12 months ago are considered "old news"; 2) a robust new methodology to evaluate the impact of automation and AI on specific skills and activities in healthcare in Europe; 3) a substantial review of use cases that illustrate the potential that AI is already on track to deliver; 4) a unique view from the frontline, hearing from healthcare professionals, investors and startup executives on where the real potential, opportunities and barriers lie.

The report does not attempt to cover all facets of this complex issue, in particular the ethics of AI or managing AI-related risks, but does reflect the efforts on this important topic led by EIT Health and other EU institutions. Equally, while it acknowledges the potential disruptive impact of personalisation on both healthcare delivery and healthcare innovation in the future (e.g., in R&D), the report focuses primarily on the impact of AI on healthcare professionals and organisations, based on the use cases available today.

Last, AI is in its infancy and its long-term implications are uncertain. Future applications of AI in healthcare delivery, in the approach to innovation and in how each of us thinks about our health, may be transformative. We can imagine a future in which population-level data from wearables and implants change our understanding of human biology and of how medicines work, enabling personalised and real-time treatment for all. This report focuses on what is real today and what will enable innovation and adoption tomorrow, rather than exploring the long-term future of personalised medicine. Faced with the uncertainty of the eventual scope of application of emerging technologies, some short-term opportunities are clear, as are steps that will enable health providers and systems to bring benefits from innovation in AI to the populations they serve more rapidly.

AI in healthcare today

More data, better data, more connected data

What do we mean by AI in healthcare? In this report we include applications that affect care delivery, including both how existing tasks are *performed* and how they are *disrupted* by changing healthcare needs or the processes required to address them. We also include applications that enhance and improve healthcare delivery, from day-to-day operational improvement in healthcare organisations to population-health management and the world of healthcare innovation. It's a broad definition that covers natural language processing (NLP), image analysis and predictive analytics based on machine learning. As such, it illustrates a spectrum of AI solutions, where encoding clinical guidelines or existing clinical protocols through a rules-based system often provides a starting point, which then can be *augmented* by models that learn from data.

AI is now top-of-mind for healthcare decision makers, governments, investors and innovators, and the EU itself. An increasing number of governments have set out aspirations for AI in healthcare, in countries as diverse as Finland, Germany, the UK, Israel, China, and the United States and many are investing heavily in AI-related research. The private sector continues to play a significant role, with venture capital (VC) funding for the top 50 firms in healthcare-related AI reaching $8.5 billion, and big tech firms, startups, pharmaceutical and medical-devices firms and health insurers, all engaging with the nascent AI healthcare ecosystem.

Geographically, the dynamics of AI growth are shifting. The US still dominates the list of firms with highest VC funding in healthcare AI to date, and has the most completed AI-related healthcare research studies and trials. But the fastest growth is emerging in Asia, especially China, where leading domestic conglomerates and tech players have consumer-focused healthcare AI offerings and Ping An's Good Doctor, the leading online health-management platform already lists more than 300 million users. Europe, meanwhile, benefits from the vast troves of health data collected in national health systems and has significant strengths in terms of the number of research studies, established clusters of innovation and pan-European collaborations, a pan-European approach to core aspects of AI (e.g., ethics, privacy, "trustworthy AI") and an emerging strategy on how to ensure the "EU way" for AI helps deliver the advantages for AI to its population. Yet, at the same time, valuable datasets are not linked, with critical data-governance, access and security issues still needing to be clarified, delaying further adoption. European investment and research in AI are strong when grouped together but fragmented at the country or regional level. Overall, there is a significant opportunity for EU health systems, but AI's full potential remains to be explored and the impact on the ground remains limited. A surprising 44 percent of the healthcare professionals we surveyed – and these were professionals chosen based on their engagement with healthcare innovation – had never been involved in the development or deployment of an AI solution in their organisation.

Growing number of use cases

While there are widespread questions on what is real in AI in healthcare today, this report looked at 23 applications in use today and provides case studies of 14 applications already in use. These illustrate the full range of areas where AI can have impact: from apps that help patients manage their care themselves, to online symptom checkers and e-triage AI tools, to virtual agents that can carry out tasks in hospitals, to a bionic pancreas to help patients with diabetes. Some help improve healthcare operations by optimising scheduling or bed management, others improve population health by predicting the risk of hospital admission or helping detect specific cancers early enabling intervention that can lead to better survival rates; and others even help optimise healthcare R&D and pharmacovigilance. The scale of many solutions remains small, but their increasing adoption at the health-system level indicates the pace of change is accelerating. In most cases, the question is less whether AI can have impact, and more how to increase the potential for impact and, crucially, how to do so while improving the user experience and increasing user adoption.

Three phases of scaling AI in healthcare

We are in the very early days of our understanding of AI and its full potential in healthcare, in particular with regards to the impact of AI on personalisation. Nevertheless, interviewees and survey respondents conclude that over time we could expect to see three phases of scaling AI in healthcare, looking at solutions already available and the pipeline of ideas.

First, solutions are likely to address the low-hanging fruit of routine, repetitive and largely administrative tasks, which absorb significant time of doctors and nurses, optimising healthcare operations and increasing adoption. In this first phase, we would also include AI applications based on imaging, which are already in use in specialties such as radiology, pathology and ophthalmology.

In the second phase, we expect more AI solutions that support the shift from hospital-based to home-based care, such as remote monitoring, AI-powered alerting systems or virtual assistants, as patients take increasing ownership of their care. This phase could also include a broader use of NLP solutions in the hospital and home setting, and more use of AI in a broader number of specialties, such as oncology, cardiology or neurology, where advances are already being made. This will require AI to be embedded more extensively in clinical workflows, through the intensive engagement of professional bodies and providers. It will also require well designed and integrated solutions to use existing technologies effectively in new contexts. This scaling up of AI deployment would be fuelled by a combination of technological advancements (e.g., in deep learning, NLP, connectivity etc.) and cultural change and capability building within organisations.

In the third phase, we would expect to see more AI solutions in clinical practice based on evidence from clinical trials, with increasing focus on improved and scaled clinical decision-support (CDS) tools in a sector that has learned lessons from earlier attempts to introduce such tools into clinical practice and has adapted its mindset, culture and skills. Ultimately respondents would expect to see AI as an integral part of the healthcare value chain, from how we learn, to how we investigate and deliver care, to how we improve the health of populations. Important preconditions for AI to deliver its full potential in European healthcare will be the integration of broader datasets across organisations, strong governance to continuously improve data quality, and greater confidence from organisations, practitioners and patients in both the AI solutions and the ability to manage the related risks.

How will AI change the healthcare workforce?

The MGI has studied how automation and AI are likely to affect the future of work. It concludes that automation will affect most jobs across sectors, but the degree varies significantly, and healthcare is one of the sectors with the lowest overall potential for automation – only 35 percent of time spent is potentially automatable and this varies by type of occupation. The potential for automation is different to the likelihood of adoption.

The analysis uses a midpoint scenario, which estimates that 15 percent of current work hours in healthcare are expected to be automated. Exhibit 2 shows the share of hours currently worked that could be freed up by automation by 2030 for a wide range of healthcare occupations in selected European countries. This does not reflect the potential for further disruption through other factors, such as personalisation, that may revolutionise healthcare by focusing on a "segment of one".

Exhibit 2 – Share of hours worked that could be freed up by automation by 2030 in selected European countries in the midpoint adoption scenario

SOURCE: McKinsey Global Institute. Selected European countries: France, Germany, Hungary, Italy, Portugal, Sweden, UK

How will automation and AI affect the number of jobs in healthcare? The reality is that the European healthcare sector faces a significant workforce gap that is only expected to widen. The World Health Organization estimates overall demand for healthcare workers to rise to 18.2 million across Europe by 2030 and, as an example, states that the current supply of 8.6 million nurses, midwives and healthcare assistants across Europe will not meet current or projected future need.[4] The MGI analysis of the demand for specific types of healthcare activities suggests significant increases in the need for specific professionals, such as licenced practical and vocational nurses, home health aides and others, who are core to the day-to-day delivery of care to European citizens. It highlights that automation could, in fact, alleviate workforce shortages in healthcare, as demand for occupations is set to increase. For example, a 39 percent increase in all nursing occupations is expected by 2030, even allowing for the fact that approximately 10 percent of nursing activities could be freed up by automation.

The impact on the workforce will be much more than jobs lost or gained – the work itself will change. At the heart of any change is the opportunity to refocus on and improve patient care. AI can help remove or minimise time spent on routine, administrative tasks, which can take up to 70 percent of a healthcare practitioner's time. A recurring theme in interviews was that this type of AI role would not just be uncontroversial but would top of most people's wish list and would speed up adoption. AI can go further. It can augment a range of clinical activities and help healthcare practitioners access information that can lead to better patient outcomes and higher quality of care. It can improve the speed and accuracy in use of diagnostics, give practitioners faster and easier access to more knowledge, and enable remote monitoring and patient empowerment through self-care. This will all require bringing new activities and skills into the sector, and it will change healthcare education – shifting the focus away from memorising facts and moving to innovation, entrepreneurship, continuous learning and multidisciplinary working. The biggest leap of all will be the need to embed digital and AI skills within healthcare organisations – not only for physicians to change the nature of consultations, but for all frontline staff to integrate AI into their workflow. This is a significant change in organisational culture and capabilities, and one that will necessitate parallel action from practitioners, organisations and systems all working together.

The final effect on the workforce will be the introduction of new professionals. Multiple roles will emerge at the intersection of medical and data-science expertise. For example, medical leaders will have to shape clinically meaningful and explainable AI that contains the insights and information to support decisions and deepen healthcare professionals' understanding of their patients. Clinical engagement will also be required in product leadership, in order to determine the contribution of AI-based decision-support systems within broader clinical protocols. Designers specialising in human-machine interactions on clinical decision making will help create new workflows that integrate AI. Data architects will be critical in defining how to record, store and structure clinical data so that algorithms can deliver insights, while leaders in data governance and data ethics will also play vital roles. In other data-rich areas, such as genomics, new professionals would include 'hybrid' roles, such as clinical bioinformaticians, specialists in genomic medicine and genomic counsellors. Institutions will have to develop teams with expertise in partnering with, procuring and implementing AI products that have been developed or pioneered by other institutions. Orchestrating the introduction of new specialisations coming from data science and engineering within healthcare delivery will become a critical skill in itself. There will be an urgent need for health systems to attract and retain such scarce and valuable talent, for example, by developing flexible and exciting career paths and clear routes to leadership roles.

What needs to change to encourage the introduction and scaling of AI in healthcare?

The strides made in the field of AI in healthcare have been momentous. Moving to a world in which AI can deliver significant, consistent and global improvements in care will be more challenging.

Of course, AI is not a panacea for healthcare systems, and it comes with strings attached. The analyses in this report and the latest views from stakeholders and frontline staff reveal a set of themes that all players in the healthcare ecosystem will need to address:

1) **Working together to deliver quality AI in healthcare.** Quality came up in our interviews time and again, especially issues around the poor choice of use cases, AI design and ease of use, the quality and performance of algorithms, and the robustness and completeness of underlying data. The lack of multidisciplinary development and early involvement of healthcare staff, and limited iteration by joint AI and healthcare teams were cited as major barriers to addressing quality issues early on and adopting solutions at scale. The survey revealed this is driven by both sides: only 14 percent of startup executives felt that the input of healthcare professionals was critical in the early design phase; while the healthcare professionals saw the private sector's role in areas such as aggregating or analysing data, providing a secure space for data lakes, or helping upskill healthcare staff as minimal or nonexistent.

   One problem AI solutions face is building the clinical evidence of quality and effectiveness. While startups are interested in scaling solutions fast, healthcare practitioners must have proof that any new idea will "do no harm" before it comes anywhere near a patient. Practitioners also want to understand how it works, where the underlying data come from and what biases might be embedded in the algorithms, so are interested in going past the concept of AI as a "black box" to understand what underpins it. Transparency and collaboration between innovators and practitioners will be key in scaling AI in European healthcare.

   User-centric design is another essential component of a quality product. Design should have the end user at its heart. This means AI should fit seamlessly with the workflow of decision makers and by being used, it will be improved. Many interviewees agreed that if AI design delivers value to end users, those users are more likely to pay attention to the quality of data they contribute, thereby improving the AI and creating a virtuous circle. Finally, AI research needs to heavily emphasise explainable, causal and ethical AI, which could be a key driver of adoption.

2) **Rethinking education and skills.** We have already touched on the importance of digital skills – these are not part of most practitioners' arsenal today. AI in healthcare will require leaders well-versed in both biomedical and data science. There have been recent moves to train students in the science where medicine, biology and informatics meet through joint degrees, though this is less prevalent in Europe. More broadly, skills such as basic digital literacy, the fundamentals of genomics, AI and machine learning need to become mainstream for all practitioners, supplemented by critical-thinking skills and the development of a continuous-learning mindset. Alongside upgrading clinical training, healthcare systems need to think about the existing workforce and provide ongoing learning, while practitioners need the time and incentive to continue learning.

3) **Strengthening data quality, governance, security and interoperability.** Both interviewees and survey respondents emphasised that data access, quality and availability were potential roadblocks. The data challenge breaks down into digitising health to generate the data, collecting the data, and setting up the governance around data management. MGI analyses show that healthcare is among the least digitised sectors in Europe, lagging behind in digital business processes, digital spend per worker, digital capital deepening and the digitisation of work and processes. It is critical to get the basic digitisation of systems and data in place before embarking on AI deployments – not least because the frustrations staff have with basic digitisation could spill over to the wider introduction of AI.

   In addition, as more healthcare is delivered using new digital technologies, public concerns about how healthcare data are used have grown. Healthcare organisations should have robust and compliant data-sharing policies that support the improvements in care that AI offers while providing the right safeguards in a cost-efficient way. Physicians we interviewed emphasised that, given the volume of data required for AI, a poorly thought out process of anonymisation could be a major cost, making diagnostic algorithms prohibitively expensive.

   Interviewees also emphasised, however, that both healthcare as a sector and Europe as a region have significant advantages. First, both healthcare organisations and health systems are used to dealing with sensitive data through well-structured data governance and risk-management processes. In some cases, healthcare could lead the way for other sectors seeking to put such measures in place. Secondly, Europe benefits from national health systems with extensive datasets, often shared within integrated care systems, offering a set of systems and processes to build on that could also serve as examples to other regions.

   The final data challenge is getting datasets to talk to each other. Policy makers, funding bodies and nonprofit organisations need to support efforts to sufficiently anonymise and link data and, where sensible, to build databases that can be accessed by stakeholders with the appropriate safeguards. In order to make the most of the rich data that is available, healthcare systems need an interconnected data infrastructure. This is an area where Europe, as mentioned, could have a significant advantage, in terms of its extensive national datasets and its networks of innovations clusters or hubs and pan-European collaborations with academia and industry, providing a prototype for the creation of centres of excellence for AI in healthcare.

4) **Managing change.** Managing change while introducing AI is no different to managing change in complex institutions more broadly, but for healthcare, clinical leadership is key, as is being open to identifying the right use cases that support rather than antagonise practitioners and truly augment rather than substitute their ability to deliver the best possible care to their patients. This could include prioritising solutions that focus on reducing the time people spend on routine administrative tasks, rather than those that seek to act as virtual assistants who interact directly with patients, or CDS tools that facilitate activities physicians see as core to their professional role, i.e., the clinical diagnosis.

   Healthcare providers also need to be transparent about the benefits and risks of AI and work with staff to harness the collective energy of their teams and capitalise on the opportunities AI can bring. It may not be a rapid process, but it soon becomes increasingly rewarding for practitioners and is an important part of the overall adoption process.

5) **Investing in new talent and creating new roles.** Healthcare organisations need to consider how they will develop and recruit the new roles that will be critical to the successful introduction and adoption of AI, such as data scientists or data engineers. Demand for such skills is heating up across industries and the competition for talent will be fierce, but many young data professionals find a true vocation in healthcare and its mission and are excited about the potential of digital health and AI. Developing flexible, agile models to attract and retain such talent will be a key part of these organisations' people strategy.

6) **Working at scale.** The lessons from public- and private-sector actors aiming to develop AI in healthcare to date suggest that scale matters – largely due to the resources needed to develop robust AI solutions or make them cost-efficient. Not every hospital will be able to afford to attract new AI talent, or have access to enough data to make algorithms meaningful. Smaller organisations can benefit from working in innovation clusters that bring together AI, digital health, biomedical research, translational research or other relevant fields. Larger organisations can develop into centres of excellence that pave the way for regional and public-private collaborations to scale AI in European healthcare.

7) **Regulation, policy making and liability, and managing risk.** Responsibility for AI solutions – both clinical and technical – is split today between healthcare organisations and their staff. Interviewees emphasised the importance of clarifying whether AI will be regulated as a *product* or as a *tool* that supports decision making, and of introducing a consistent regulatory approach for AI similar to that provided by the European Medicines Agency (EMA) on medicines or by national authorities on medical devices. Another issue to be clarified across Europe is the extent to which patients' access to some AI tools needs to be regulated or restricted to prescription. The issue of liability and risk management is a particular challenge. Patient safety is paramount, but healthcare providers also have to think about the professional accountability of their clinicians, as well the protection of their organisations from reputational, legal or financial risk. Healthcare lawyers interviewed in this report were clear that accountability ultimately rests with the clinician under current laws. Innovators are also proactively addressing related risks. Many are putting new processes in place and ensuring a "compliance by design" approach is at the core of product development.

8) **Funding.** The reimbursement of medicines and medical devices across Europe is complicated and is even less clear when it comes to AI solutions. The responsibility for decisions on the reimbursement of a medicine or device rests with national and local payor organisations depending on the country, and this decision usually covers what will be reimbursed and at what price. Clear criteria for the potential reimbursement of AI applications will be crucial for its adoption at scale, alongside creative funding models that ensure the benefits are shared across organisations.

What this could mean for healthcare organisations

European healthcare providers need to assess what their distinctive role or contribution can be in introducing or scaling AI in healthcare. They need to take stock of their capabilities, level of digitisation, availability and quality of data, resources and skills and then define their level of ambition for AI as it fits with their strategic goals. They should also define the enablers they need to put in place. These could include creating an AI ecosystem through partnerships to codevelop the right solutions for their population; codeveloping a compelling narrative on AI with patients and practitioners; defining and developing the right use cases jointly with end users; defining and addressing skill gaps in digital literacy for their staff; refining their value proposition for AI talent; addressing data-quality, access, governance and interoperability issues; and shaping a culture of entrepreneurship. All these themes were echoed by the healthcare professionals in the survey, who listed the top three things healthcare organisations could do, as: bringing together multidisciplinary teams with the right skills, improving the quality and robustness of data and identifying the right use cases.

What this could mean for health systems

European health systems can play a more fundamental role in catalysing the introduction and scale-up of AI. Key actions they could take include:

- Develop a regional or national AI strategy for healthcare, defining a medium- and longer-term vision and goals, specific initiatives, resources and performance indicators. Define use cases to support through targeted funding and incentives to enable scaling of AI solutions across the system; ensure these deliver against both clinical and operational outcomes.
- Set standards for digitisation, data quality and completeness, data access, governance, risk management, security and sharing, and system interoperability; incentivise adherence to standards through a combination of performance and financial incentives.
- Redesign workforce planning and clinical-education processes to address the needs of both future healthcare and AI-focused professionals; and invest upfront in upskilling frontline staff and designing lifelong-learning programmes through continuing professional development and degrees or diplomas for healthcare professionals.
- Provide incentives and guidance for healthcare organisations to collaborate in centres of excellence/clusters of innovation at the regional or national level.
- Address AI regulation, liability and funding issues, creating the right environment for appropriate, safe and effective AI solutions to be adopted but minimising the risk to practitioners.
- Ensure this is reflected in funding and reimbursement mechanisms for innovation in healthcare – the number one priority for survey respondents from health systems, alongside simplifying data-governance and data-sharing processes.

What this could mean for Europe

Our early analyses of levels of VC investment and AI-related clinical trials, as well as the number of companies and M&A deals in digital health and AI, show this is a fast-moving market where Europe, as a group of countries, plays a growing role internationally alongside the US and China. The scale needed to effectively roll out AI in healthcare may place a toll on smaller EU Member States but could be easily reached through collaborations across Europe. Interviewees and survey respondents were clear on the potential impact of the EU in helping deliver the promise of AI, faster and at a greater scale for Europe's population. They highlighted the following specific strands of work that could be considered:

- **Consolidating funding against strategic AI priorities.** Defining a few concrete priorities for AI in European healthcare and consolidating funding to support them strategically could provide a much-needed stimulus to fast-track promising developments in AI for healthcare.
- **Creating a level playing field across Europe.** Common standards on data, regulation, access, privacy or interoperability, and shared requirements on data exchange, would enable innovators to scale AI solutions cost-effectively, while focusing their energies on entrepreneurship. It would also enable patients, practitioners and health systems to develop the same confidence in new AI solutions that they have now in new medicines and medical devices that have undergone European approval.
- **Clarifying key aspects of regulation around product approval, accountability, governance and litigation.** The EU can help remove barriers to adopting AI at the national and local level, providing clarity on approval processes across Europe, potentially creating regulatory centres of excellence for AI regulation, and setting expectations on accountability and liability.
- **Encouraging and supporting the creation of centres of excellence for AI in healthcare.** This can help consolidate scarce AI talent in high-profile and agile networks that can move quickly from design to implementation and spearhead the introduction of new capabilities in national health systems. These centres of excellence would also lead the way in adopting and implementing technologies and approaches developed elsewhere. Indeed, their expertise in applying approaches to improve care will be as critical as their expertise in developing those approaches in the first place. They can also ensure that talent creation and continuous learning are prioritised and enhanced at the European level.
- **Playing an active role in AI.** This will ensure that the thoughtful European approach to ethics, health data and patient confidentiality shapes the AI sector, in the same way that GDPR has for privacy protection.

Overall, this report highlights the excitement of Europe-wide stakeholders, healthcare professionals, investors and innovators about the impact of AI on European healthcare, and about the thoughtful approach taken across Europe to ensure this delivers ethical and trustworthy AI. It also highlights that this is only the latest view across Europe and internationally – speed is of the essence if Europe is to continue playing a leading role in shaping the AI of the future to deliver its true potential to European health systems and their patients.

Chapter 1

Introduction

This report addresses both the state-of-play in healthcare AI today, and the implications for the sector from the frontline staff right up to the regulatory bodies that oversee it. In this chapter we consider the potential that AI has to transform healthcare – a sector that despite making huge medical advances, is grappling with challenges around funding and staffing levels. We also discuss the precise scope of the report in more detail and explain the methodology used to develop its findings.

1.1 AI and its potential to transform healthcare

Healthcare is one of the major success stories of our times. Advances in medicine, supported by progress in public health, research, innovation and technology, have significantly reduced mortality and morbidity.

Over the past century, average life expectancy at birth has risen from less than 50 years to 78.9 years for the USA and to 80.9 years on average for EU Member States, with some reaching 83 years.[5] As the global population ages and longevity increases, healthcare systems around the world face growing demand for services, rising costs of delivery and innovation, and significant challenges in building the workforce required to deliver care. Demand is driven by a combination of unstoppable forces, including population ageing, ever-greater patient expectations, new lifestyle choices and the neverending cycle of innovation. Of all of these, the implications of an ageing population are the most stark.

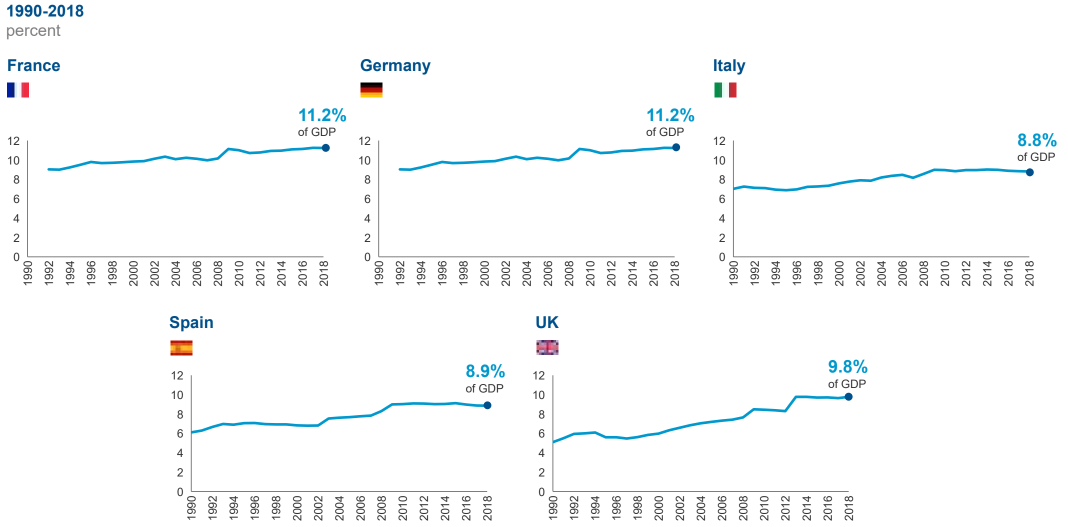
As most countries aim to increase their population's access to healthcare, they are experiencing growth in both the number and proportion of older people in their population. By 2050, 1 in 6 people will be over the age of 65 – in Europe and North America, this will be 1 in 4. This demographic shift, combined with rapid urbanisation, modernisation, globalisation and accompanying changes in risk factors and lifestyles, means chronic conditions will be more common, and an increasingly comorbid population's demand for healthcare will increase.[6]

In 2014, people over 60 accounted for 23 percent of the total global disease burden in terms of disability-adjusted life years, with the highest burden in high-income regions. Many people over 60 live with two or more long-term conditions (multimorbidity), with cardiovascular disease (30%), malignant neoplasms (15%), chronic respiratory disease (9.5%), musculoskeletal disease (7.5%) and neurological and mental disorders (6.6%) as the leading contributors to their disease burden.[7]

Managing patients with complex needs is typically more expensive for health systems that are already stretched. It also adds complexity to information flows, as large volumes of healthcare data no longer sit primarily in hospital. It requires healthcare systems to move their focus from episodic care based around hospital admissions to long-term proactive management of chronic care, often in the community or at home. It also requires a different set of skills and a strong culture of collaboration between physicians across specialties and between physicians and other healthcare practitioners.

In this context, financial sustainability is a core challenge for European healthcare systems. In 2018, healthcare expenditure in France, Germany, Italy, Spain and the UK ranged between 8.8 percent and 11.2 percent of gross domestic product (GDP) and is expected to continue rising (Exhibit 1.1). As Professor Michael Porter highlights, healthcare spending as a share of GDP has been growing since 1990, outpacing average wage growth and the growth of GDP itself.[8]

Exhibit 1.1 – Healthcare expenditure as a share of GDP



SOURCE: OECD Statistics Health expenditure and financing

While healthcare costs have continued to rise, public healthcare budgets in Europe have typically grown in line with the economy and have therefore been subjected to several years of slow or negative growth following the economic crisis of 2008. EU-wide health spending per capita grew in 2009-2013 in real terms (adjusted for inflation) at around 0.6 percent, but ten countries saw health expenditure fall in real terms over that period. Since 2013, budgets have started recovering in most EU countries, and average health spending per capita in 2013-2017 grew at 1.9 percent, but growth has still remained slow in several countries.[9] Without major structural and transformational change, healthcare systems will struggle to contain costs or find the funding increases needed to address growing demand, whilst maintaining or improving standards of care, access and patient experience.

Staff shortages and skill gaps are also limiting healthcare systems' ability to cater to this increasing demand. Although the global economy is projected to create 40 million new health-sector jobs by 2030, mostly in middle- and high-income countries, there will still be a projected shortfall of 9.9 million physicians, nurses and midwives globally over the same period, according to the World Health Organization (WHO). In Europe, even though the number of physicians and nurses has risen by 10 percent over the past ten years, demand still outstrips supply due to the ageing population. There are also significant disparities between European countries, with some having five times as many doctors or nine times as many nurses than others. Physicians in Europe are also getting older – nearly 1 in 3 are already over 55. To maintain the same numbers of physicians in the future that we have today would require a significant increase in the number of medical graduates and would still not fully address the additional demand we expect to see in healthcare.[10] Health systems are already struggling to meet rising demand, with increased waiting times and staff shortages across medical specialties and nursing in many public healthcare systems across Europe.

Artificial intelligence (AI) has the potential to transform how care is delivered and to help meet some of the challenges set out above. Using the European Parliament's definition: "AI is the capability of a computer program to perform tasks or reasoning processes that we usually associate with intelligence in a human being."[11]

AI in healthcare can support better care outcomes, patient experience and access to healthcare services, while improving the productivity and efficiency of care delivery. It can enable healthcare systems to provide more capacity to deliver better care to more people. AI can help improve the day-to-day life of practitioners, letting them spend more time looking after patients, reducing burnout and improving staff retention. Finally, it can support the faster delivery of life-saving treatments through its application in research & development (R&D) and help healthcare systems proactively manage population health by allocating resources to where they can have the biggest impact.

The potential impact that AI can bring to healthcare is increasingly being recognised by many healthcare organisations, researchers and professional organisations:

> *Artificial intelligence and its first and second cousins, machine learning and robotic process automation, will fundamentally change how almost everyone working in hospitals and health systems will do their jobs in the future.*
>
> **American Hospital Association, 2019**[12]

> *Using AI-based technologies, automated image interpretation in radiology and pathology will lead to faster diagnosis, while speech recognition has the potential to free up more staff time to deliver care. AI will transform patient-generated data into clinically useful information, and empower patients to manage their own health, or seek appropriate health support.*
>
> **Topol Review, 2019**[13]

> *Healthcare as a sector, with all the longitudinal data it holds on patients across their lifetimes, is positioned to take advantage of what data science and AI have to offer. From diagnostics, interpretation of lab tests and scheduling appointments, to personalising care, finding cures to conditions, and creating new and innovative solutions to long-standing problems – the opportunities are endless.*
>
> **World Innovation Summit for Health (WISH), 2018**[14]

The positive disruptive impact that AI can have in healthcare has been discussed widely but, while its full potential is still being defined, questions have already been raised about the impact it could have on practitioners and some specialties (e.g., radiology, pathology), while issues around ethics and the use of personal data in AI solutions are also being discussed by public bodies, such as the European Commission (EC).

Nevertheless, while these debates continue, investment in AI in healthcare is increasing at pace across the world, particularly in North America, Europe and Asia. This risks creating or accentuating disparities in the use of innovation in healthcare and raises questions around the role that health systems and healthcare providers can play in ensuring populations reap the full benefits of AI.

1.2 The focus and scope of this report

There has been a host of recent reports on AI in healthcare. Some attempt to define its impact on healthcare and a few are starting to address its impact on practitioners, in particular the 2019 UK National Health Service's (NHS) *Topol Review* and the American Hospital Association's (AHA) recent work on AI and the healthcare workforce.

The Topol Review focuses more broadly on digital healthcare technologies (defined as genomic, digital medicine, AI and robotics), as the new means of addressing the significant healthcare challenges of the 21st century. It acknowledges that within twenty years, 90 percent of all jobs in the English NHS will require some digital skills and that the UK has the potential to become a world leader in digital healthcare technologies. The report concludes that these will not replace healthcare practitioners but enhance ("augment") their role, giving them more time to care for patients. It provides an overview of key digital healthcare technologies and their high-level impact on healthcare, in order to start defining the organisational development needs for the NHS, such as agile working and cultural change. Topol highlights the need for tailored education and training for NHS professionals and for a structured leadership development approach.

The AHA work focuses on the seven core ways that AI will reshape the healthcare workforce in hospitals, assuming 40 percent of tasks performed by nonclinical staff and 33 percent of tasks performed by clinical staff can be performed by AI. It highlights improving productivity, efficiency and overall performance, expanding job responsibilities, with practitioners operating at the "top of their licence", and creating the need to upskill and retrain staff. The report describes new roles that will support the development of AI, including data scientists, data engineers, data entry and data-governance experts, AI engineers and chief AI officers. It also emphasises the new digital skills that the AI-enabled healthcare practitioners of the future will need. Finally, it highlights AI use cases for health systems across administrative, financial, operational and clinical delivery tasks, and sets out steps to overcome challenges to AI adoption. This work, with its hospital focus, provides a set of practical recommendations for hospital executives seeking to introduce or scale AI but does not provide a broader perspective across the wider healthcare system.

This EIT Health and McKinsey report aims to complement the debate surrounding AI in healthcare, specifically looking at how healthcare practitioners and organisations will be affected, and the role of different elements of the healthcare system in helping introduce or scale AI. It focuses on the impact of AI on the future of the healthcare workforce, and on defining the new organisational models and skillsets that practitioners will need. It does so by moving from theory to practice, providing an honest assessment from those people on the front line who are already implementing these changes. It aims to contribute to the emerging debate on this exciting topic and help cast light on the priorities and trade-offs for different parts of the healthcare system in Europe and beyond.

Last, although the report focuses on issues where there is a gap in the understanding of AI in healthcare, it does not attempt to cover all facets of this complex issue, in particular the ethics of AI. As the possibility of AI-augmented healthcare is becoming more concrete, questions around the responsible and ethical use of healthcare data and AI are coming to the fore across Europe. In April 2019, the EC published its *Ethics guidelines for trustworthy AI*, stating that trustworthy AI should be lawful, ethical and robust, and including a list of key requirements for AI to be considered trustworthy.[15]

Recent work by EIT Health also highlights the biggest concerns among practitioners, decision makers and patients, which are related to data privacy and governance, technical robustness and safety, and human agency and oversight. Another area of concern cited relates to data gaps and biases that propagate societal inequalities, and how AI relates to notions of fairness and a lack of discrimination.[16] This work does not repeat the key themes covered in these reports, but addresses ethics issues in Chapter 4, where we consider the relevant barriers and enablers for the successful adoption of AI.

1.3 Approach and methodology

The content of this report draws on proprietary research and analyses undertaken by EIT Health and McKinsey & Company. More detail can be found in the appendices of this report. The report also builds on existing literature on AI, automation and the future of work.

1.3.1 MGI analyses on the impact of automation and AI on healthcare

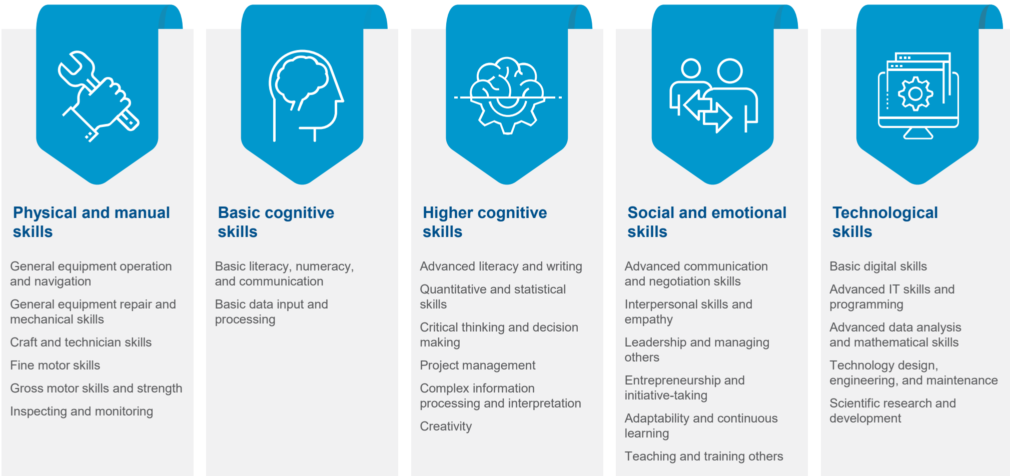
Over the past three years, McKinsey's independent think-tank, the McKinsey Global Institute, (MGI) has launched a programme of research to help shed light on the future of work in the era of automation and AI.[17] More recently, within the context of this report, the McKinsey team has tailored this analysis to look specifically at the impact on healthcare in Europe.

The MGI methodology starts from the core principle that automation and AI do not typically affect entire occupations, but rather specific activities and the skills involved within them. Some professions rely more than others on skills that lend themselves to displacement by automation or AI, but most include some skills that can be displaced and others that cannot. The focus of the analysis is therefore on specific activities carried out by the healthcare workforce, rather than on specific occupations, or clinical specialties.

MGI analyses suggest that although automation has the potential to reduce demand for specific activities and roles, the overall demand for the workforce could still increase as economies grow. Rising incomes and consumption, increasing healthcare needs for aging societies, investment in infrastructure and energy, and other trends will all contribute to this growing demand.

This does not mean, though, that there will not be any changes in the type of work, associated activities and the necessary skills required. The MGI defines 25 skills across five categories: physical and manual, cognitive, higher cognitive, social and emotional and technological (Exhibit 1.2). The MGI model used in this work highlights where demand for specific skills in healthcare will increase or decrease, the implications for different roles in the workforce, the key shifts by 2030 (in terms of time spent on specific activities), and the implications for Europe. It achieves this by focusing on seven European health systems that provide a representative mix in terms of geography, type of health system, level of maturity and level of healthcare spend and resourcing.[18]

Exhibit 1.2 – The MGI defines 25 skills across five categories



SOURCE: McKinsey Global Institute

1.3.2 Expert interviews and survey

Between October 2019 and January 2020, we conducted a series of one-to-one interviews with 62 healthcare and other leaders with experience in AI and digital health. The interviewees were drawn from public and private healthcare systems and providers across Europe, North America, Asia and the Middle East, leading academic medical centres, health insurers, healthcare investors and startups, the pharmaceutical and medical devices industries, telecommunications and digital native businesses, and regulators. Interviewees also included healthcare professionals in selected specialties, nurses, academics, investors, C-suite executives, startup founders, CEOs of innovation ecosystems and others.

Interviews focused on the key themes of this report: the state-of-play of AI in healthcare, the most promising areas of AI in healthcare under development, the impact of AI on practitioners, the barriers to scaling AI, the implications for health systems providers and national bodies and the implications for health regions, states and the EU in creating opportunities and removing barriers to adoption of AI. An overview of interviewees is provided in Appendix 1.

Alongside the one-on-one interviews, EIT Health and McKinsey & Company conducted a detailed online survey to help define the impact of AI on healthcare resources and healthcare organisations today and in the future, targeting three specific groups of stakeholders: healthcare professionals, healthcare investors and AI startup executives.

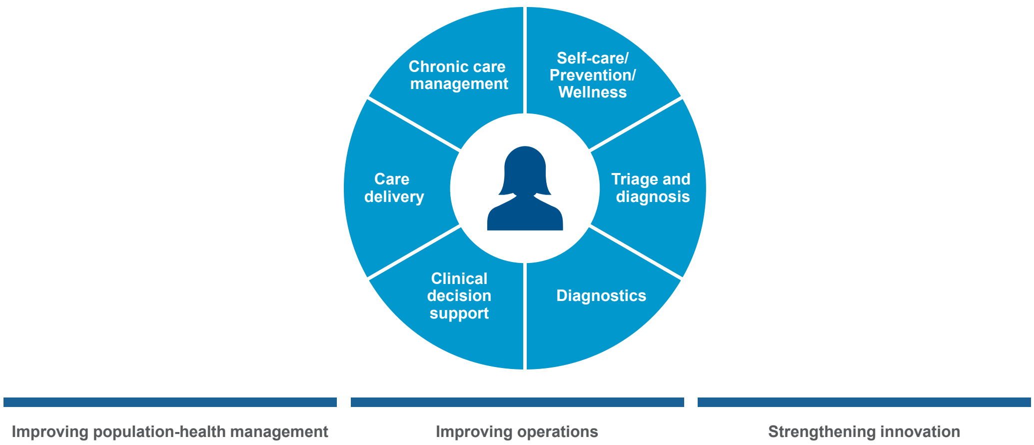
The survey was distributed to a diverse group of stakeholders belonging to the EIT Health Network of 140+ leading healthcare organisations across Europe and generated 175 responses. The mix of respondents and overall sample reflect the relative weight of EU countries and institutions more active within the EIT Health Network. As such, it may not offer a complete representation of the state of AI in healthcare across Europe, but rather the view of an informed group of respondents.

While every attempt was made to provide a comprehensive, cross-Europe view, the interviewees and survey respondents include some people who are already healthcare AI experts or who have stepped up to lead AI-related projects in their organisations – some of these people were explicitly chosen for their expertise. Their views may therefore not be representative of all healthcare professionals across Europe in terms of their excitement and propensity to engage with AI, or the barriers to adoption they would identify. Results are qualitative, aiming to support the latest thinking and decision making on this important topic. Future research efforts may want to try and provide a comprehensive, quantitative view, potentially surveying practitioners across all EU Member States and across all disciplines and specialties.

1.3.3 Case studies

To highlight promising areas where AI is having an impact in healthcare today, we first identified six areas where AI has a direct impact on the patient: self-care, prevention and wellness, triage and early diagnosis, diagnostics, clinical decision support (CDS), care delivery and chronic care management. We also identified three areas of the healthcare value chain that could benefit from introducing AI: improving population health, healthcare operations and healthcare-related innovation (Exhibit 1.3).

Exhibit 1.3 – Areas of impact for AI in healthcare



We then mapped promising examples of AI onto these six areas of patient impact, based on AI literature, interviews and the report survey, professional experience and other expert advice. These are discussed in detail in Chapter 2. They are by no means exhaustive, but rather demonstrate the breadth of impact AI already has in healthcare today.

Chapter 2

Artificial intelligence in healthcare today

The prospect of computers deriving insights from data to transform efficiency and improve operational and clinical decision making has excited computer scientists for decades, but the idea initially raised sceptical eyebrows among physicians. However, higher quality data available in greater volumes and more connected than ever, combined with more computing power and advances in algorithms, is enabling a wave of innovation. Consequently, we see venture capital (VC) firms and tech giants increasing their funding of AI in healthcare, clinical trials testing the benefits of applying AI and, since 2017, a series of US Food and Drug Administration (FDA) approvals for AI.[19]

Despite all the noise, the effect to date on healthcare organisations has been limited. Of the healthcare professionals we surveyed, chosen for their interest in healthcare innovation and AI, 44 percent had never been involved in the development or deployment of an AI solution in their organisation. When we asked to what extent AI affects the healthcare workforce today in Europe on a scale of one to five (1=high impact), most responses hovered around three ("somewhat").

This chapter sets out how we define AI in healthcare, considers why its relevance is increasing around the world, and then looks in detail at a series of examples of how AI is being applied in healthcare.

2.1 What do we mean by AI in healthcare?

The term "artificial intelligence" has been given many definitions, and applications have been included or excluded according to the definition used. As we said in the introduction, our working definition describes AI as "the capability of a computer programme to perform tasks or reasoning processes that we usually associate with intelligence in a human being."[20]

Our scope includes applications that affect care delivery, including both how existing tasks are performed and how they are disrupted by changing healthcare needs or the processes required to address them. It also includes applications that work across areas enabling, augmenting or improving healthcare delivery, from healthcare operations to population-health management and broader healthcare innovation (e.g., R&D).

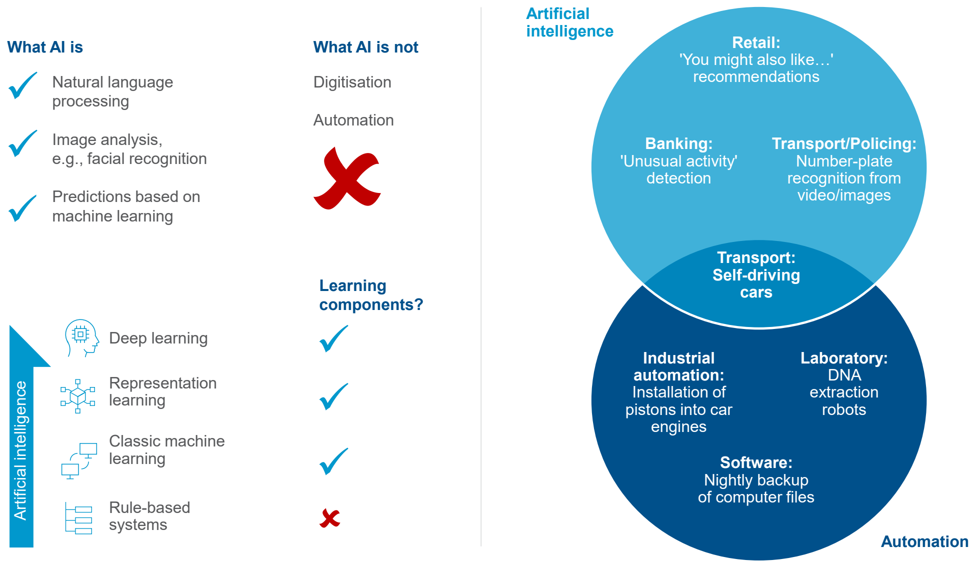
This definition is deliberately broad; it includes the application of rules-based systems as well as cutting-edge methodologies that include classic machine learning, representation learning and deep learning. Examples of AI applications would include NLP, image analysis and predictive analytics based on machine learning.

We apply such a broad definition for two reasons. First, we believe the wider use of rules-based systems will be one of the greatest changes to delivering care in the medium term, enabled by richer data and improved computing. Second, we see AI in healthcare as a spectrum, where encoding clinical guidelines or existing clinical protocols often provides a starting point, which then can be augmented by models that learn from data and demonstrate the distinctive properties of AI: autonomy (the ability to perform tasks in complex environments without constant user guidance) and adaptivity (improving performance by learning from experience).[21] This transition from rules drawn up by experts to systems that learn from data is exemplified in healthcare AI today by applications to triage patients, applications to support clinical decision making, and by robots that restock a nurse's station automatically while using AI to navigate their environment.

We have not included in our working definition digitisation efforts that do not generate insights, such as the transition from paper-based to digital patient charts or the introduction of single-sign-on, although these may be crucial enablers of some of the approaches described. Nor do we consider digital approaches driven purely by improved connectivity, such as video consultations. Applications beyond the scope of care delivery, such as claims processing, are also not considered.

For the purpose of this report, AI therefore comprises a spectrum of solutions that start with rules-based approaches, but increasingly introduce the capacity to learn by training a specific task on large datasets. Exhibit 2.1 illustrates this point, mapping the key learning components of AI and what *is* and *is not* included in a "pure AI" solution, while showcasing the growing overlap between fields, e.g., in AI and automation-enabled solutions such as self-driving cars and broader "smart automation" applications.

Exhibit 2.1 – AI exists on a spectrum, with algorithms displaying increasing learning capabilities



2.2 How recent advances have made AI in healthcare a reality

Improvements in data, processing power and algorithms are rapidly changing what is feasible. The scope and quality of healthcare data produced and the potential to link datasets are opening new possibilities. By the 1950s, medical knowledge had doubled in about 50 years. In 2020, the volume of medical knowledge will double in 73 days.[23]

Both the quality and consistency of data are improving as more data are machine generated. Wearables produce new types of longitudinal data. Genomics data are becoming more accessible as the costs of sequencing and bioinformatic techniques have plummeted (US company Illumina announced the $1,000 genome in 2014 and promises a $100 genome sequencing within a decade[24]). One application of AI is improving image acquisition and reconstruction, which in turn improves that potential for the use of data produced for clinical decision support. The increased adoption of electronic health records (EHRs) and personal healthcare records that can connect longitudinal data and genomics data provides further possibilities for AI to grow.

However, the lack of linked and comprehensive datasets limit AI's potential, leading to Silicon Valley investments in creating distinctive linked datasets. Verily's Project Baseline project, for example, aims to "map human health and disease" by building a detailed dataset from 10,000 participants over four years and the Healthy Nevada Project aims to enrol 250,000 participants to generate combined genomic, EHR and environment data.[25] Europe may take a different tack, given that its public healthcare systems could provide datasets of unique breadth and depth, creating a distinctive advantage in using AI to improve healthcare.

> *Healthcare leaders today can steer the next wave of progress in healthcare, by harnessing advances in data science to generate valuable insights from the large, complex data sets accruing in health systems.*
> **WISH Report, 2018[22]**

The ability of algorithms to interpret data has transformed over the past decade. In 2015, algorithms overtook humans in visual recognition in the ImageNet Challenge Large Scale Visual Recognition Competition, improving from an error rate of 28 percent in 2010 to 2.2 percent in 2017, versus a typical human error rate of about 5 percent. [26] Dramatic improvement is also occurring in NLP: in 2019, algorithms overtook human performance on General Language Understanding Evaluation, a metric for measuring language understanding.[27] Similar improvements are being made in reading, sound and video comprehension, translation and the ability to answer questions with an algorithm trained on text innovation: new solutions, for example, include neural networks (a form of AI) that can read scientific papers and provide a full summary.[28]

Advances in deep learning mean that algorithms can generate layers of abstract features that enable computers to recognise complicated concepts (such as a diagnosis) by building on simpler ones that are accessible in the data (such as the colour of a pixel). This enables them to learn discriminative features automatically and approximate highly complex relationships. Such algorithms have been around since the 1940s, but the recent expansion of datasets and computational resources have enabled a series of breakthrough improvements that are now being applied to augment healthcare provision.[29]

Explainable and causal AI is another area of advancement. A challenge of applying insights from deep learning is that abstracting features through multiple layers means it can be hard (if not impossible) to interpret *why* an algorithm reaches a specific conclusion. Innovations in explainable and causal AI have sought to combine the benefits of the accuracy of deep-learning algorithms with visibility on the factors that are important to the algorithm's conclusion in a way that is accessible to physicians and other practitioners.[30] For example, an algorithm assessing the chance of cancer would be more useful to physicians if it highlights the most relevant biomarkers used in making its assessment and the reference patients from a dataset that it has identified as most similar.

AI advancements have generated significant excitement around the world and many are being fast-tracked and adopted into healthcare delivery. The following sections illustrate the latest view on implementation in different regions and specific use cases that show the potential of AI to transform care.

2.3 Implementation around the world

AI in healthcare – and beyond – has become an important focus for policy makers and investors, with implications for research and further pipeline development. It is instructive to assess what various players in the sector are doing to drive AI in healthcare forward.

2.3.1 Government action

Governments around the world have, in recent years, published national strategy documents on AI that set out their aspirations.

The EU itself has published a wealth of reports on the topic since 2018. In addition, there are a series of initiatives underway in areas such as health policy (e.g., regulation around medical devices, Health Technology Assessments, clinical trials, European reference networks, healthcare workforce); the digital agenda – a Europe "fit for the digital age"; digital health policy (digital transformation of health and care); the Digital Europe programme (on AI, digital skills, digital take-up, cybersecurity & trust, supercomputing); the Horizon Europe programme (including funding on R&D and innovation on health and ageing); as well as plans on AI, data and industrial-policy implementation (see sidebar "Europe and AI in healthcare – the EU's strategy for AI").[31]

Governments are not just developing strategies, they are investing strategically in AI, with large investments in multidisciplinary AI research centres in countries as diverse as the US, Russia, China and Qatar.[38] In Israel, for example, the government announced a $264 million initiative in 2018 to combine national digital medical records in a unified system to maximise the usefulness of data for AI/advanced analytics, and ensure healthcare can be made cheaper, more effective and more personalised. The Israeli government has long encouraged partnerships and cooperation between foreign and domestic business, Israeli startups, research institutes, hospitals and Health Maintenance Organisations (HMOs). It has contributed to the birth of a vibrant and productive digital and AI ecosystem, with Israeli digital-health companies raising more than $400 million, and many now expanding internationally.[39]

2.3.2 Private-sector investments

The private sector is also playing a leading role – not just AI innovators and startups, but established payors/health insurers and healthcare providers, leading pharmaceutical and MedTech companies, digital natives and telecommunications companies, all making commitments, investments and announcements of plans to scale AI to improve healthcare.

Investors are also leading the way. VC funding into AI in healthcare has been rising steadily: by December 2019, the 50 largest cumulative investments had reached $8.5 billion, with the top five companies receiving more than 40 percent of the total funding and the top ten, 58 percent (Exhibit 2.2). When split by region, Exhibit 2.3 shows how dramatically VC funding increased in the US and Asia in 2017, and in Europe in 2018.

The US dominates the list of VC deals in AI in healthcare, accounting for 221 deals from the start of 2010 to the end of 2019, followed by 108 in Europe and 76 in Asia. Although the number of deals has doubled since 2015 in the US and Europe, there has been a five-fold increase in Asia over the same period.[40]

Europe and AI in healthcare – The EU's strategy for AI

On April 10, 2018 – Digital Day 2018 – EU countries signed the "Declaration of Cooperation on AI", aiming to build a framework through which Member States can cooperate on areas ranging from AI's impact on the labour market, sustainability and trustworthiness, to ethics and funding.[32] Following the European Council's call to put forward a European approach to AI, the European Commission (EC) published its *Communication on AI*, setting out its strategic approach to AI and aiming to boost the EU's technological and industrial capacity and AI uptake, prepare Europe for the socioeconomic changes associated with it and ensure an appropriate ethical and legal framework.[33] A second strategic document, the *Coordinated Plan on AI* (December 2018), outlines the European approach to AI and areas of implementation that will be supported by Member States.[34] The EC also established two working groups: the European AI Alliance, built around a diverse multistakeholder online platform and open to all members of society, and the High-Level Expert Group on AI (AI HLEG), which is advising the EC on short- and long-term challenges and opportunities arising from AI, acting as the steering group to the European AI Alliance and publishing its draft suggestions on the Alliance's platform for stakeholder feedback. The EU's vision of itself as a leader in "ethical AI" is also reflected in the AI HLEG's *Draft Ethics Guidelines for Trustworthy AI* (December 2018).[35]

In terms of setting up a broader environment to enable digital- and analytics-led innovation in healthcare, the *Communication on enabling the digital transformation of health and care in the Digital Single Market* (April 2018) looks at how the meaningful use of digital innovation could promote health, prevent and control disease, help address patients' unmet needs and make it easier for citizens to have equal access to high quality care.

This communication is the basis for the funding of health dataspace work under the Digital Europe Programme (2021-2027).[36] The Digital Europe Programme is an EU innovation and deployment programme focused on five areas: AI, digital skills, digital take-up, cybersecurity & trust, and supercomputing. Last, in terms of education, the Commission adopted a Digital Education Action Plan (January 2018) that includes 11 actions to support technology use and the development of digital competences in education. In particular, Action 10 (on AI and analytics) defines how the Commission will pilot data analytics projects to predict the learning journeys and training requirements for future competence profiles.[37]

Exhibit 2.2 – Since 2010, $8.5 billion of VC funding has been invested in the 50 best-funded AI companies in healthcare

	Company	Headquarters	Total raised $ million
1	Ping An Medical and Healthcare Mgmt	China	1,150
2	Babylon Health	UK	635
3	Indigo Agriculture	US	621
4	Zymergen	US	592
5	Change Healthcare	US	557
6	Tempus	US	520
7	Recursion Pharmaceuticals	US	249
8	Accolade	US	240
9	iCarbonX	China	200
10	insitro	US	200
11	Synthego	US	162
12	GoForward	US	158
13	LinkDoc	China	151
14	Sophia Genetics	Switzerland	140
15	Beta Bionics	US	132
16	OrCam	Israel	130
17	Blackthorn Therapeutics	US	130
18	Verana Health	US	119
19	Augmedix	US	116
20	Clarify Health Solutions	US	108
21	Finch Therapeutics	US	105
22	MeMed Diagnostics	Israel	101
23	AI Therapeutics	US	98
24	caresyntax	US	91
25	HealthTap	US	88
26	Helian Health	China	84
27	Singlera Genomics	China	80
28	Viz	US	79
29	VoxelCloud	US	79
30	Healthy.io	Israel	78
31	Sight Diagnostics	Israel	77
32	Saama	US	76
33	PathAI	US	75
34	Infervision	China	74
35	AiCure	US	69
36	Olive (Robotic Process Automation)	US	68
37	Healx	UK	68
38	Frontier Medicines	US	67
39	XtalPi	US	66
40	Lark Technologies	US	64
41	TeraRecon	US	62
42	InSilico Medicine	US	61
43	Evidation Health	US	61
44	ImagenTechnologies	US	60
45	Mindstrong Health	US	60
46	Nuritas	Ireland	60
47	Paige.ai	US	59
48	Atomwise	US	58
49	K Health	US	56
50	GNS Healthcare	US	56

Total funding reported

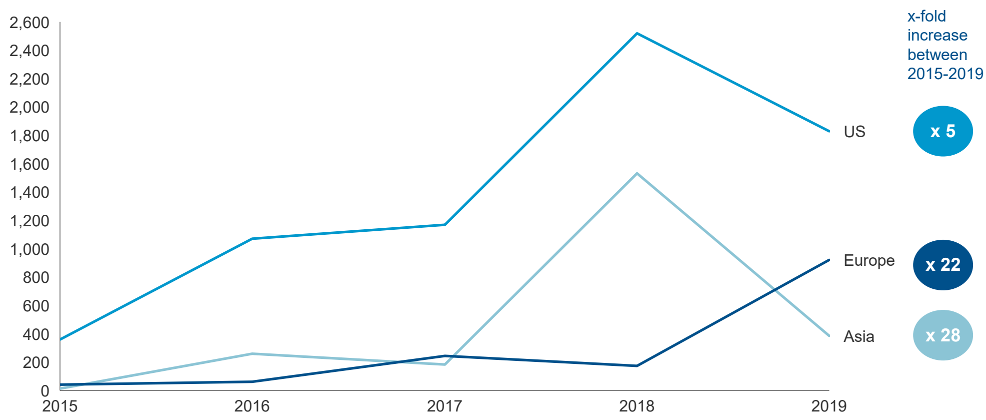
Top 50 $8,490 million

Top 10 $4,964 million (58%)

SOURCE: PitchBook Data, Inc., http://pitchbook.com/research-process

Exhibit 2.3 – The venture capital invested in AI companies in healthcare has grown significantly since 2015

Venture capital invested
$ million



SOURCE: PitchBook Data, Inc., http://pitchbook.com/research-process; team analysis

2.3.3 A diverse research pipeline

Just as VC firms broaden their geographic scope, healthcare AI research studies and clinical trials also reflect a more diverse picture. Initially, the US dominated AI-related research, but China now outpaces the rest of the world in the number of healthcare research studies with an AI focus, followed by the US and Europe, which taken collectively is on par (Exhibit 2.4).

China and AI in healthcare

China is emerging as a leader in healthcare AI, with large datasets, strong government support, a large pool of tech talent and an innovation-friendly environment. Interviewees also pointed out that in some areas, China's healthcare system faces poor access to care, lack of awareness of treatment options, bottlenecks in patient referral and gaps in long-term disease management. A particular challenge is access to primary care, especially in rural areas, and variability in quality. At the same time, Chinese consumers of all ages are aware of and broadly accept digital AI solutions in different areas, through self-pay models in China's cashless landscape. As Dr. Alexander Ng, from Tencent Healthcare, explains, "Making the leap to using AI in healthcare for the Chinese consumer will be easier than elsewhere. Everyone is used to having chatbots and AI in many services."

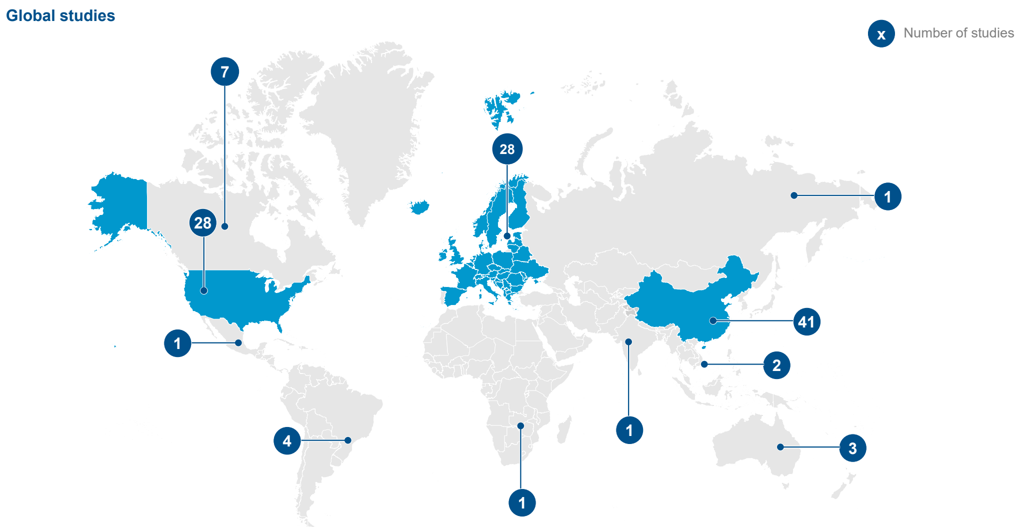
The Chinese government has developed a range of policies showing its commitment to the use of AI in healthcare, setting the goal of becoming a global innovation centre by 2030 and laying out recommendations for the use of AI to improve population health. In recent years, the government has also invested not only in academic collaborations, but also directly in innovative startups.

Chinese tech leaders and conglomerates have evolved as major healthcare players. They aim to change the paradigm for access to healthcare and address system inefficiencies through customer-centric solutions, e.g., scheduling appointments, e-triage, access to primary care.

- Tencent uses its WeChat platform to engage and manage users of its healthcare services across the care continuum, aiming to diagnose and prevent a broad range of diseases. It offers online AI-based triage and appointment scheduling, is building a WeChat-based physician community for patient management and has an AI imaging platform.
- Alibaba has used its e-commerce platform to set up an online business-to-consumer healthcare platform (e.g., over-the-counter drugs, plastic surgery), adding telemedicine, traceable barcodes for healthcare products, and the use of Alipay to pay for services.
- Ping An has used its insurance customer base and data to build a complete health ecosystem, connecting patients, payors, hospitals and other care providers. Ping An's Good Doctor, its online health-management platform, is the largest globally, with more than 300 million users.[41]

Such companies are now increasingly developing AI solutions, such as the AI-powered cloud doctor in Ping An's One-Minute-Clinics in shopping centres, which registers medical history and symptoms and offers e-triage, diverting complex cases to physicians at Ping An's network/call-centre. It also offers access to 200 medicines within the clinic and home delivery through local pharmacies, creating an end-to-end primary access experience for its users.

Exhibit 2.4 – China has the largest number of healthcare research studies with an AI focus



SOURCE: http://clinicaltrials.gov, as of December 16, 2019. Study types included in search results from Clinicaltrials.gov are interventional (clinical trials) and observational studies.

2.3.4 The view from Europe

Europe is making significant progress in key areas. The EU has sought to develop a pan-European approach, strategy and plan for AI, including in healthcare. It has established working groups with a balance of expert input and stakeholder representation and sought to develop "the EU way" for AI, focusing on transparent, ethical and trustworthy applications. EU public healthcare systems hold a treasure trove of healthcare information at the population level that, if linked, could provide distinctive advantages in speeding up AI adoption and impact in healthcare.

Private investment in Europe is increasing fast, albeit from a smaller base than the US, and EU countries have significant research strengths, with established digital and innovation clusters and collaborations at the regional and pan-European level and – as we saw above – AI-related healthcare research and trials are on a par with the US.

At the same time, the pace of change reflects the complexity of aligning the approach and aspirations of diverse Member States and other stakeholders. Valuable datasets are not linked, with critical data-governance, access and security issues not yet addressed, delaying further AI adoption. European investment and research in AI are strong when grouped together but fragmented at the country or regional level. There is a significant opportunity for EU health systems, but AI's full potential remains to be explored and the impact on the ground remains small.

> *Europe has large public healthcare systems, which should put us at an advantage regarding data, compared to nations with more fragmented systems.*
> **Julián Isla Gómez, Microsoft EMEA**

These themes were echoed in both the interviews and the survey of EU-based stakeholders, which provides a view from the front line of the AI applications present in European healthcare today and where investors and startups who work in Europe see the most potential.

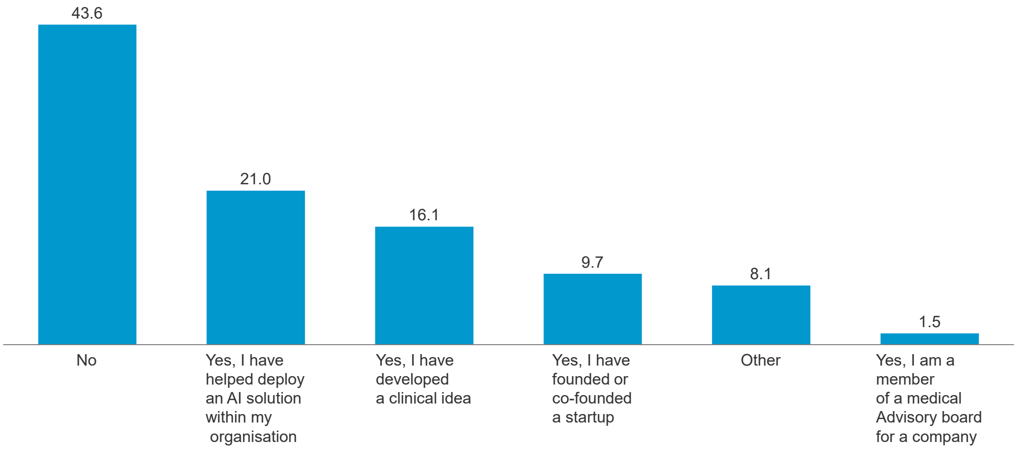
For instance, despite great interest in AI among the survey group, 44 percent of healthcare professionals have yet to experience deployment or development of AI solutions in their organisation (Exhibit 2.5). Where AI is being used in European healthcare today, just over one in five of the healthcare professionals surveyed mentioned its application in diagnostics (imaging, pathology, sequencing), one of the earlier uses of AI in healthcare, with clinical decision making and data management the next most common uses (Exhibit 2.6).

Exhibit 2.5 – Many healthcare professionals have had limited exposure to developing or deploying an AI solution

HAVE YOU EVER BEEN INVOLVED IN THE DEVELOPMENT AND/OR DEPLOYMENT OR USE OF AN AI SOLUTION?

Healthcare professional responses

percent



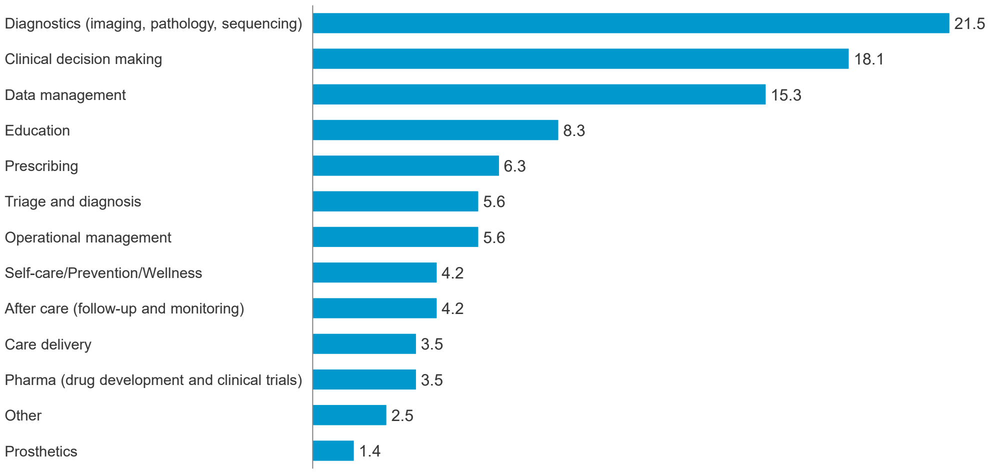
SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

Exhibit 2.6 – Diagnostics is the most common field for AI solutions in healthcare today

WHAT ARE THE APPLICATIONS OF AI IN YOUR ORGANISATION TODAY?

Healthcare professional responses

percent



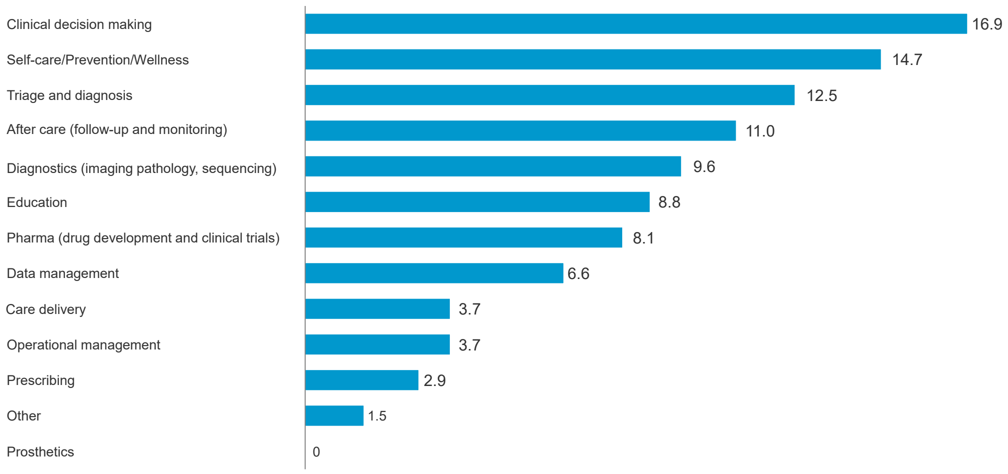
SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

Startup executives, on the other hand, put more emphasis on consumer-facing solutions, such as self-care, prevention and wellness, or triage (including e-triage solutions) and diagnosis. This partly reflects a consumer orientation and a focus on empowering individuals to take more care of themselves, but also reflects an expectation of faster adoption and the potential to scale AI through this route (Exhibit 2.7).

Exhibit 2.7 – Startups are focusing their efforts on clinical decision-making solutions

WHICH OF THE FOLLOWING AREAS IS YOUR SOLUTION GOING TO AFFECT?

Startup executive responses
percent



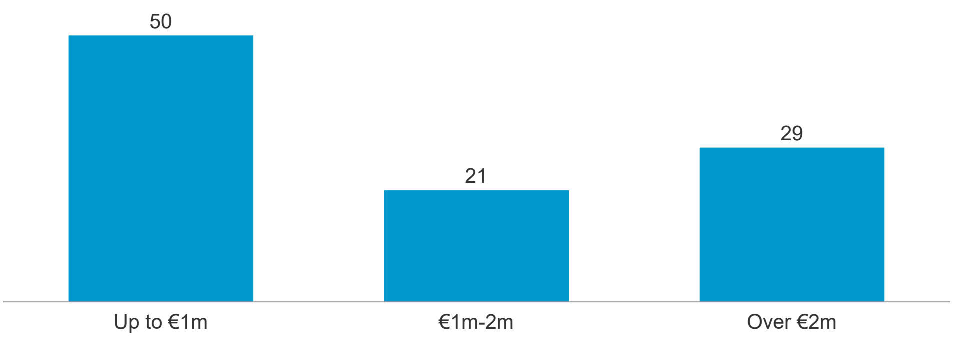
SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

The investors surveyed were focused mainly on Europe and most are already investing in AI in healthcare, however, for just under three-quarters, the investments represent less than 20 percent of their total portfolio. More than two-thirds are invested in one or two AI in healthcare solutions, and in almost half the cases, the average ticket size for these investments is below €1 million (Exhibit 2.8).

Exhibit 2.8 – The average investment in healthcare AI made by investors surveyed is less than €1 million

WHAT IS YOUR AVERAGE TICKET IN THIS TYPE OF VENTURE?

Investor responses
percent



SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

Overall, the progress of AI in Europe would appear marred by fragmentation, both in terms of investment and the pooling of critical resources to develop, test and implement – but with significant potential to scale based on the strengths of the European health systems, and of their practitioners, researchers and investors.

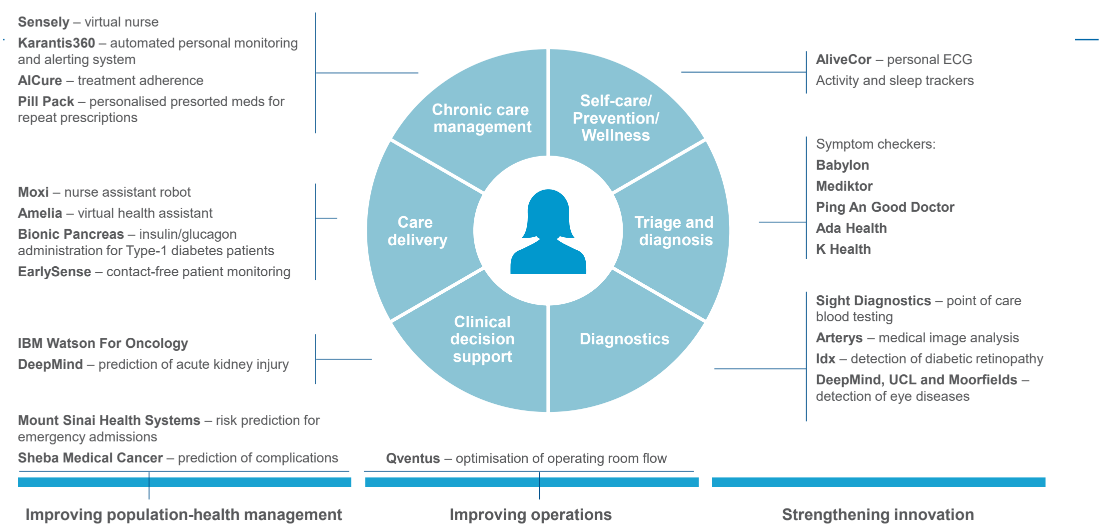
2.4 Selected use cases along the AI in healthcare framework

Despite the increasing levels of government attention on AI in healthcare and increased funding, we still need to define the critical use cases that can deliver the biggest impact in healthcare through AI (using our broader definition of AI as a spectrum) and what is actually being delivered on the ground or showing promise in terms of developments in the pipeline.

This section uses the framework we introduced in Chapter 1 that set out the key areas of impact of AI in healthcare, placing the patient at the centre, and across the healthcare value chain. Beyond the patient, we also highlight areas of impact of AI in terms of healthcare more broadly, by improving population health, healthcare operations and healthcare-related innovation.

A summary of the key AI cases identified and profiled in the report are included in Exhibit 2.9 mapped onto the framework. These examples illustrate the range of areas where AI is having an impact in healthcare and are by no means exhaustive; nor does their inclusion constitute an endorsement of a specific solution or organisation. Use cases listed were highlighted by our interviewees as prominent or promising, or reflect our collective experience in AI over recent years, and serve to demonstrate the diversity of applications available today.

Exhibit 2.9 – AI use cases at each stage of the AI in healthcare framework



2.4.1 Self-care, prevention and wellness

Patients are increasingly empowered to take care of their own health and wellness. Countless wellness applications that aim to support people to live healthier lives (e.g., activity and sleep trackers) are part of the growing group of health applications that consumers can buy directly with no need for a healthcare consultation. Many applications began as monitoring or tracking devices only, but there is a trend to enhance these solutions with AI models, for example to provide personalised plans and guidance based on individual health goals.

> *Nearly all self-care options will have some type of AI component.*
> **Michal Rosen-Zvi,**
> **IBM Research and The Hebrew University**

These apps collect large amounts of data, which can be used both to provide more personalised guidance to individuals, and to develop longitudinal views of broader population health and triggers for disease onset or deterioration, gradually adding a learning component.

The field also includes personal devices that cross over into diagnostics by monitoring vital signs among presumably healthy individuals and then flagging specific healthcare risks, such as higher than average blood pressure; and devices that cross over into remote disease monitoring tools that support the needs of patients with a chronic condition (e.g., atrial fibrillation). In such examples, systems have evolved from generating large amounts of unprocessed and unorganised data available to clinicians for decision making, to assessing the patient's condition and outlook, increasingly involving independent learning components.

Self-care, prevention and wellness

AliveCor – Personal Electrocardiogram (ECG)

What is it and what is its role in healthcare?

US-based company AliveCor developed KardiaMobile, a personal ECG device that can monitor heart rhythm and instantly detect and flag atrial fibrillation, bradycardia or tachycardia to clinical teams. Atrial fibrillation affects 7.6 million people over 65 in Europe, a number expected to rise to 14.4 million by 2060.[42]

How does it work?

Patients record their personal ECG remotely using KardiaMobile in combination with the Kardia app. Depending on the patient's monitoring needs, a single or 6-lead ECG can be acquired with no need for additional leads and cables. The Kardia app allows patients to track data over time and shares the ECG recordings directly with their physician.

What does this mean for healthcare practitioners and organisations?

Physicians can monitor patient data remotely on the KardiaPro platform. They can get additional datapoints from patients between visits and establish a more complete picture of the patient's heart rhythm, to further inform clinical decision making. ECGs may reveal intermittent atrial fibrillation not detected in periodic measurements at the physician's office, and lead to change of treatment.

The existence of such applications in self-care, prevention or wellness more broadly, means that physicians need to be able to calibrate the point at which an intervention may be needed, as many technologies have a low threshold for alerts. This can only be overcome by physicians collaborating in AI multidisciplinary teams to identify real trigger points for intervention versus noise in the system, taking a population view. Some organisations have already started collaborating in this direction, for example Sheba Medical Center and two Health Maintenance Organisations in Israel are planning to combine their data to create predictive models to help proactively address the health of their population by identifying the right intervention trigger points.

For payors and insurers, the increased use of personal monitoring devices may require reimbursement policies, potentially through outcome-based models, for the time physicians spend analysing the recorded data, providing information and discussing individual findings. Organisations also need to ensure interoperability and the ability to integrate readings from diverse sources (e.g., wearables) into a single view of the patient for the physician, integrating seamlessly into the typical clinical workflow.

What is its reach (and potential)?

KardiaMobile is available in 35 countries (13 in Europe) and has been used to record more than 50 million ECGs to date. Devices can be used by patients, nurses or caregivers in situations when a full 12-lead ECG is not required or feasible. As such, they could serve as mobile devices in home-care settings for the monitoring of patients with atrial fibrillation, bradycardia or tachycardia and help reduce a substantial rise across Europe of disabling strokes.

2.4.2 Triage and diagnosis

Symptom checkers such as Babylon, Mediktor, Ping An Good Doctor, Ada Health, K Health and others, can help triage patients and provide guidance if the symptoms require additional healthcare resources. This e-triage is a promising way to provide direct and immediate access to care where otherwise there may have been delays – for example, in healthcare systems with long waiting times, in primary care in different parts of Europe, in rural areas with shortage of primary care resources, or in some emerging markets. It is also potentially a very effective way for hospital systems to ensure that only patients for whom hospital care is essential actually turn up in emergency rooms, while others are routed to more appropriate channels.

> *The only way to know if you need to see a doctor, is to see a doctor. This maxim can and should change. Patients are now going to Google all the time. They prefer an imperfect answer now than a perfect answer in a week, and need to know whether they should be worried.*
>
> **Josep Carbó, Mediktor and Barcelona Health Hub**

Triage and diagnosis

Online symptom checkers/e-triage tools

What are they and what is their role in healthcare?

These tools aim to improve access to healthcare by letting patients check common pathologies typically addressed in primary care and providing information on related symptoms, potential treatments and outcomes. Some offer follow-up via online chat or video consultations with physicians.

How do they work?

The symptom checkers in use today are broadly similar, but they do have some important differences (e.g., training of algorithm, access to data or scale). Key examples include:

- **Babylon Health (UK), Mediktor (Spain) and K Health (Israel).** Babylon's AI-powered chatbot uses NLP to understand symptoms defined in the patient's words and provides relevant health and triage information using algorithms trained on NHS data. It offers an initial diagnosis with possible scenarios and a percentage-based estimate of each being correct. Babylon is also working on a technique, inspired by quantum cryptography, that would allow medical databases to be tapped for causal links.[43] **Mediktor** uses an approach also focused on e-triage and has been validated in a prospective observational study in a tertiary university hospital emergency department.[44] **K Health** was developed in partnership with Maccabi Health Services in Israel, which granted the company access to the anonymised electronic medical record data of more than 2 million people from the past 20 years. Using NLP and advanced modelling, the algorithm was trained to understand symptoms and the likelihood of an underlying diagnosis being connected with a patient's data. A built-in feedback loop lets the system learn with every case and improve continuously.[45]
- **Ada Health (Germany).** Its system connects medical knowledge with AI and the app compares answers to questions about symptoms to similar cases drawing from extensive clinical literature.
- **Ping An Good Doctor (China).** The symptom checker is an integral part of a closed-loop ecosystem that connects patients with physicians, online or offline, after initial assessment. It is also deployed in a physical setting as an AI-enabled virtual doctor accessible in Ping An's One-Minute-Clinics. These are found in eight provinces in China, with contracts signed for nearly 1,000 units in large and medium-sized enterprises, community centres, chain pharmacies and other high footfall areas.[46]

What does this mean for healthcare practitioners and organisations?

Symptom checkers can boost productivity as practitioners spend less time collecting data and forming an early view of patients, and they can help reduce the risk of misdiagnoses. They may also help relieve pressure on primary-care providers and organisations, lead to fewer people presenting in emergency departments and reduce overall caseloads. This lets organisations dedicate more time to the patients with the highest needs (though patients who eventually present at hospital may have more complex needs on average). Today, most symptom checkers are not reimbursed. Many grow through direct-to-consumer sales (e.g., in China), or collaborations with hospital organisations (e.g., in Europe).

What is their reach (and potential)?

Symptom checkers are widely available in the US, Europe and China. In 2019, Ping An Good Doctor registered users exceeded 300 million. Babylon Health records 2.2 million AI consultations and almost 4 million users. Ada Health claims it has made more than 15 million symptom assessments and has 8 million users. Mediktor reports more than 3 million assessments, and K Health more than 2 million users and 80 million user questions answered in the app.[47]

2.4.3 Diagnostics

When further clinical work is needed to determine the underlying reason for symptoms, diagnostic AI solutions may help by improving accuracy or saving time. Across the different diagnostic areas, we see a variety of applications for diagnostic tests, which started with the simple (e.g., moving from haemocytometers with counting grids, to automated live/dead cell counters) to more sophisticated diagnostic applications such as OLO, an AI-enhanced blood testing device that counts blood cells at the point of care.

Some medical specialties lend themselves naturally to AI applications, due to their large emphasis on pattern recognition, such as radiology, pathology, dermatology and ophthalmology. In these areas, several AI applications have received regulatory approval by the FDA, such as Arterys, an AI-enhanced medical image-analysis platform with several applications including LungAI for lung-nodule analysis allowing for the early detection of lung cancer.

Despite the rapid pace of development of diagnostic AI applications, they still generally focus on a specific, well-defined task. Although several AI models have shown higher accuracy rates than board-certified medical experts, clinical trials are needed for further evaluation and to derive potential clinical implications from the findings. Research also highlights that the relative accuracy of AI models compared to physicians can also be influenced by external context. For example, a recent *Nature* article highlights differences in the relative success of AI based on the frequency of mammography and number of reviewers. In the US, where there are more frequent reviews but by a single practitioner, AI was more valuable than in the UK, where reviews are typically conducted by two practitioners, albeit less frequently.[48]

Interviewees in our survey also highlighted the potential for significant added value in countries where resources to train the workforce are more limited or there are wider variations in clinical education and quality. As Tencent Healthcare's Dr. Alexander Ng says of China, "It would be impossible from a human-resources perspective to skill up everyone. The transition will have to be through digital tools to enable physicians to manage their patients to address their needs in a nascent primary care system."

Another example shared during our interviews is a solution developed at Sheba Medical Center in Israel. A new algorithm for image reconstruction can reduce the radiation exposure of a conventional chest CT to 4 percent and could be suitable for annual screening of smokers with a high risk of developing lung cancer. A reduction of radiation exposure for CT scans could lead to broader benefits at the population level, as CT scans are high-volume diagnostic tools – in 2016, there were 36 million CT scans in France, Germany, the UK, Italy and Spain.[49]

Diagnostics

Sight Diagnostics

What is it and what is its role in healthcare?

Israeli company Sight Diagnostics has developed OLO, a point-of-care blood testing device that can perform a full blood count (FBC) using AI machine-vision technology. Almost half a petabyte of anonymised blood image data was used to train the AI powering the blood diagnostics system. The device allows a healthcare professional to carry out an accurate test within 10 minutes from a finger prick and requires only minimal training. This makes it suitable for use in primary care settings, emergency departments or outpatients, and settings without a lab.

How does it work?

The AI technology interprets multiple images of a small blood sample producing an FBC test of similar quality to a traditional laboratory test. Point-of-care blood testing means the healthcare professional can get the results much more quickly, which in turn means the patient can be diagnosed potentially immediately, rather than waiting hours or days. It also reduces the need for samples to be transported, tracked and tested in a lab. Performing the test from a finger prick reduces the need for a larger blood sample to be taken from a vein, which can require phlebotomy services. The AI approach also removes the need for device calibration, which is typically done by lab technicians, or under their supervision.

What does this mean for healthcare practitioners and organisations?

OLO can save time by removing the need for follow-up appointments and even in the time needed to draw blood. Time can also be saved for lab staff by reducing the amount of calibration required. Training is required to use the device correctly and ensure accurate results, but new data and analytics skills are not required. The main consideration for organisations is ensuring quality assurance processes are adapted to incorporate the use of new point-of-care diagnostics.

What is its reach (and potential)?

OLO has a CE Mark registration and has been deployed in several European healthcare systems, while undergoing clinical trials in the US. The blood testing market globally is expected to exceed $62 billion by 2024, driven in part by the growing prevalence of chronic diseases such as diabetes and cardiovascular disease that may require more frequent testing.[50] Delivering an FBC through AI-augmented point-of-care blood testing regardless of setting, could revolutionise diagnostics and reduce complexity for millions of patients.

2.4.4 Clinical decision support

With the rapid increase of medical knowledge, it is ever harder for physicians to keep up to date. AI solutions that retrieve relevant medical knowledge for each patient and present it in a structured way can help the physicians decide on the best treatment option, saving time and leading to a more comprehensive evidence-based decision-making process.

In a routine clinical setting, AI models may also be able to detect patients at high risk of complications or early deterioration (e.g., DeepMind Health can predict acute kidney injury[51]) and provide guidance for further clinical decision support, with the opportunity for prevention or early intervention. Reducing complication rates by intervening early may result in improved health outcomes and reduced length of stay in hospital and related healthcare costs.

> *AI needs to serve as a decision-support tool. In the end, it is the decision of a doctor. AI is not going to substitute doctors in the foreseeable future.*
> **Dr. Eyal Zimlichman, Sheba Medical Center**

Despite the potential sizeable benefits, early applications have shown that clinical implementation may be less straightforward than other use cases. While many clinicians are excited about the potential use of AI in clinical decisions, others cast doubt on the readiness of the technology, or the relative value to focusing on CDS, compared to applying AI in areas that simplify routine processes and thus free up physician time.

For example, IBM Watson was one of the first companies eager to bring AI into clinical settings. It entered the field with clear strengths in NLP and machine learning but found it hard to deliver fully on the early promises of its Watson Health division and of Watson for Oncology, an AI system developed and trained in collaboration with the Memorial Sloan Kettering Cancer Center in New York City.[52] Such experiences show how complicated today's healthcare system can be. Data can be incomplete or of poor quality and, more importantly, there can be a fundamental mismatch between the way machines learn and the way doctors work. More broadly, AI is only as good as the data used to generate it.

CDS requires large comprehensive databases with high-quality data on which to build the decision tool (for example, it needs to cover all ages and ethnicities). This is as critical as the development process itself. The careful codevelopment of CDS solutions in a multidisciplinary setting, with clinical and AI input, the continuous evaluation during all development stages (including after deployment) and thorough testing for validation will all be crucial to ensure a safe and efficient use in clinical practice. Last, any solution perceived as a black box may face significant barriers to adoption and is therefore something developers need to preempt. As Dr. Thomas Senderovitz, Director General of the Danish Medicines Agency, says, "There need to be transparency and ethics in AI. In healthcare, it is unacceptable that companies are asking us to trust that their algorithms work, without being able to examine it. We need to push against that and develop mechanisms to assess such solutions, potentially developing centres that can specialise in assessing SaMDs [Software as a Medical Device]."

Clinical decision support

DeepMind Health and Moorfields Eye Hospital NHS Foundation Trust

What is it and what is its role in healthcare?

In 2016, Moorfields Eye Hospital (an NHS hospital in the UK), and DeepMind (a UK-based AI company owned by Google) started a partnership to explore how machine learning and AI can support medical research into eye disease, including age-related macular degeneration and sight loss as a result of diabetes.[53]

How does it work?

The joint team used thousands of anonymised eye scans to train algorithms to identify signs of eye disease and recommend referral or treatment. In 2018, results showed that AI could match world-leading experts in diagnosing a range of conditions, making the correct referral decision for more than 50 eye diseases with 94 percent accuracy. The team uses a dual-layered neural network to avoid creating a black box. The first neural network analyses the scan to provide a mapping of types of eye tissue and features of disease, allowing professionals to reach a clinical decision independently. The second network analyses this map to present clinicians with a potential diagnosis and recommendation.

What does this mean for healthcare practitioners and organisations?

This type of algorithm can help reduce the time to diagnosis for conditions that threaten permanent loss of sight, allowing providers to treat patients or refer them to the right specialists for further treatment more quickly. Today, eye-care professionals use optical coherence tomography scans to help diagnose eye conditions – 3D images offering a detailed map of the back of the eye – but these can be hard to read and need expert analysis to interpret. At Moorfields, where practitioners may review more than a thousand scans a day, delays in triaging scans can make the difference between an urgent case being addressed properly or a patient losing his or her sight. Such applications therefore help prioritise the most complex cases, increase productive time and potentially reduce clinical error.

To maximise their use, practitioners need to understand the technology behind these applications, their key features and limitations, and engage in their ongoing development. In the absence of clinical trials or regulatory approval, the onus is higher on practitioners to integrate such solutions in their workflow, but the benefits to patient care and productive clinical time are becoming more pronounced. For healthcare organisations, such applications must be well-governed and stewarded, and partnerships need to have a long-term perspective: Moorfields and DeepMind launched their collaboration in 2016 and development is still ongoing.

What is its reach (and potential)?

DeepMind is expanding CDS in breast-cancer detection and acute kidney injury, and Sheba's collaborations in Israel focus on colorectal cancer – a few examples of the vast potential of CDS.

2.4.5 Care delivery

In care delivery, NLP-based solutions could support practitioners in various areas. For example, Moxi is a nurse-assistant robot that proactively completes tasks such as refilling stock, and there are AI solutions that can take notes or retrieve required information from medical records such as lab results or medical history. In our interviews, AI solutions using NLP were mentioned several times as areas where people see potential for significant progress within the next couple of years. As Antanas Montvila, a radiologist and Vice President of the European Junior Doctors' Association says, "Once NLP gets started, every area of healthcare should be affected."

> *Voice tech, such as digital assistants, is changing the game. There is a huge opportunity with the shift to voice, breaking down the barrier of usability, in particular with older adults.*
>
> **Mary Lou Ackermann, SE Health**

Another potential use of AI in care delivery is in monitoring or treatment devices such as AI-powered artificial pancreas solutions for patients with type 1 diabetes. These patients need their blood glucose levels checked frequently and insulin and glucagon have to be administered accordingly. Having a solution that constantly monitors the blood glucose levels and autonomously administers the right dose can both free up time and potentially reduce the error rate when compared to manual calculations and administration.

A third area where AI can support care delivery is patient monitoring in an inpatient setting. Healthcare organisations aim to provide timely delivery of care but emergencies or unexpected changes in schedule can lead to longer waiting times, a poor patient experience, and worse clinical outcomes. For example, a nurse on an orthopaedic ward may receive an alert when a patient shows signs of cardiac arrythmia and thus might be at risk of suffering from an acute myocardial infarction. Patient monitoring solutions such as EarlySense, which uses AI to provide actionable health insights, help nursing staff focus their attention where it is needed and provide immediate help in case of early signs of patient deterioration.

> *The reason we become nurses is to care for patients and save lives, not to enter data.*
>
> **Rebecca Love, OptimizeRx**

Care delivery

Amelia – Virtual Health Agent Platform

What is it and what is its role in healthcare?

Amelia, a cognitive virtual agent platform from IPSoft, demonstrates learning abilities and elements of emotional intelligence. It can perform autonomic task management using conversational AI and manage some operational and administrative hospital processes.

How does it work?

Amelia can play the role of a care protocol "whisper agent" (e.g., reminding practitioners of steps that need to be followed), as well as a care operations agent, helping document a patient visit, admitting patients, retrieving medical history prior to a conversation, checking availability of hospital beds, retrieving lab results and scheduling specialist appointments. The Amelia Health agents, enabled by AI technology, learn continuously with every completed task and can communicate through voice, mobile, web, and chat.

What does this mean for healthcare practitioners and organisations?

Nurses may save time using virtual agents to help them admit, discharge and transfer patients. Practitioners preparing for patient consultations can save time by instantly retrieving the patient's medical history rather than searching through several systems. Virtual assistants can help physicians identify available colleagues from another specialty when a consultation is needed. The ability to document patient visits can help practitioners focus on the direct interaction with the patient, without manually filing notes. Another impact area is lab test results. The time between taking samples and getting results can vary, depending on factors such as availability of transport and lab capacity. Amelia can provide that information directly, reducing the need for staff to repeatedly check manually.

Given the wide range of capabilities of virtual agents such as Amelia, organisations need to define where the technology will bring the most value in their specific context and guide their employees through the training and adoption process to interact with virtual agents.

What is its reach (and potential)?

Amelia is already available in the US and the UK, and IPSoft has also partnered with NHS Digital to build a Digital Virtual Data Assistant (ViDA), a chatbot to help extract information from the NHS' healthcare data repository, e.g., on emergency system waiting times.[54] Such technologies may also support caregivers and patients in outpatient and home-care settings, reducing the time practitioners spend scheduling appointments or sharing with patients notes from their last visit and care plan details.

Bionic Pancreas by Beta Bionics

What is it and what is its role in healthcare?

The bionic pancreas (iLet, developed by US company Beta Bionics) uses machine learning to constantly monitor and independently manage blood sugar levels in insulin-dependent type 1 diabetes patients, mimicking the function of the pancreas. This could provide vital support for patients, many of whom find adherence to strict monitoring and insulin-management regimes very restrictive, especially adolescent patients.

How does it work?

The iLet device is worn on the skin and connects wirelessly to a smartphone-sized portable unit that contains the hormone(s). It defines timing and dosage to administer through an algorithm.

What does this mean for healthcare practitioners and organisations?

Today, practitioners have to teach patients who use a conventional insulin pump or who manually inject insulin, how to count the intake of carbohydrates. With a bionic pancreas, this may no longer be required. The time of caregivers, who used to measure blood sugar levels several times a day and then administer insulin and glucagon, will also be freed up. Physicians and nurses may have to develop critical appraisal skills of the functionality of the bionic pancreas so they can identify patients who are suitable for this treatment and enable them to use it correctly. The biggest impact could be on the patients, as they can care for themselves more effectively, improving their outcomes. This type of support enables hospitals and other providers to focus on those interactions with diabetes patients that have the most value in terms of outcomes, and therefore prioritise the use of resources.

Despite the promise of such solutions, we are still a long way from scaling them. Regulators and payors need to evaluate which devices are safe and effective, and payors would need to develop criteria for the reimbursement of using a bionic pancreas. The workforce would need the right coaching and counselling and would have to be confident they were choosing the right patients for such applications in the first place.

What is its reach (and potential)?

Currently, iLet is used as an investigational device and has been tested for use in type 1 diabetes patients in clinical trials for outpatient and home use, with hormones from different pharmaceutical companies. It could potentially be used to treat insulin-dependent type 2 diabetes patients, who make up more than 90 percent of the world's diabetic population. With the diabetic population (diagnosed and undiagnosed) estimated at 415 million – or 1 in 11 of the world's adult population – rising to 642 million by 2040, such solutions could be one of the largest potential applications of AI healthcare devices in terms of global health outcomes and population impact.[55]

2.4.6 Chronic care management

AI solutions help patients (as well as relatives and caregivers) to manage their chronic disease on a day-to-day basis and potentially remain independent and stay at home longer. For example, patients with congestive heart disease may be supported by virtual-nurse systems monitoring vital signs and symptoms, ensuring medication is taken and encouraging the adoption of healthy habits. This could reduce the need for a 24/7 caregiver. The patient may share data recorded in the application, providing relatives, caregivers and physicians with a comprehensive longitudinal dataset of personal health information, potentially reducing the need for some in-person visits to the physician. According to Dr. Marco Inzitari, President of the Catalan Society of Geriatrics and Gerontology, "AI enables health professionals to better select patients who can be empowered to take action for their own care."

> *AI can be used to continue the care cycle without patients being hospitalised. With AI-based solutions, we can help people have a better quality of life outside of hospitals.*
>
> **Federico Menna, EIT Digital**

Personal monitoring and alert systems for use at home can help elderly people stay in their familiar environment for as long as possible. These solutions may be particularly helpful for people with increased frailty or with cognitive impairment or dementia, where a monitoring and alert system could provide enough oversight to allow them to live at home, while knowing that healthcare services could help in a timely manner if needed.

Adhering to medication is another chronic-care challenge that AI could tackle. Many older patients have to take several prescription drugs at different times of the day. Remembering when to take which pill can be daunting, especially if the patient has (mild) cognitive impairment. A personalised AI-enhanced pill-presorting delivery system could reduce the risk of patients making mistakes, or the need for caregivers to sort medication. AI applications may also be able to help patients by monitoring and encouraging treatment adherence.

Chronic care management

Sensely

What is it and what is its role in healthcare?

US company Sensely offers a virtual nurse assistant, with modules for chronic diseases that can be used for personalised monitoring and follow-up care. Patients can use the virtual assistant on a tablet at home to support their daily routine of managing their care or connect with healthcare practitioners.

How does it work?

Sensely's avatar-based chronic-care platform provides personalised conversational content using text-to-speech and speech-recognition technologies. It helps guide the patient through daily monitoring needs and can assess symptoms to determine whether to contact a healthcare professional. The assistant guides the patient step-by-step through the process (e.g., "Now it's time to take your blood pressure. Please make sure the cuff is on by pressing the orange button") and provides instant feedback ("Your blood pressure is a little high today"). Using speech recognition, the solution also allows the patient to speak to the virtual assistant, for example to report symptoms.

What does this mean for healthcare practitioners and organisations?

The practitioners who receive the recorded measurements from their patients need to understand the functionality of the platform (including potential customisation options for patients with comorbidities and complex diseases) and determine which patients may benefit from using the solution. To ensure the self-monitoring results are of value, the caregiver needs to ensure the patient can follow the assistant's instructions and take the measurements correctly. The healthcare practitioner may also receive alerts when measurements are above a certain threshold, allowing him or her to monitor patients and identify situations that require further action. This enables them and their organisations to have an ongoing but targeted interaction with patients, focusing the service where it adds most value. Such solutions can bring significant value to payors, as they may increase patient adherence and may allow for early interventions to prevent risk and reduce complications and avoidable hospitalisations.

What is its reach (and potential)?

Sensely provides content for chronic-care management in 32 languages across 14 conditions, including congestive heart failure, chronic obstructive pulmonary disease and diabetes, and is increasingly adopted not just by healthcare providers but also by insurers. Virtual-assistant applications more broadly may also be of value for policyholders (e.g., providing wellness information, e-triage and online customer service) or for pharmaceutical companies to support clinical-trial monitoring or patient education, and to improve pharmaceutical adherence and engagement.

Elderly care

Karantis360

What is it and what is its role in healthcare?

UK company Karantis360 has developed an automated, personal monitoring and alerting system that enables elderly people to live independently, ensuring caregivers and families can stay informed.

How does it work?

Karantis360 has partnered with IBM Watson and EnOcean to provide a comprehensive solution using AI and Internet of Things capabilities combined with intelligent sensors linked to a mobile device. The device shares information via a web and mobile dashboard, and can send reports and alerts to caregivers and family members. The sensors can provide information about the patient's daily routine, e.g., when individuals get up or go to bed, use the bathroom or leave the house. Using AI, the system identifies deviations from typical behaviour that could indicate that something is wrong – such as a fall – and informs caregivers and families about these abnormalities in order to inform the plan of action.

What does this mean for healthcare practitioners and organisations?

Professional caregivers can stay informed about their patients and react to urgent situations or intervene to help prevent deterioration. The real-time speech-recognition feature allows caregivers to fully concentrate on providing care, while patient records are updated in the background. Being able to immediately connect with the patient as required may provide the assistance needed for the patient to be able to live at home rather than move into a nursing home or assisted-living facility. Caregivers may need to undergo training to calibrate alerts and prioritise when to intervene.

Such applications have important implications for healthcare providers. They not only help prioritise when and how to deploy outpatient, community-based support, but also enable patients to return home earlier from hospital, freeing up hospital capacity to be used by others in need and reducing waiting times and costs. Providers may also find such systems offer them a competitive advantage, as families and caregivers increasingly look for peace of mind when it comes to their loved ones. Over time, AI-generated insights can be used for population-health management, enabling the system to prioritise use of resources and proactively identify, on a population-basis, drivers and triggers of deterioration.

What is its reach (and potential)?

The percentage of the population who are 65 years or over is growing, rising to 19.2 percent in the EU in 2016, and almost one third of those people lived alone at home in 2015.[57] The annual growth in demand for care and housing for elderly people in the EU is expected to grow by 3.5 percent and 5.5 percent respectively.[58] The increasing unsustainability of European healthcare systems when factoring in the increasing care needs of ageing populations, indicates the impact such systems could have if scaled across Europe.

2.4.7 Improving population-health management

AI can be used on large datasets to predict health outcomes within a population, which helps health systems focus more heavily on prevention and early detection, improve population health outcomes and, over time, ensure the financial sustainability of the care system.

Using AI to analyse large datasets may prove useful both in healthcare settings and epidemiological studies. AI-powered models based on clinical data from a large population (e.g., patients within a health region, or an integrated provider system) may help identify early risk factors that can trigger preventative actions or early interventions at a system level. They may also be useful in determining what to prioritise during times of staff shortages. Similarly, identifying an increased risk of unplanned hospital admissions could help practitioners intervene preemptively to avoid them.

> “*We have changed how people use the healthcare system. We have algorithms to predict future health risks and, based on them, we have developed interventions.*
>
> **Ossi Laukkanen, Mehiläinen**

In population health research, AI may be able to uncover previously unidentified correlations between factors, for example combining data collected by wearables and health outcomes, which can be investigated together in hypothesis-driven studies with the goal of a better understanding of underlying factors that cause diseases. Such algorithms are already used in systems that are at least partially integrated across provider settings and on a population-health region basis, or that have shared incentives to deliver population-based outcomes (clinical, operational or financial). At Sheba Medical Center in Israel, an AI solution aims to predict which of the colorectal cancer patients undergoing surgery will suffer from leakage as a complication. By identifying the at-risk patients early, it aims to minimise or remove the risk through intervention. AI solutions may also help in prevention as part of national screening programmes, improving accuracy rates and enabling earlier detection of problems.[59]

While these applications generate a high degree of enthusiasm, there can be a concern that they are of limited use beyond the populations on which they are trained (their “generalisability”). In practice, this means further development, external validation and testing in clinical practice and across settings and geographies will be crucial to allow for a more wide-spread use of AI-based models.

Improving population health

Mount Sinai Health Systems – Risk prediction for hospital emergency admissions

What is it and what is its role in healthcare?

Mount Sinai Health Systems, a hospital network in New York City, has developed a model to identify patients from their population health programme that are at risk of unplanned admission. This is part of Mount Sinai's effort to transition to a delivery model focused on value and risk-based population health.[60]

How does it work?

Mount Sinai's Department of Population Health has been using machine-learning algorithms to mine data that identifies patients who are at risk of an unplanned admission among the system's 500,000 patient population health programme and develop predictive modelling features.

What does this mean for healthcare practitioners and organisations?

The system can enable clinical pathways and protocols to be redesigned towards intervening proactively in the highest risk cases. This shifts the working patterns of practitioners from reactive care to proactive care. To adequately address the risk, practitioners and social workers need to understand how the model identified the patient and which factors may need to be addressed to mitigate the risk. They may, therefore, become more alert to the risk factors that the model identifies, which can help reduce unnecessary admissions. In turn, to increase the clinical validity of the model, they need to feed back into the model which interventions were made and whether patients were admitted to the hospital as predicted. Organisations that can implement risk-prediction models and intervene accordingly may also deliver better health outcomes for their patients, as well as reduce overall avoidable hospitalisation costs.

What is its reach (and potential)?

AI-based models could help reduce the significant numbers of avoidable admissions and subsequent lengthy hospital stays, a feature of many EU health systems. Ambulatory care sensitive conditions, for example, account for up to 14 percent of emergency admissions in the UK.[61] This would imply systems aggregating larger population datasets and aligning resources and incentives to adequately address identified risks while continuing to improve AI models. AI-based models can also help predict the progression of chronic disease, a leading cause of death and disability within the EU, slowing down disease progression and significantly improving population outcomes.[62]

2.4.8 Improving healthcare operations

> *Most of the potential value in healthcare via AI will be realised through the cognitive augmentation of routine interactions – rather than the more headline-grabbing applications in clinical decision support that tend to get much of the attention. By assuming delegated routine tasks, these applications free up human professional carers for those high-touch patient interactions that only humans can provide and that allow them to take care of more people.*
>
> **David Champeaux, Cherish Health and HIMSS Advisory Council Member[63]**

The use of AI in healthcare may be more readily accepted when it helps free up practitioners from routine, low value-add administrative tasks, to increase direct time with patients. According to one study, "AI currently creates the most value in helping frontline clinicians be more productive and in making back-end processes more efficient […less so] in making clinical decisions."[64] Potential areas for improving healthcare operations include scheduling, hospital admissions, discharge and capacity management, optimising processes in the operating room and the emergency department, as well as moving patients between diagnostics and the ward. Such applications can significantly and directly affect patients by reducing waiting times, and increasing transparency on process, times and outcomes – all of which lead to a better patient experience, as inefficiencies along the patient pathway are ironed out.

Improving healthcare operations

Qventus

What is it and what is its role in healthcare?

Qventus is an AI-based software platform that solves operational challenges that occur in the hospital. Delays or cancellations of surgeries plague hospitals and can result in worse clinical outcomes, ineffective use of healthcare resources (e.g., theatres, anaesthetist time) and higher costs per patient.

How does it work?

Qventus's operating-room solution helps optimise the different steps of the perioperative flow and proactively addresses potential bottlenecks using machine learning. During patient preparation, the platform identifies missing requirements to avoid last-minute cancellations. The software detects unexpected orders and late-start risks during the preoperative phase and optimises the block schedules in real-time. It helps hospital teams prioritise, for example, by identifying high-priority actions and nudging the teams to resolve issues. The influx of patients to peri-acute care units, intensive care units or standard in-patient wards can be predicted to locate suitable hospital beds, minimise postop holds and speed up inpatient recovery.

What does this mean for healthcare practitioners and organisations?

The platform can help staff complete all the presurgery requirements, e.g., reminding the physician to complete consent forms or issuing reminders for missing diagnostics. Ward nurses benefit from having reliable start times and estimates for the length of surgery, which helps them better plan daily work and prioritise which patients need to be prepared, when a staff member needs to provide postoperative care or more time-consuming monitoring, or plan the admission of a new patient who has a predicted need for intensive care after surgery. For physicians, reliable operating times reduce waiting times for the operating room (e.g., taking care of patients on the ward instead of waiting in the operating room for a delayed surgery to start). For surgery coordinators, the software helps schedule operations and day-to-day staffing decisions through instant AI-enabled recommendations.

Such solutions can have significant impact on hospital flows. According to Qventus, its operating room solution has helped clients reduce same-day cancellations by 25 percent, and peri-acute care unit transfer delays by 23 percent, while seeing a 20 percent increase in patient satisfaction score. To be set up for success, hospitals have to develop an adoption plan that allows for an initial transition period during which staff members can be trained on the software to reap its full potential.

What is its reach (and potential)?

There is significant need for operational improvements in hospital operations – in October 2019, 84 percent of NHS patients had to wait more than four hours in A&E to be seen, and waiting times are increasing.[66] AI solutions that solve operational challenges have huge potential across healthcare – from hospitals to outpatient clinics, assisted living and nursing facilities, as well as home care.

2.4.9 Strengthening healthcare innovation

> *The digital revolution in healthcare provides new ways to both collect high-quality data from each patient and connect it to data from large pools of patients for analysis with artificial intelligence-based algorithms. This enables us to arrive at a deeper understanding of how to treat an individual… Real-world evidence, molecular information generated from next-generation sequencing, data from wearable devices and mobile apps, and novel clinical trials are transforming the future of care.*[57]

AI is being applied to many pharmaceutical R&D activities although, as in clinical practice, the opportunities identified are often far ahead of the impact on the ground. Early applications include disease state and target understanding, lead selection and optimisation, clinical dose and endpoint selection, therapeutic tailoring and portfolio management. Applications in development, regulatory and safety support include protocol optimisation, adaptive development plans, trial planning and execution, portfolio management and active safety surveillance.[68]

Startups such as Recursion Pharmaceuticals and BenevolentAI are innovating, while big pharmaceutical and technology players are focused on realising opportunities from AI. Big Pharma is also making major investments and partnerships to address opportunities. In 2019, Novartis and Microsoft announced a partnership to apply AI to developing personalised therapies for macular degeneration, cell and gene therapy and drug design; Bristol-Myers Squibb entered a multiyear strategic agreement with Concerto HealthAI to use machine learning to help design protocols for precision treatment; and AstraZeneca announced partnerships with BenevolentAI and Schrödinger to accelerate drug discovery using machine learning.[69]

However, even as capital-rich global organisations invest heavily in data and capabilities to address priority applications, pharma companies have found it hard to realise the promise of AI. Novartis CEO, Vas Narasimhan, has reflected that beyond applications in clinical trial operations and finance there is "a lot of talk and very little in terms of actual delivery of impact" from machine learning and AI.[70] One major challenge is data – although pharma companies have a lot of data, they are often poorly suited to AI due to quality issues, inconsistent formats or the challenges of linking data and obtaining the necessary consent to use in different use cases.

As a result, major investments are now taking a step back, focusing on developing distinctive data assets and consistent data formats that will enable future applications. Sanofi's DARWIN platform, for example, applies AI to anonymised data from the records of 450 million patients to accelerate and deepen insights on treatment effectiveness, safety and value.[71] Roche's Navify Tumour Board solution, which curates and presents data to promote collaboration and accelerate workflow in tumour boards, also highlights the potential for structuring data in a way that can improve the efficiency of healthcare delivery to develop datasets with consistent formats of high value for research.[72] Overall, AI is now applied in different elements of the business system in the pharmaceutical and medtech industries in order to increase the speed to market of new products, reduce costs, enhance clinical outcomes and serve a variety of organisational goals.

2.5 From AI today to AI tomorrow

We cannot make predictions for exactly how AI applications in healthcare will evolve, but three distinct phases of development are starting to emerge.

Phase 1: near term

> *The low-hanging fruits of AI in healthcare will come with image recognition, triage and helping people with chronic diseases to manage independently and live well.*
>
> **Stefan Vlachos, Karolinska University Hospital**

In the first phase – the near term – we expect AI solutions to pick up pace in areas with low-hanging fruit – i.e., a need for support in completing certain tasks, where the technology is available and where practitioners are willing to adopt the solutions. These are likely to be administrative, repetitive and operational tasks, which will have an impact on a wide range of healthcare practitioners, especially nurses and support staff. Medical specialties leading the way with AI solutions that have already received regulatory approval and are expected to continue developing AI solutions include radiology, pathology, ophthalmology and dermatology.

Phase 2: midterm

> *The most promising area of technology is how to optimise patients going home and having the right alert systems in place. Machine learning is helping define the right trigger points for alerts. We cannot serve all these people in hospital anymore.*
>
> **Monique van Dijk, Erasmus MC**

In the second phase – the midterm – we expect to see more AI solutions embedded into clinical workflows. In particular, these will support the shift from hospital-based to home-based or remote healthcare, and more applications that help patients take ownership of their own health, at different levels of complexity (e.g., from noncomplex acute discharge patients to oncology patients). As Hiyam Nadel from Massachusetts General Hospital says, "With machine learning, a patient with a cancer diagnosis can be matched with a personalised treatment or clinical trial; acute patients who urgently need to check symptoms at home appreciate such technologies; as do providers who see greater opportunities for predictive analytics."

NLP solutions may be increasingly applied in a variety of applications, such as medical notetaking and information retrieval, both in the hospital as well as the home. In this second phase, we would expect to see an increase in AI-related clinical trials and in regulatory approvals of AI solutions, paving the way for the development of reimbursement models. Specialties likely to become more involved with AI during this second phase will probably be clinical disciplines such as oncology, cardiology or neurology, where advances are already being made. We would also expect the continued scaling up in diagnostics-focused specialties, focusing on the development and evaluations in the areas of diagnostics and CDS. Solutions empowering patients and releasing pressure on practitioners, such as virtual assistants and administrative workflow tools could also become more commonplace in this phase. This scaling up of AI deployment would be fuelled by a combination of technological advancements (e.g., in deep learning, NLP, connectivity etc.) and cultural change and capability building within organisations.

Phase 3: longer term

In the longer term, we would expect to see more AI solutions in clinical practice that drive improvements in quality of care, with approaches demonstrated in clinical trials. These will increasingly use longitudinal data sets, providing insights across episodes of treatment and settings of care, and incorporating new types of data from wearables and sensors. There will be increasing focus on improved and scaled CDS tools in a sector that has learned how to implement AI into clinical practice and has adapted its mindset, culture and skills. New applications will include the ability of AI-based mathematical formulas to determine the correct dosage of immunosuppressant drugs to administer to organ-transplant patients – a task previously done through a combination of guidelines and educated guesswork. With dosing errors accounting for more than 35 percent

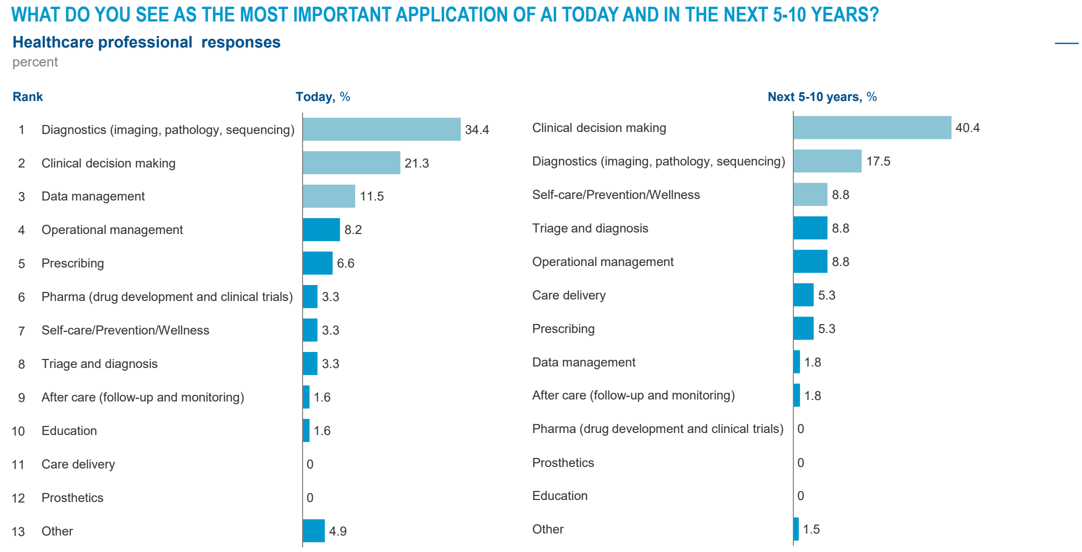
> *The future will bring further integration of data, including the relevant context of the patient, which will help to create an enriched "digital twin" of the patient that will help decide on the optimal therapy outcome for each specific patient – and maybe help to predict the risk of developing a disease or complication.*
>
> **Hans Hofstraat, Philips Chief Technology Office**

of preventable medical errors, these would be powerful examples of significant quality and outcome improvements for patients with complex histories.[73] While we ultimately expect to see the development of AI solutions in all medical specialties, some – such as obstetrics – are likely to take longer.

As data integration allows us to develop the "digital twin" of the patient – i.e., a comprehensive data record of an individual – AI may also open new routes to delivering better, faster and more cost-effective care, many of which we may find hard to imagine at this early stages of AI's evolution, and may have a greater focus on prevention and promoting wellness. An important precondition for AI to deliver its full promise in European healthcare will be the integration of broader datasets – and robust governance on the use of algorithms across partitioned datasets and organisations – alongside increasing organisational, user and patient confidence in AI and in their own ability to harness its potential to improve care.

This progression from routine tasks to more complex applications was echoed in our survey of healthcare practitioners. The main AI applications they see today are in diagnostics, clinical decision making and data management and operational management, but over the next five to ten years, they expect other areas to grow, such as self-care, prevention and wellness, triage and diagnosis, or applications linked to care delivery, in and outside the hospital (Exhibit 2.10). This direction of travel is also reflected in the solutions startups are developing.

Exhibit 2.10 – AI will become increasingly important for clinical decision making

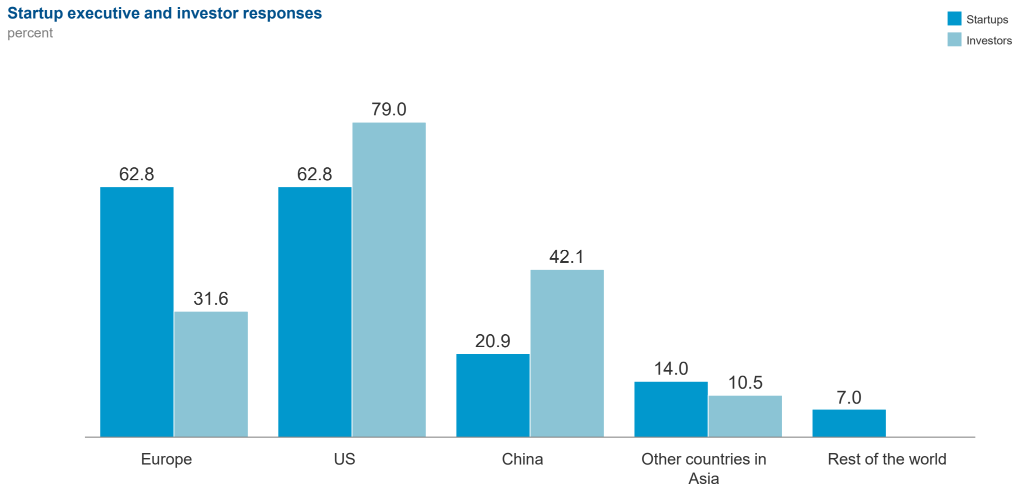


SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

AI startups and healthcare investors agree that the US will continue to be a major growth market. Startups seem bullish about the prospects of the European market, seeing it on a par with the US (Exhibit 2.11), while investors see the US dominating, with China as a growing new market.

Exhibit 2.11 Startups and investors agree on the importance of the US AI healthcare market, but have differing views on Europe and China

WHERE DO YOU SEE THE BIGGEST MARKET GROWTH FOR YOUR TYPE OF SOLUTION IN THE NEXT FIVE YEARS?



SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020; multiple choices

All survey respondent segments were equally bullish, however, about the potential of AI in European healthcare and internationally. Despite scepticism around the maturity or effectiveness of specific solutions available today, healthcare professionals, health investors and AI startups are increasingly excited about growing AI in European healthcare and are increasingly ready to contemplate the changes it could bring to their day-to-day life and work.

Chapter 3

How will AI and automation change the healthcare workforce?

Despite the undeniable potential of the various technologies and applications reviewed in Chapter 2, the jury is still out both on the potential impact of automation and AI as a spectrum of applications on healthcare practitioners and on the likelihood of adoption at scale in a way that could revolutionise healthcare delivery. In this early stage of AI evolution, it is hard to predict all the ways in which healthcare delivery will change, and there are multiple possible operational and business models that could emerge.

To prepare to make the most of the opportunities AI offers to improve patient care, healthcare practitioners would need to start changing their approach to education, lifelong learning, teamwork, patient empowerment and consumerism; and welcome and integrate new categories of professionals, with hybrid "clinical+data" profiles, or entirely new profiles, such as data scientists.

Automation and AI are often used interchangeably but are not the same thing. However, as described in Chapter 2, automation solutions increasingly involve an AI component in order to expand their flexibility and effectiveness in addressing the challenges faced by healthcare organisations and by individuals. Given that AI represents a subset of solutions referred to broadly as automation, in this report we draw on the MGI work on the impact of automation and AI across industries to explore the possible impact of AI on healthcare practitioners in Europe. We complement this view with an activity-based perspective on the areas where AI can transform the lives of practitioners and a review of some of the new profiles that might be needed, to highlight the major changes organisations will have to address.

3.1 Jobs lost, gained and changed: Healthcare in 2030

In a series of publications since 2017, the MGI has studied how automation is likely to affect the workforce, with an emphasis on how automation may reduce the need for some activities, as well as how many drivers such as productivity, ageing, investments and consumption could increase demand for certain occupations and work activities.[74]

> *AI is not there to take over the meaningful part of the clinician's job – it would never work if it were to cut the human connection between nurses and their patients.*
>
> **Dr. Kyra Bobinet, Fresh Tri**

This report goes further, focusing on healthcare specifically and on the impact of automation and AI on the workforce in Europe. Using the methodology of the earlier MGI automation work, this analysis attempts to identify the activities and occupations within healthcare that are most and least susceptible to the impact of automation and the introduction of AI.

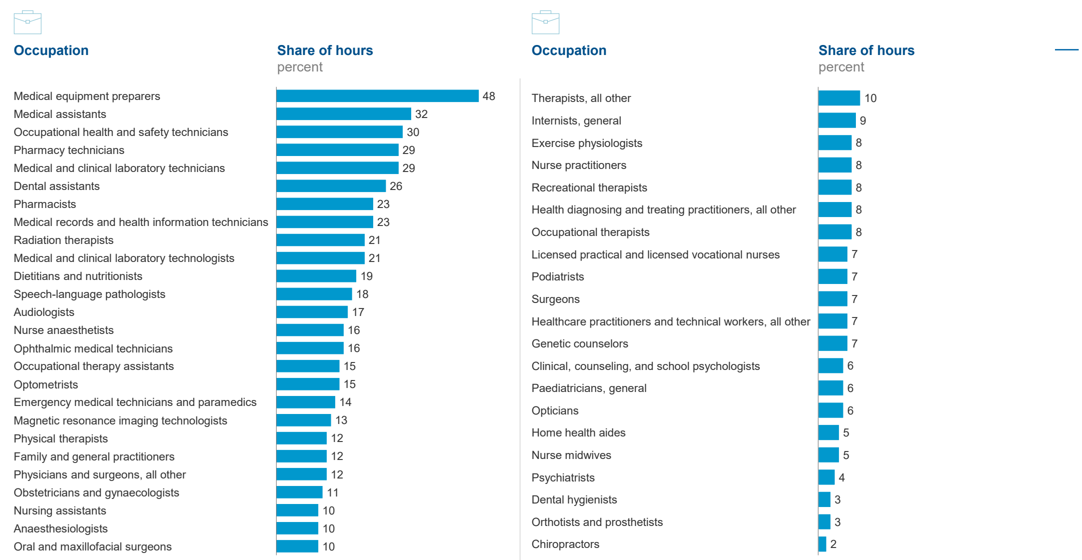
Automation will affect most jobs across sectors, but the degree varies significantly. For example, up to 58 percent of time spent in manufacturing today in the selected EU countries is potentially automatable with existing technology and could be freed up for other tasks, but in healthcare the time spent is as low as 30 percent – among the lowest of any sector. In most cases, automation only affects specific activities within occupations, freeing up time to be used in a different way. In healthcare, this could translate to providing more direct care to patients as opposed to handling administrative tasks. The MGI analyses suggest that the potential for automation of tasks in healthcare varies significantly, with activities performed by nurse assistants or dental lab technicians, for example, having more potential for automation; activities performed by surgeons and psychiatrists having less.

The mix of activities carried out by the healthcare workforce include many that have specific skills that are harder to automate, and those skills are needed in greater proportions within the sector than in many others. Occupations that involve unpredictable physical activities, the application of expertise or social skills have far less potential for automation than predictable physical tasks, routine data collection or processing tasks. Indeed, the healthcare sector will not see a decline in physical and manual skills, the percentage of time practitioners use gross motor skills and strength, or fine motor skills to operate equipment is expected to rise, while their time spent inspecting and monitoring will decline noticeably with the advent of digital and AI-enabled monitoring solutions.

The potential for automation is, in turn, different to the likelihood of adoption. While technical feasibility is a crucial element of automation, the cost of developing and implementing automation solutions, local labour supply, demand and wage rates, net economic benefits of automation including increased quality and safety, and regulatory and social acceptance are all factors that affect the rates of adoption across countries. The analysis highlights, for example, that prevailing local wage rates can vary widely between countries, even for similar occupations, and the relative mix of occupations also has a strong local component. The analysis presented in this report uses a midpoint scenario, which estimates that up to 15 percent of current work hours in healthcare are likely to be automated by 2030, compared to the 30 percent that have the technical potential for automation today.

Exhibit 3.1 shows the share of time that could be freed up through automation by 2030 for a wide range of healthcare occupations in seven specific European countries.[75] As discussed, the reduction in work hours varies significantly by occupation. For example, up to half of time spent on current work activities of medical-equipment preparers could be automated by 2030 in the midpoint automation scenario, while the percentage could be as low as 5 percent of time for midwives or almost nothing for chiropractors.

Exhibit 3.1 – Share of hours worked that could be automated by 2030 based on the midpoint scenario



SOURCE: McKinsey Global Institute. Selected European countries: France, Germany, Hungary, Italy, Portugal, Sweden, UK

3.1.1 Impact on employment numbers

Some healthcare practitioners may be worried that automation and the scale up of AI solutions may threaten employment, but the reality is that the European healthcare sector faces a workforce gap that reflects the global workforce gap in healthcare – and this gap is only expected to widen.[76] The WHO estimates the gap in doctors, nurses and midwives globally to be 9.9 million by 2030. In Europe, WHO expects overall demand for healthcare practitioners (across professions) to rise to 18.2 million by 2030. It also states that the current supply of 8.6 million nurses, midwives and healthcare assistants across Europe is not deemed adequate to meet either the current or projected future need.[77] According to UK healthcare think tank, the King's Fund, for the UK NHS alone, the gap between supply and demand for staff is expected to rise to nearly 250,000 full-time equivalents (FTEs), up from more than 100,000 today.[78] This means that we need not only to attract, train and retain more healthcare practitioners in the future, but also to enable them to spend time with their patients where it adds most value by reducing unnecessary processes.

Rather than threatening jobs, could AI and automation help close the gap? And to what extent? Exhibit 3.2 shows MGI's latest analysis on the change in FTEs needed by 2030, taking into account the impact of automation. The change is driven by demographic and other macroeconomic factors, including population ageing, the increased onset of chronic disease and comorbidity for elderly frail patients and the entry of caring activities into the market economy (e.g., monetisation of caring previously provided informally or within the family setting). The analysis suggests significant increases in demand for specific professionals, such as nursing assistants, licenced practical and vocational nurses, home health aides and others, with reductions in demand for occupations such as medical-equipment preparers and medical-records and health-information technicians.

Exhibit 3.2 – By 2030, different occupations will be affected to varying degrees by demographic factors and the introduction of automation and AI in healthcare

xx Percent change from 2017

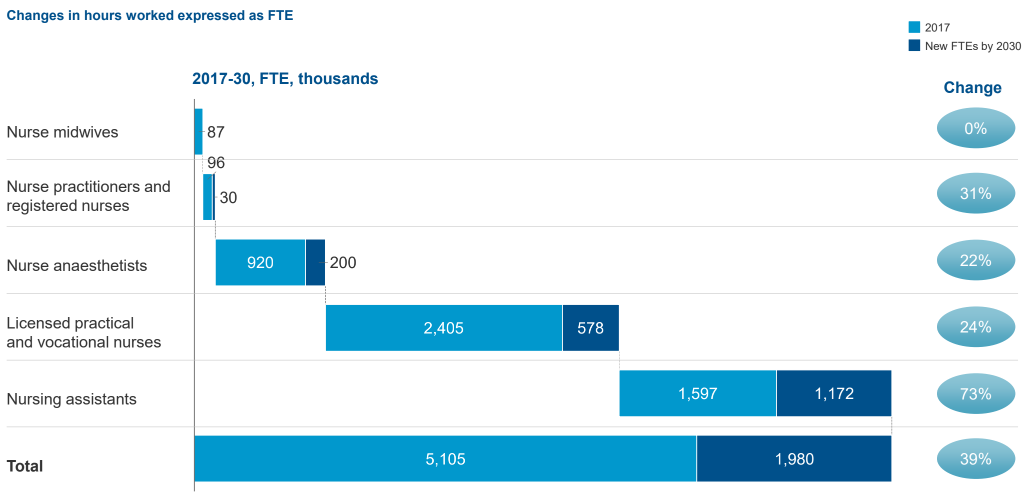
Top 10 occupations by demand growth	FTEs created by 2030		Bottom 10 occupations by demand growth	FTEs lost by 2030	
Nursing assistants	1,172,365	73	Social and human service assistants	348,957	-18
Licensed practical and licensed vocational nurses	577,900	24	Medical equipment preparers	70,497	-43
Home health aides	264,453	63	Ophthalmic medical technicians	33,204	-11
Nurse anaesthetists	200,232	22	Dental assistants	20,025	-21
Anaesthesiologist	103,968	27	Medical records and health information technicians	17,493	-18
Internists, general	74,101	28	Medical assistants	16,078	-6
Pharmacists	49,224	15	Oral and maxillofacial surgeons	11,236	-5
Exercise physiologists	46,139	23	Rehabilitation counselors	6,781	-11
Emergency medical technicians and paramedics	38,067	21	Obstetricians and gynaecologists	6,139	-7
Family and general practitioners	37,331	24	Mental health counselors	5,741	-8

SOURCE: McKinsey Global Institute. Selected European countries: France, Germany, Hungary, Italy, Portugal, Sweden, UK

The overall conclusion for both European and international health systems would be that automation, if anything, could play a significant part in alleviating workforce shortages in healthcare. Nurses, for example, spend less than 40 percent of their time directly caring for patients, with other time often occupied preparing and dispensing medication, communicating with other staff for patient handover between shifts, completing documentation and coordinating ward operations (e.g., managing beds and staffing).[79] Many of these activities, especially administrative tasks, could be supported by automation or augmented by AI to free up nurses' time and allow them to spend more time on direct care to patients and communication and coaching offered to families and caregivers.

Demand in European healthcare systems for occupations such as nursing is expected to increase significantly. Under the MGI midpoint scenario for automation, for example, by 2030, we could see a 39 percent increase in all nursing occupations (Exhibit 3.3). The biggest increase in both absolute and relative terms would be for nursing assistants, but all nursing occupations would increase apart from midwives, whose numbers would remain stable (partly reflecting EU-wide birth rates[80]). This analysis includes the estimate that approximately 10 percent of nursing activities would be freed up by automation, illustrating how automation could affect how we manage potential staff shortages.

Exhibit 3.3 – Hours worked by nurses are set to increase across the board, based on the midpoint scenario for automation



SOURCE: McKinsey Global Institute. Selected European countries: France, Germany, Hungary, Italy, Portugal, Sweden, UK

3.2 How will AI and automation change the activities of healthcare practitioners?

Having considered the impact on the sector overall, we now turn our attention to how healthcare practitioners' daily activities could change as AI and automation are introduced or scaled.

Given the spectrum of AI applications described in Chapter 2 (including varying levels of automation), it is not always possible to separate how much of the automation impact in healthcare we described in section 3.1 can be attributed solely to AI. Many interviewees and survey respondents agree that AI's impact will be felt across the healthcare workforce. They also agree that at the heart of any change is the opportunity to refocus on and improve patient care, especially for nursing. As nurse Rebecca Love puts it, "Intelligent scheduling and staffing optimisation through AI would be a game changer for nurses." This improvement could include not only providing better diagnosis and more effective treatments, but also fundamental changes to clinician-patient interactions and reimagining patient-centric care delivery, such as AI-enabled home care and chronic disease management, each with its own effect on the quality of care and clinical outcomes.

> *In the future, AI will not replace clinicians. Clinicians who use AI will replace clinicians who do not use AI.*
> **Dr. Eyal Zimlichman, Sheba Medical Center**

In this section, we discuss how the activities of practitioners will likely change as AI becomes more prevalent in the sector. Overall, AI is expected to allow practitioners to operate at the top of their licence, focusing on those activities that add the most value for patients. AI is not expected to replace clinicians but rather augment their capabilities to deliver impact for patients and the health systems they serve.[81]

3.2.1 Less admin; more patient care

Administrative tasks absorb a tremendous amount of healthcare practitioners' time, with some studies suggesting they can take up to 70 percent of a physician's time, while nurses spend only around 40 percent of their time on direct or indirect care.[82] Much of this administrative burden can be alleviated by well-designed AI solutions, which will not only mean more time spent with patients, but significantly higher job satisfaction. And, of course, making life easier for clinical staff increases the likelihood that they adopt and champion these solutions within the organisation. As Robert Freeman from Mount Sinai Hospital says, "AI is going to help to bring back more joy to our nursing team. No one wants to spend half their day on data entry."

> *The best AI will be invisible to the workflow.*
> **David E. Albert, AliveCor**

We have already seen some of the applications than can assume administrative tasks, such as clinical note takers using NLP abilities. Speech recognition has been introduced in several clinical settings to address the vast amount of clinical documentation and here we focus on the potential impact in terms of actual resources needed in care. For example, the South Tees Hospital NHS Foundation Trust Accident & Emergency (A&E) department, which provides healthcare services to around 1.5 million people in the UK, partnered with a private-sector provider to improve the speed and quality of document completion.[83] This dramatically changed activities across the A&E department: previously, 95 percent of staff were writing notes by hand or typing them; now 69 percent use speech recognition to complete clinical notes, saving on average 3½ minutes per patient in the main A&E unit – the equivalent of two full-time A&E clinicians a year.

Considering that an additional 2,200 A&E consultants are needed to fully address the staffing needs of all A&E departments across the UK, freeing up consultant time could have significant impact on the delivery of safe and timely care and on improving patient experience.[84] Similar software was implemented in East London's Homerton NHS Trust, where turnaround time for clinical letters was reduced from 17 days to just two.[85] The Topol Review estimates that saving just one minute per clinical consultation would be the equivalent of the time worked by 230 A&E doctors, 600 outpatient hospital clinicians and 3,200 GPs.[86]

AI can not only improve operations in hospitals, but also in primary and community-based care, including the out-of-hospital care of elderly and frail patients. For example, predictive scheduling – intelligently predicting which appointments are likely to overrun in a GP surgery and adapting appointment planning accordingly – and capacity management tools can help reduce waiting times for patients, improve patient experience and outcomes, and free up resources in elderly care. This is especially important where delays in access to treatment could compromise clinical outcomes, such as in specific types of cancer diagnoses.

Two notable examples of healthcare capacity management are bed management and operating room (theatre) preparation and utilisation management. These logistical challenges involve matching available resources against expected demand or a planned schedule, taking into account patient context, frailty and comorbidities, demographics, seasonality, reduced capacity in neighbouring facilities etc., but also the specific hospital context such as the operating surgeon and surgical team, clinical protocols, levels of experience, peri-operative processes, protocols around anaesthesia and recovery, and so forth. Not unlike airline operations, where matching an aircraft to a scheduled flight often needs to be revised to respond to disruption, AI solutions could allow hospitals to run operations more smoothly.

At one level, bed management is a digitisation effort that involves constantly monitoring admissions, discharges and patients moving within the hospital, to understand which beds are available. Allowing staff to see available beds on digital displays in real time, rather than call other departments to confirm availability, frees up capacity from routine tasks to spend in clinical care. Over time though, clinical staff can use the data generated to help inform an AI-augmented learning process that reduces system inefficiencies and delays; for instance, identifying the drivers of clinically unnecessary long stays. In 2016, the Johns Hopkins Hospital in the US launched a Capacity Command Center to better predict and manage patient flow; patients are now assigned a bed 30 percent faster once the decision has been made to admit them.[87] Singapore's Tan Tock Seng Hospital, one of the country's largest multidisciplinary hospitals, uses a similar system to replace a process where healthcare staff had to go through more than 300 rules during admission to correctly prioritise assigning beds.[88] These solutions can lead to small, centralised bed management teams who take all that effort away from nurses, physicians and other practitioners.

Operating rooms are a very different situation but also lend themselves to AI-based solutions. They are highly complex environments. Scheduling is complicated even without unplanned emergencies and disruptions. Determining how much time each patient will require, and exactly what resources they need is challenging. Procedures often run longer than planned, leading to cancellations for procedures booked later in the day, or booking processes allow for significant gaps, leaving operating rooms underused. AI could free up valuable time for surgeons and other staff (e.g., anaesthetists, nurses), forecasting the likely time a procedure for a specific patient could take. The Frederick Memorial Hospital in Maryland uses just such a tool and similar applications are being developed and implemented by hospitals and the private sector. Overall, there are high expectations for AI in surgery. As Todd Ponsky, Professor of Surgery at Cincinnati Children's Hospital Medical Center, says, "The flow of patients through a busy operating room could be 'smarter'. Using AI-based algorithms could predict time flow better, which could substantially increase efficiency and allow more patients to be cared for on a given day."

From just these two examples, it is clear that AI enabled solutions can take repetitive automatable tasks away from practitioners and can deliver operational efficiencies that allow physicians, nurses, and other clinical staff more time to spend on direct patient care. There should be few impediments to adoption. A recurring theme from our interviews was that a reduction of administrative work is not just less controversial, it is top of most people's wish list.

3.2.2 Supporting clinical activities

Apart from supporting routine tasks, AI can also augment a range of clinical activities. It can speed up labour-intensive processes and give practitioners information that can lead to better patient outcomes and higher quality of care. We have already looked at some examples in Chapter 2. Here, we will consider the implications for the daily lives of practitioners in more detail.

Improve the speed and accuracy of diagnostics

Radiology, pathology and ophthalmology are clinical disciplines already being reshaped by AI. In recent years, AI algorithms, and deep learning in particular, have made remarkable progress in image-recognition tasks. They have thus propelled the field of medical-image analysis forward. These specialties involve large numbers of images delivered across different care settings, through interoperable systems. The evidence basis for these technologies keeps expanding and specific technologies have been shown to perform as well as experts in medical-image analysis in selected trials and industry-led applications.[90]

In radiology, trained physicians visually assess medical images to detect, characterise and monitor diseases. But AI can automatically recognise complex patterns in imaging data and provide quantitative, rather than qualitative, assessments of radiographic characteristics. It can be used in multiple stages of the workflow, helping with many of the steps required to improve patient safety, diagnostic accuracy and time-efficiency. In these early stages, AI can help the physician determine the most appropriate imaging procedure and define personalised radiation doses during the imaging process, reducing patient exposure to radiation based on specific risk factors using machine-learning processes based on population data.[91]

During image capture, AI can analyse images as they are acquired, saving the physician time by performing relatively simple steps, from image rotation to real-time quality checks of the field to be acquired. These AI-generated, physician-validated images can, in turn, be used to improve the underlying algorithms. As Egil Samset from GE Healthcare Cardiology Solutions says, "The goal is to have fully AI-augmented workflows connected to treatment guidelines; allowing the physician to focus on care delivery."

Automated segmentation, i.e., annotating the medical-imaging data, is another time-consuming step for physicians that can be supported using AI. Conservative estimates suggest that radiologists spend 60 percent of their time reviewing images. AI can help the radiologist spot areas of interest and suggest the most likely diagnosis.[92] The Topol Review suggests that extrapolating results from breast-cancer-detection algorithms alone could reduce the time radiologists review images by 20 percent. AI can also save physicians' time by providing structured reporting, generating the bulk of the final report, linking words, images and quantitative data. Adopting reporting standards could make the data more interoperable too, and feed into radiology case collections to teach both clinicians and algorithms.[93]

Radiology today often employs "double reading" to reduce diagnostic errors, ensuring images are reviewed by two different radiologists. Recent research suggests that if an AI system participates in the double-reading process (as happens in some UK hospitals), the AI performance is comparable to the double-reading results and could reduce the workload of the second radiologist by up to 88 percent.[94] Such advances will be necessary to allow physicians to cope with the sheer amount of healthcare data now being generated. "Twenty years ago, you would see maybe 100 X-rays per shift," explains Dr. med. Dominik Pförringer, orthopaedic and trauma surgeon at TUM Hospital, "Through modern tomography, you will have a large multiple of this number."

Once images are captured, they need to be triaged to decide which cases are more urgent and whether a patient requires more comprehensive imaging, such as an MRI. Dr. med. Pförringer compares AI to a hunting dog: "It has a better nose. An AI-enhanced CT scanner that tells me 'in pictures 840-880 I saw some irregularities' would be incredibly helpful. It could even identify detectable conditions that I am not looking for at that time."

This ability to identify potential risks of disease onset, even when not specifically looking for them, could save lives, as radiologists often focus on a specific question while handling increasing amounts of imaging data. AI could be complementary to the radiologist's diagnostic effort, always bearing in mind that, as radiologist Antanas Montvila says, "We are still going to be the ones signing the report." Radiology today sees increasing applications of AI, from oncology (e.g., breast-cancer or prostate-cancer detection), to interpretation of chest radiographs and liver-lesion analysis.[95] Last, as discussed in Chapter 2, new solutions in Sheba Medical Centre, Israel, explore how AI-based image reconstruction could help reduce the radiation exposure of a patient to 4 percent of a conventional CT, one of the highest volume diagnostics in Europe.

Improve the speed and accuracy of diagnosis and detection

There are many examples of how AI could help healthcare practitioners make decisions and supplement the diagnosis and detection process, from identifying hospital patients at risk of deterioration to detecting cardiac arrest during emergency calls.

Identifying patients at risk of deterioration at the hospital – and in the community

During a hospital stay some patients are, or can become, vulnerable to adverse outcomes caused by malnutrition, septic shock or acute respiratory failure. Patients are typically evaluated against standardised clinical-risk scores and monitored routinely for deterioration. AI-based warning systems can more accurately identify patients at risk.[96] For example, patients admitted to hospital with malnutrition have longer hospital stays, higher rates of 30-day readmission and an increased risk of infections. Identifying patients at risk and treating the underlying causes early therefore improves patient outcomes and reduces strain on the hospital.

At the Mount Sinai Health System's hospitals, algorithms are changing how dieticians work. Previously, dieticians would move between wards trying to identify and prioritise patients based on preset criteria such as age or condition. AI-based solutions are now integrated into patients' EHRs and when a dietician logs in to the system for his or her morning round, a dashboard highlights the patients most likely to be malnourished and thus who should be seen first. The algorithm ranks and colour-codes patients, but also allows sorting and filtering so dieticians themselves can quickly identify priority patients in their unit. AI, yet again, is not a replacement for practitioners' clinical judgement, but a tool that takes basic tasks out of the hand of clinicians so they can spend less time screening patients and more time caring for them.

IBM Research similarly highlights the potential of AI to change how hospital teams work when caring for epileptic patients, by preemptively detecting the likely onset of epileptic seizures. An intensive-care unit can have an average of almost 700 alarms per patient per day and can process approximately 10 gigabytes of data per day. Such data can be used in epilepsy research to observe conditions that exist before seizures, or to define correlations between the disease and nonadherence. They can help clinical teams recognise seizures rapidly, while reducing the labour-intensive need for continuous in-person monitoring.

Outside the hospital, mobile technology and remote sensor-generated data and machine learning can allow care teams to deliver personalised seizure forecasting and seizure detection, reducing the time taken to administer medication when a seizure occurs. Such approaches can be used to support at-home monitoring or, more broadly, the continuous monitoring of patients in resource-poor environments, and can reduce patient self-reporting, increasing the efficiency of clinical trials in this field.[97]

Detecting cardiac arrest during emergency calls

Emergency services dispatchers have a variety of duties such as keeping callers calm, obtaining essential information, providing first-aid instruction and, vitally, determining what the caller requires in order to triage them correctly and advise on the correct first-aid procedure – all while handling vast volumes of calls and running the risk of not prioritising the most critical cases, which could have an impact in terms of lives saved or lost.

In Copenhagen, Corti, a startup, has used AI to analyse emergency calls in real-time and identify signs of cardiac arrest. According to Corti, dispatchers recognise cardiac arrest over the phone in 73 percent of cases, while the algorithm, focusing on verbal and nonverbal patterns of communication such as the caller's tone of voice, reportedly identifies it correctly in more than 93 percent of cases. It also does so faster (which is critical, as each minute of delay reduces chances of recovery by 7-10 percent). The algorithm acts as a virtual assistant, prompting the dispatcher to ask certain questions and making a recommendation on whether the person concerned is suffering cardiac arrest. Similar solutions could be developed to identify other critical conditions, such as a stroke or even heart attacks in women, who often present differently to men suffering heart attacks and are less likely to be spotted.[98]

While such algorithms could revolutionise emergency care, the stakes are also high if an error is made. For now, such solutions offer only guidance, which means the dispatcher needs a good understanding of the algorithm and its strengths and limitations in order to take the final decision.

3.2.3 Easier access to more knowledge

The traditional model of learning and care delivery has relied on physicians, nurses and other practitioners dedicating a lot of time to accessing and then memorising information, whether in early training, or in ongoing efforts to maintain their skills. The volume of information has always been high, but recent advances in data and research output are making the effort almost insurmountable. Despite their best efforts and determination to deliver the best care possible, many clinicians feel they cannot keep up.

AI could bring an enormous amount of relevant, curated and prioritised knowledge to the practitioner's fingertips, creating new possibilities for both learning and care delivery. During early education, it could mean that examinations are less about memorising knowledge and more about delivering insights through learning, augmented by AI support, while honing clinical counselling skills – a trend already observed in some medical schools. During practice, it could also give practitioners easy access to the latest advances in innovation so they can give their patients high quality personalised care. Practitioners can focus more on the human component of their job, ensuring not only that they have the right diagnosis and treatment but that they have the time to coach, counsel and empower patients to self-care where appropriate, and take ownership of their health and well-being.

AI solutions would also allow practitioners to work more deeply with multidisciplinary teams to deliver truly integrated care across care settings (e.g., from hospital ward to primary care and home), shifting the healthcare system culture towards more collaboration, integration and joint ownership of clinical outcomes. This potential of AI is now increasingly welcomed by clinicians. Anthony Chang, founder of AIMed, says, "As we try to create an ecosystem and a community of AI and clinical professionals, we now see a profound shift on both sides, but particularly among clinicians."

3.2.4 Patient empowerment, self-care and remote monitoring

There is a broad trend in the healthcare sector away from caring for patients in hospitals and towards more community-based care, built on patient empowerment, self-care, and the technical possibilities of remote care and home monitoring. In addition, more emphasis is being placed on prevention and population-health management.

AI-enabled e-triage solutions, such as Ada, Babylon, Mediktor or K Health, could increasingly divert patients to appropriate solutions for their specific symptoms and underlying conditions. This could reduce the clinical workload – especially in primary and emergency care – and free up time for healthcare professionals to address patients with severe and urgent needs.

> *It's time to reduce paternalism in healthcare. Other industries involve the customer as much as possible. Why should medicine be different?*
> **Adolfo Fernández-Valmayor, Quirónsalud**

Patients with chronic conditions will increasingly manage their disease helped by AI-enabled monitoring and decision support. Diabetic patients have been some of the first to be involved in a degree of automated self-care. Historically, patients have monitored the progression of diabetes with pen and paper and through fortnightly visits to the hospital. Digital apps now allow healthcare specialists to monitor patients remotely and AI-enabled continuous blood glucose monitors have allowed more accurate tracking of blood glucose levels. Similarly, solutions such as the closed-loop "artificial pancreas" could allow type 1 diabetes patients to improve self-care and blood glucose control, while practitioners receive and review patient data remotely, reducing the need for regular physical examination.

Home-based care is also on the rise. Most patients who need to recover from illness or surgery would rather do so at home, and health systems increasingly try to reduce clinically avoidable hospital stays or long lengths of stay. Advances in monitoring technology and AI-augmented clinical-alert systems, could mean that even some patients with cardiac and blood-pressure complexities could be moved from the intensive-care unit to their homes with centralised monitoring from nurses and physicians. Hospital-based professionals will need the right skills in order to work closely with AI teams to develop the right calibration, for example on risk-alert thresholds, and to ensure they can use resources most efficiently. It is true that AI-enabled solutions are already learning and calibrating which alerts physicians perceive as more or less important – a trial in Israel is improving the frequency of alerts in radiology using algorithms based on the action physicians take following specific recommendations. However, there is no doubt that physicians and other healthcare practitioners will need to be an intrinsic part of the AI development process.

3.3 New activities and new skills

New technologies inevitably lead to new types of activities for healthcare practitioners – not least because of changes to the way patients themselves interact with the healthcare system – and entirely new skills to help them navigate this digital world.

> *Our job profile will change over time. AI will be able to do some tasks that take a lot of time. We are happy if we can delegate this and concentrate on diagnostic thinking and talking to patients. I don't see any threat for radiologists through AI in the next 20 to 30 years.*
>
> **Felix Nensa, University Hospital Essen**

3.3.1 A new way of interacting with patients

Patients already have unprecedented to access medical knowledge. Their expectations for digitally accessed services are high, carried over from more consumer-focused sectors. Indeed, patients are becoming more like consumers when accessing healthcare, evaluating options in advance and often coming into a consultation with information to discuss with their physician – even if that information is often erroneous.

The introduction of AI solutions, especially e-triage or self-diagnostic tools, may exacerbate the trend for patients to attend a consultation with a preformed view on likely diagnosis and treatments. The quality of this information can vary widely, which may lead to frustration as physicians need to address questions raised by incomplete or at times even erroneous information.

But the quality of information patients has can also be significantly better. Physicians and other healthcare practitioners will be increasingly asked to give a second opinion – the first having been derived by an algorithm. This will require the clinician to have a basic understanding of how these applications work, be able to discuss their limitations and whether they have been used appropriately. But beyond that, it will require an open mind and a willingness to engage with the AI-driven recommendation. It may even require additional consultation time, which may be alleviated by the increased digital and AI literacy of the wider patient population, potentially reducing the overall numbers of patients seeking frontline care.

> *An acquaintance called me for a second opinion having first accessed an AI online triage tool while on holiday. They had been on a surfing vacation and reported a severe headache. AI made a correct diagnosis: a carotid dislocation. The patient took an aspirin and flew home. My work focuses on bones and joints – I would have not immediately thought about the vascular aspect. I was in fact distracted by the fact that the patient accessed the AI online triage tool first. I am now convinced this could be the future of medicine.*
> **Orthopaedic surgeon**

As we have seen, AI-enabled solutions are also increasingly available for care delivery, including for patients to administer care themselves, and there have been increasing efforts to allow for the prescription and reimbursement of "digital medicine". In Germany, as of 2020, patients can be prescribed digital apps, including digital diaries for diabetes, apps to support physiotherapy or psychotherapy treatments or to measure blood pressure, which will be reimbursed by Germany's statutory health insurance.[99]

For physicians to prescribe such apps, they of course need to be aware of them and understand for whom they are appropriate and under what conditions. They need to understand the relative advantages and limitations of AI solutions, as well as the ethical implications. If an AI-enabled solution could be an option for a patient, physicians will need to decide not only whether the technology is appropriate for the underlying condition, but also whether the patient will be able to use it correctly. They will need to spend time introducing patients and caregivers to the technology and advise them on the implications of the clinical data generated. This will be a world of transparency, collaboration and dynamic interaction between healthcare professional, patient, carer and AI provider, not only to improve outcomes but also to preemptively manage potential risks, including ones of calibration on how and when to use specific solutions.

3.3.2 Boosting digital skills in the broader healthcare workforce

Healthcare staff have been working on their digital literacy for the past 15 years but it is still listed as a major priority in *The Topol Review*.[100] Practitioners need not only to be able to use AI solutions, but assess when they are appropriate for patients and those on the front line need to explain them to those patients. This requires a mixture of digital literacy and critical thinking skills rather than specific qualifications in statistics – and these skills are needed across all healthcare staff.

The MGI 2018 discussion paper, *Skill shift: Automation and the future of the workforce*, analysed these changing requirements, which has informed our discussion on changes needed for the healthcare workforce. This new report takes an explicitly European perspective, using seven diverse European countries as a starting point.[101] Healthcare practitioners will undeniably need stronger technological skills in order to understand how AI works at a certain level of detail, while the data scientists and engineers will need some basic medical knowledge and strong communication skills to help them translate clinical requirements into technology solutions. All staff will need both digital and genomics literacy. This means practitioners will need ongoing expertise and guidance to evaluate new technologies, based on real-world evidence and their understanding of data validity and accuracy.

> *A massive shift needs to happen in education and training. We need to upskill the workforce as a whole – we cannot rely on pockets of specialist knowledge but need to embed the new skills across a range of disciplines.*
> **Claire Bloomfield, National Consortium of Intelligent Medical Imaging, University of Oxford**

Exhibit 3.4 illustrates how much more time healthcare practitioners will need to spend using technology skills. Notably, the time spent using basic digital skills will more than double.

Exhibit 3.4 – In the healthcare sector in Europe, the highest growth in skills demand by 2030 will be for basic digital skills

≤-20 … ≥80

Skill categories	Evolution in skills: 25 skills	Hours worked in healthcare, 2017 (millions)	Change in hours by 2030 (percent)
Physical and manual skills	Craft and technician skills	158	-19%
	Fine motor skills	6,179	24%
	General equipment operation and navigation	647	7%
	General equipment repair and mechanical skills	282	5%
	Gross motor skills and strength	3,867	32%
	Inspecting and monitoring	492	-27%
Higher cognitive skills	Advanced literacy and writing	880	-31%
	Complex information processing and interpretation	673	5%
	Creativity	125	8%
	Critical thinking and decision making	4,406	16%
	Project management	1,551	-5%
	Quantitative and statistical skills	138	-25%
Basic cognitive skills	Basic data input and processing	5,414	-6%
	Basic literacy, numeracy and communication	970	-6%
Social and emotional skills	Adaptability and continuous learning	133	27%
	Advanced communication and negotiation skills	1,241	21%
	Entrepreneurship and initiative-taking	65	20%
	Interpersonal skills and empathy	2,777	29%
	Leadership and managing others	1,602	24%
	Teaching and training others	1,908	37%
Technological skills	Advanced data analysis and mathematical skills	328	23%
	Advanced IT skills and programming	144	29%
	Basic digital skills	**1,389**	124%
	Scientific research and development	534	19%
	Technology design, engineering, and maintenance	728	9%

SOURCE: McKinsey Global Institute. Selected European countries: France, Germany, Hungary, Italy, Portugal, Sweden, UK

The Topol Review identified specific areas for education and training related to AI and robotics such as health-data provenance, curation, integration and governance, ethics of AI and autonomous systems and tools, and critical appraisal and interpretation of AI and robotics technologies.[102] Now, more than ever in healthcare, there will be a professional imperative to stay relevant through a culture of ongoing learning and development, inclusivity and openness to change. Health systems will need to enable such a shift, developing a structured learning philosophy and programme, as they help practitioners adapt to the scaling up of new technologies.

3.4 Introducing new professionals in healthcare

This report focuses primarily on the relationship between AI and today's healthcare practitioners, but it is instructive to consider that the projected growth of AI solutions suggests that entirely new roles will need to enter the healthcare workforce.

Multiple roles will emerge at the intersection of medical and data-science expertise. These will be required to develop algorithms and turn them into products, implement those products in clinical workflows, apply new approaches at scale and establish the conditions to facilitate the application of AI. For example, medical leaders will have to shape clinically meaningful and explainable AI that contains the insights and information to support decisions and deepen healthcare professionals' understanding of their patients. This might include adapting algorithms to highlight those lab results that have the greatest bearing on the likelihood of a diagnosis and share comparable cases, rather than simply providing a risk score. Clinical engagement will also be required in product leadership in order to determine the contribution of AI-based decision-support systems within broader clinical protocols. Adapting algorithms into products that are usable and fit into clinical workflows will specifically require product leadership from senior clinicians. These are the people who can define protocols that benefit from the insights of AI but who are also able to use them safely and appropriately. To do this, medical leaders will require a deep understanding of the potential and limitations of the outputs from algorithms.

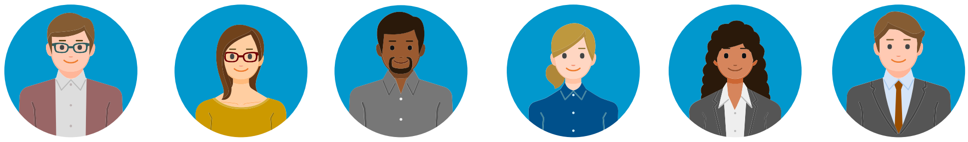
Designers specialising in human-machine interactions on clinical decision making will help create new workflows that integrate AI. Data architects will be critical in defining how to record, store and structure clinical data so that algorithms can deliver insights, while leaders in data governance and data ethics will also play vital roles. In other data-rich areas, such as genomics, new professionals will include 'hybrid' roles, such as clinical bioinformaticians, specialists in genomic medicine and genomic counsellors.

Institutions will have to develop teams with expertise in partnering with, procuring and implementing AI products that have been developed or pioneered by other institutions. Orchestrating the introduction of new specialisations coming from data science and engineering within healthcare delivery will become a critical skill in itself. Experts in the ethics and legalities of data use, intellectual property questions when working with third parties, and best practices on data privacy and data governance, will also become increasingly important. Last, although the ability to develop new approaches will be important to centres of excellence, being able to implement these approaches at scale will be essential if the benefits are to reach the majority of patients. In fact, implementing AI approaches at scale is as challenging as their development and to do so successfully will require new roles in training, remodelling workflows and communicating the benefits of AI.

The 2018 AHA report describes the new positions, competencies and skill sets AI could create in healthcare, focusing on individual hospital organisations (Exhibit 3.5).[103]

Exhibit 3.5 – AHA: new positions, competencies and skills

NEW ROLES IN HEALTHCARE: SELECTED EXAMPLES



DATA SCIENTIST

Knows how AI works

Can design AI models to perform tasks required at a hospital or health system.

AI ENGINEER

Builds the AI models to perform the tasks required at a hospital or health system.

DATA-GOVERNANCE EXPERT

Makes sure data are clean and accurate, setting policies on data collection

Makes sure staff do their jobs ethically, protecting the privacy and security of patients' data and following data-governance policies of the hospital or health system.

DATA-ENTRY EXPERT

Curates, cleans, scrubs and structures data from a variety of internal and external sources into the system that feeds AI models with the data they need to perform the tasks required at a hospital or health system.

DATA ENGINEER

Builds the system that fuels the AI models with the data needed to perform the tasks required at a hospital or health system.

CHIEF AI OFFICER

Leads the effort to explore potential opportunities, develop a cogent AI strategy, and identify the funding, professionals, technology and organisational resources to implement them.

Understands the clinical workflow, the workforce and the culture that drives care delivery.

Adapted from AHA, "AI and the Health Care Workforce", 2019, https://www.aha.org/

Many new roles will be populated by science, mathematics and computer graduates, fulfilling roles in computational genomics, data science, public-health informatics and bioinformatics. Such professionals will be embedded across medical specialties, through the appointment of consultant-level bioinformaticians, and also across scientific specialties and within primary care environments. *The Topol Review* suggests there is an urgent need for health systems to attract and retain such scarce and valuable talent, for example, by developing flexible and exciting career paths and clear routes to healthcare leadership roles.

Chapter 4

What needs to change to encourage adoption of AI in healthcare

From all that we have discussed so far, it is clear that the strides made in the field of AI in healthcare have been momentous. But moving from the hype and excitement to a world in which AI can deliver significant, consistent and global improvements in care will be more challenging. Moving from creating a solution to adoption requires considering financial, ethical, regulatory and operational factors, which could all make or break the success of AI.

> *Everyone tells you why it won't work!*
> **Zayna Khayat, SE Health**

In this chapter, we will explore a set of themes that will affect the adoption of AI and consider the role that healthcare systems, policy makers and regulators can play in pushing this transformation. Our themes are:

- Quality and suitability of solutions
- Education and training
- Data quality, governance, security and interoperability
- Change management
- Talent
- Regulation, policy making and liability
- Funding

Finally, we will explore potential implications for the EU, given the *European Strategy on Artificial Intelligence* and the EC's priority to "join forces in the European Union to stay at the forefront of technological revolution, to ensure competitiveness and to shape the conditions for its development and use (and respect of European values)."[104] In doing so, we look at the role the EU could play in encouraging greater adoption of AI in healthcare.

4.1 Quality and suitability of solutions

If AI solutions are to become embedded in healthcare, they have to work and they have to be useful. This includes providing information pertinent to clinical decisions, being supported by robust evidence, being embedded in clinical workflows and being applicable for each patient.

Yet in our interviews and surveys, the quality of existing AI solutions was frequently cited as a concern. Interviewees were worried about a poor choice of use cases, issues around the design and ease of use of AI, the quality and performance of algorithms, and the robustness and completeness of the underlying data. Many healthcare professionals emphasised the lack of multidisciplinary development and the limited iteration and improvement of technical solutions from joint AI and healthcare teams. They also stressed that many use cases of AI in healthcare are driven by what data are available rather than where the greatest need lies.

> *It's easy to let ourselves be driven by what we can do with the data, rather than by the most pressing clinical need. We see many AI solutions addressing the same tasks, because those are the tasks for which the data are available.*
> **Bethany Percha, Mount Sinai Health System**

The most obvious way to overcome this problem is to engage end users in the early stages of designing solutions – and to keep them involved as the product evolves. These are the people with the deepest understanding of the nature of the problem to be addressed and the issues that emerge during implementation, and the best placed to assess the usability of any new solution. They can also act as great advocates for solutions in their organisations and among their colleagues, which can greatly improve adoption rates.

When considering which end users to involve, developers should be as inclusive as possible, including practitioners and patients. Nurses, in particular, are on the front line of implementing new technology solutions but are often not involved early (or enough) in the design, development or implementation of these solutions.

Codeveloping solutions from start to finish is also crucial if AI is to integrate into the workflow and deliver clear value that will make adoption more likely. "I understand statistics, but AI algorithms are beyond most physicians. Equally, I do not know an engineer or data scientist who understands medicine and our work to the required degree. We need to work together, sitting at the same table", explains Carolina Garcia-Vidal from the University of Barcelona.

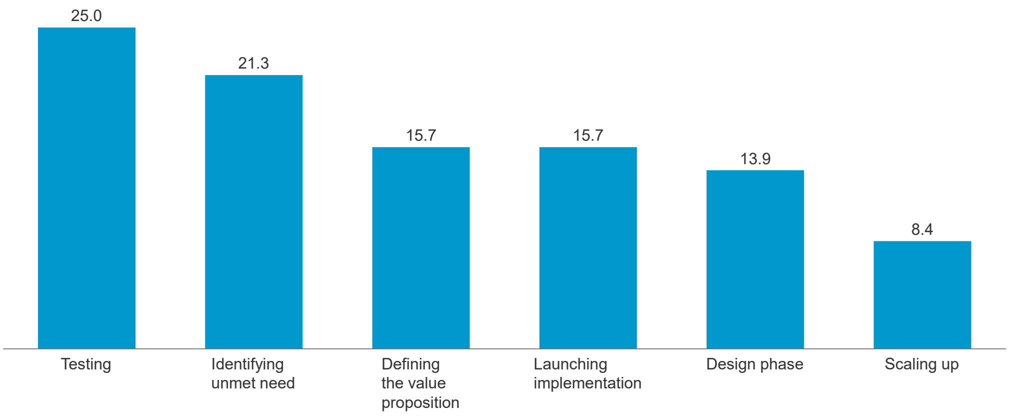
While medical practitioners seem universally keen to be involved at all stages of developing and implementing solutions – indeed, consider it an imperative – the startup community appears less convinced. Only 14 percent of survey respondents from AI startups felt that the input of healthcare professionals was critical in the design phase, rising to 25 percent for the testing phase (Exhibit 4.1).

Exhibit 4.1 – Startups place less priority on involving healthcare professionals in the early phases of development

IN WHICH PART OF THE DEVELOPMENT PROCESS WOULD YOU INVOLVE HEALTHCARE PROFESSIONALS OR PROVIDERS?

Startup executive responses

percent



SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

This certainly mirrors the experience of practitioners themselves – and it matters. One nurse explains what can go wrong when practitioners are not involved early enough: “We recently introduced AI and Internet of Things solutions at our hospital. The bed sensors are state-of-the-art, but they are not connected well enough to transmit the right information at the right time to nurses’ tablets. The lack of a ‘learning’ functionality means we cannot preemptively identify patients who may be getting worse. We could have helped design something much more useful – and likely to be used, but we were not involved upfront – and now it’s too late.”

4.1.1 *Primum non nocere* – First, do no harm: Evidence, error and bias

To become an integral part of clinical practice, AI solutions must be able to prove they work.[105] Yet many lack enough evidence – the goal can be to get into a clinical setting quickly and then adjust the solution over time in order to scale it up. For clinicians, this is a clear contradiction to the maxim that is at the heart of their profession: do no harm.

> *We are holding lives in our hands. We need proof that it works, and you have to convince people with results.*
> **Carolina Garcia-Vidal, University of Barcelona**

Any new idea must be proven to do no harm before it comes anywhere near a patient. Specifically, this means the solution needs to clear several hurdles:

- It needs to demonstrate value when applied to real-world clinical data – but getting access to that data, in order to build and validate AI models, can be a challenge.
- After initial testing, pilot studies are required to generate evidence that could inform the decision about the solution’s potential and the possibility of larger clinical trials. AI models may perform very well with data from a certain population (e.g., one with similar characteristics to the population an algorithm was trained with), but it is critical to validate models with larger, independent datasets to demonstrate that the solution can be used more widely.[106] Clinical trials are often crucial to generate the evidence on the tool’s safety and efficacy that is needed for regulatory approval.
- Even with substantial clinical evidence, many clinicians insist on seeing the tool perform themselves, well before trusting it with their patients. Running AI solutions in parallel with the traditional clinical practice for a significant time has been essential in many cases for frontline staff to develop trust in the solution. This is not necessarily how AI startups typically operate. As one startup executive says, “Why can’t we introduce AI solutions in healthcare as we do in other industries? We have been able to scale things up much easier elsewhere and deliver value, but in healthcare everything is more complicated and takes longer.”
- A final important hurdle is how to ensure safety and efficacy over time as algorithms adapt and evolve, through the continual evaluation of performance and assessing the need for reapprovals of specific AI solutions.

Moreover, it is the view of many practitioners, regulators, and company executives that AI solutions can be black boxes with no clarity over how an algorithm generates its output. As Microsoft's Julián Isla Gómez says, "For AI to be adopted, providers need to be able to explain how the model works and work on explainability. Not everyone can fully do that at the moment."[107] The problem for regulators is succinctly summed up by Peter Arlett from the European Medicines Agency (EMA): "It is very difficult as a regulator to take a leap of faith and trust something that is that difficult to assess."

Studies have tried to resolve this black box challenge by focusing on machine-learning systems that rely on image analysis. Such systems can generate saliency maps that show which area of the image was the most significant factor contributing to a diagnosis or prediction. However, as one study pointed out, "Outside of image analysis, this inscrutability is harder to manage, and detection of bias in black-box algorithms requires careful statistical analysis of the behaviour of the model in the face of changing inputs."[108] At a basic level, end users need to be able to detect potential errors, for example, by comparing the diagnosis from an AI solution with the results from a biopsy, or testing if other solutions would arrive at the same conclusion. As Steven Petit from the Erasmus MC Cancer Institute, explains, "If you use AI in these circumstances, make sure you have an additional sanity check that could detect possible flaws of the AI algorithm." It is also important to have a way to report any errors in the model and fix them, especially when those solutions have already been integrated into clinical practices.

A second area of concern is that algorithms typically perform well with data similar to the data they were trained on, but their performance can be significantly worse if the data are different, reflecting a different population's characteristics. To address this, AI providers need to proactively train and validate models on different, large independent datasets.

Last, a major concern about AI solutions is the risk of perpetuating biases baked into algorithms. Healthcare practitioners, like all humans, may be subject to cognitive biases that influence decision making. Of particular relevance is confirmation bias, where clinicians may give excessive significance to evidence that supports a presumed diagnosis, ignoring evidence that refutes it.[109] Algorithms need to be trained on diverse datasets and tested for bias before they can be introduced to clinical practice. The health system must also consider the environment for which a new AI model was initially developed and the datasets on which it was trained in order to define how the algorithm might need to be modified to take into account the setting in which it will be implemented and avoid biased results.

4.2 Education and skills

A consistent theme in our interviews was the importance of education and training of healthcare practitioners in new AI technology. In Chapter 3 we looked in detail at the new skills that practitioners would need; here we turn our attention to how that might practically happen in terms of early clinical training and continuous learning.

> *Training and educating healthcare practitioners will take more time than to develop the actual algorithm.*
> **Stefan Vlachos, Karolinska University Hospital**

4.2.1 Growing the leaders of the future: Changing education and training

Our interviewees and survey respondents were concerned about practitioners' lack of technology skills – the medical workforce themselves being the most worried. A lack of skills in analysing data among clinical professionals and a lack of AI professionals were the top concern of a quarter of survey respondents, followed by lack of funding and issues around data quality.

This lack of skills is partly due to the delay in adapting clinical education curricula: "In 2020, it is no longer acceptable for an MD to graduate without some technological skills. However, education trails reality and medical schools are slow to update curricula. I wouldn't expect the average doctor today be very well equipped to deal with these changes", said the German Ministry of Health's Lars Roemheld. It is not just doctors. "Nursing education is antiquated," says Rebecca Love. "We spent more time learning how to make a bed, than being prepared to use digital hospital systems", echoing key themes introduced by the European Federation of Nursing Associations around the adequacy of formal education in healthcare and the need for ongoing skill development for nurses.[110]

The promise of AI in healthcare will require a new generation of leaders that are well-versed not only in basic digital skills, but also in both biomedical and data science. Such individuals are scarce today, and in many parts of Europe the two subjects are rarely taught together systematically. Today, the most common way to create dual-capability professionals is to identify individuals with deep expertise in either area and then give them the knowledge and skills in the other. This tends to formally occur through postgraduate degrees in bio or medical informatics.

Recently, though, there has been a move to train students in the science where medicine, biology and informatics meet. Stanford University offers a major in Biomedical Computation, while The Technion – Israel Institute of Technology – has launched a double degree in Medicine and Computer Science, earning both a BSc in Computer Science and a BSc in Medicine, after which admission to clinical school may be granted to train the next generation of leaders with deep knowledge and intuition of both fields.[111] Such demanding programmes with small intake numbers will make a useful contribution to filling the gap of clinicians in leadership positions, but the numbers are still limited. Israel is also designing a programme for physicians who want to complete a second specialisation in digital health and health technology. There are formal two-year programmes recognised by the Ministry of Health that let a physician with a primary speciality receive accreditation in a second area of medicine. A shorter one-year programme encompassing medical devices and digital health aims to launch in 2020, and physicians will receive credits that may also be linked to salary advancement. Several interviewees emphasised that targeted programmes like these could be an excellent way of building skills in digital healthcare and AI in Europe. These could combine online courses and face-to-face training and would be particularly relevant for clinicians in specialties where AI is being introduced more rapidly, such as radiology, pathology, ophthalmology and oncology, with a view to becoming standard parts of the curriculum.

More broadly, skills such as basic digital literacy, the fundamentals of genomics, AI and machine learning need to become mainstream for all healthcare practitioners, supplemented by critical-thinking skills and the development of a continuous-learning mindset. This will be fundamental in ensuring that health systems adopt and successfully scale the most promising AI models.

Another gap in clinical education links to the broader theme of innovation and developing an entrepreneurial mindset, including a degree of comfort with taking risks. After all, risk is part of innovation; indeed, many see it as a stepping stone to success. As Qure Ventures' Dr. Yossi Bahagon says, "Dare to try, and pay significant attention to your mistakes."

While many degree courses across Europe include work placements and encourage students to develop such an entrepreneurial mindset early on, healthcare courses are less likely to incorporate such initiatives. There are some examples, such as the MIT Delta v Summer Accelerator or Stanford University's Biodesign Innovation Fellowship,[112] but there is a need to develop a larger number of similar programmes, particularly in Europe. Beyond that, AI could also be an effective tool to support clinical education itself and improve students' learning, including combining intelligent tutoring and virtual reality simulations.

4.2.2 Supporting the leaders of today: The need for continuous learning

There is an urgent need for on-the-job training given that educational curricula can be slow to adapt to new technologies, yet a significant portion of the existing workforce will be affected by these technologies. This a significant challenge for healthcare systems. The pace of medical innovation has been accelerating, but people retire later and have longer careers. AI and advanced analytics will only exacerbate this disconnect – medical innovation needs to reach the front line.

> *You don't want them to learn, you want them to want to learn. They should be hungry for innovation.*
>
> **Dr. Daniel Moreno Martínez, Hospital Germans Trias i Pujol, Barcelona**

Health and educational systems need to be set up to provide ongoing learning, and practitioners need both the time and incentives to continue learning. We also need to develop innovative approaches to professional learning. Training in innovation, the interpretation and communication of the output of AI systems, and critical assessment of such technologies should be available as freely accessible online modules.[113] Training needs to equip medical staff to examine the ethical and governance issues around AI and link to other relevant external content to allow further reading and learning.

Interviewees pointed out that single healthcare providers are often not big enough to create such programmes, but national health systems are well placed to develop and scale up such courses with input from healthcare practitioners, academia and industry. These programmes need to be accredited by bodies tasked with continuing medical education and a credit system should exist to encourage practitioners to invest their time in attending. Innovation can be encouraged by allowing frontline practitioners to develop deeper skills in digital literacy and AI, through secondments and sabbaticals, both within and outside their organisations.

In the meantime, some healthcare practitioners and providers are taking the initiative to generate awareness and interest in AI and provide their colleagues with a foundation and understanding of the topic. At the Hospital Germans Trias i Pujol in Barcelona, regular educational events and innovation days engage and inform the workforce. Recognising that a lot of staff rarely have time to go to conferences and meet people from academia, industry and other providers, some hospitals are bringing the conference to them. The aim of this is to encourage clinical teams to embrace technology when it arrives. "After a few sessions on different aspects of healthcare innovation, we no longer have to encourage people to attend," says the hospital's Dr. Moreno Martinez. "They keep coming of their own accord because they see the intrinsic value of what we are offering them. The first event we organised had 30 people – the next one will have over 250." These informal training and education sessions can complement more structured continuous education and professional development approaches and start changing the culture of healthcare organisations.

4.3 Data quality, governance, security and interoperability

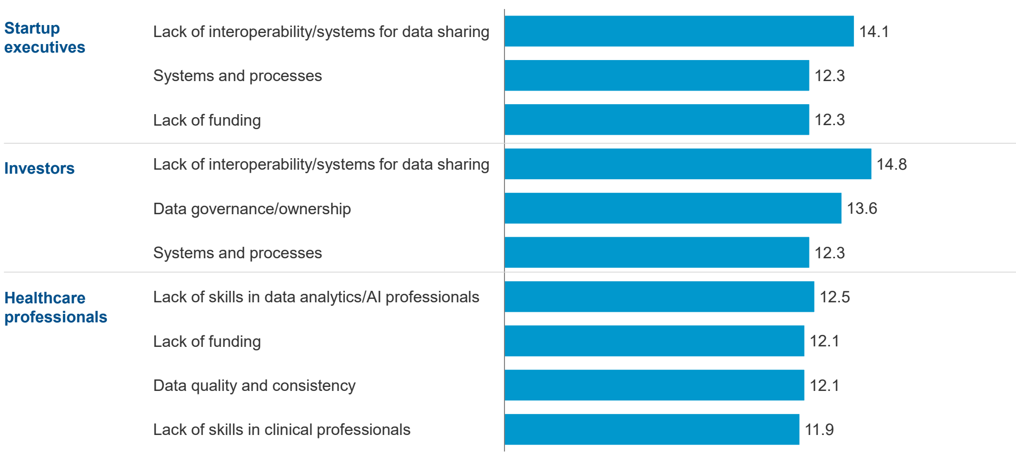
When we asked our survey participants what the major barriers were to introducing or scaling AI in healthcare, data cropped up again and again. It was at the heart of the two most popular answers for investors, the most popular for the startups themselves and a top-three answer for the healthcare professionals, reflecting concerns around data quality and security, the interoperability of systems and the governance and ownership around data (Exhibit 4.2).

Exhibit 4.2 – Data issues dominate the perceived barriers to growing AI in healthcare

WHAT ARE THE MAJOR BARRIERS FOR INTRODUCING OR SCALING AI IN HEALTHCARE ORGANISATIONS?

Startup executive, investor and healthcare professional responses

percent



SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

In the following sections we will explore the data challenge focusing on issues around digitising health to generate data, collecting the data and setting up the governance around data management.

4.3.1 Digitising health and collecting the right data

A key first step for the effective introduction of AI in healthcare is adopting digitised and automated processes. Healthcare providers have made advances in using EHRs, but there are still many examples of frontline staff recording data manually and of independent clinical systems that cannot communicate with each other or fully integrate all the information relating to a patient. As new digital solutions are introduced, such fragmentation of data increases. Interfaces that would seem imperative, such as digital data on patients' vital signs integrating with EHRs, are often still not standard and the levels of interoperability within and across hospital systems and other care providers are variable at best.

Implementing electronic data collection and automating operational and clinical tasks is still in development in many EU countries and will require significant changes to workflow practices and a shift in workforce skills. Healthcare is among the least digitised sectors in Europe, lagging behind others in digital business processes, digital spend per worker, digital capital deepening and digitisation of work and processes.

This lack of digital records and processes poses significant challenges for adopting AI solutions not just because data are needed to feed the algorithms, but also because staff frustration about the inadequacies of existing digital systems can lead to a reluctance to adopt more innovative and futuristic AI solutions. Either way, it is critical to get the basic digitisation of systems and data and the development of digital skills in place before launching AI efforts.

Systematising digital data collection, linking datasets between systems and ensuring data cleansing is performed routinely, are all prerequisites for introducing AI solutions. However, there is often a discrepancy between the aspiration for complete clean data, and the reality that most healthcare organisations deal with.

4.3.2 Ensuring strong data governance within healthcare organisations

Healthcare providers are used to dealing with vast amounts of clinical data, much of which is highly sensitive and confidential and they have well-tested policies for managing data security; for example asking patients to consent to their data being shared, including for the purposes of clinical research. However, as more healthcare is delivered using new digital technologies, public concerns about how healthcare data are being used have grown. There are well-developed data security laws in Europe, the US, Canada and other parts of the world, so one could argue that patients can be reassured about their data security.

Despite this, there have been high-profile cases where AI companies and healthcare providers have been deemed not to have communicated clearly with patients as to how their data would be used, or have appeared to have accessed data without the necessary consents. In the UK, for example, the Information Commissioner stated in 2017 that the Royal Free NHS Foundation Trust's sharing of 1.6 million patient records with Google DeepMind failed to comply with the UK Data Protection Act, as "patients would not have reasonably expected their information to have been used in this way, and the Trust could and should have been far more transparent with patients as to what was happening."[115]

Healthcare organisations should have robust and compliant data-sharing policies, which support the improvements in care that AI offers while providing the right safeguards. Our interviewees emphasised that both healthcare as a sector and Europe as a region have significant advantages in terms of data governance. First, both healthcare organisations and health systems are used to dealing with sensitive data through well-structured data governance and risk-management processes. In some cases, healthcare could lead the way for other sectors seeking to put such measures in place. Secondly, Europe benefits from national health systems with extensive datasets, often shared within integrated care systems, offering a set of systems and processes to build on that could also serve as examples to other regions.

Of course, as ever more solutions are introduced, these policies need to keep pace with technological advances and organisations and health systems will need to have rapid processes for approving data-sharing agreements with new suppliers.

Processes around data anonymisation also need to be updated to be made fit-for-purpose for the fast-evolving healthcare sector. “We should anonymise data, but not restrict access to data”, said Petia Radeva from the University of Barcelona. Clear guidelines within healthcare organisations and systems on the required levels of pseudonymisation or anonymisation, linking and de-linking of data records needed for particular applications would help both AI developers and clinicians looking to implement their solutions – in particular if they helped simplify and streamline the process of anonymisation. Physicians we interviewed emphasised that, given the volume of data required for AI, the process of anonymisation in the absence of clear guidelines could have significant cost implications and render diagnostic algorithms prohibitively expensive.

4.3.3 Data interoperability and building bigger datasets

One of the biggest barriers for AI in healthcare is that while enough data are often available across a national system, they are not connected or interoperable. Policy makers, funding bodies and nonprofit organisations need to support efforts to sufficiently anonymise or link data and, where sensible, build federated networks of datasets that are interoperable and can be queried as needed (with the right security and governance protocols), or help create scaled-up databases that can be accessed only by stakeholders with the appropriate safeguards.

> *People call data the oil of the 21st century. They should be calling it the crude oil of the century. It has huge potential, but it is not trivial to use.*
> **Dr. med. Dominik Pförringer, TUM Hospital**

Recent examples of such data sources include The European Nucleotide Archive, which allows free unrestricted access to genomic data associated with academic life science research.[116] More sensitive data, such as those generated by the Danish Reference Genome Project or the 100,000 Genomes Project by Genomics England, are also available for research purposes, but de-identified and with strict access policies. For instance, the Genomics England dataset is hosted in a secure environment within the datacentre and analytical tools are available inside this environment, but data cannot be moved outside or otherwise downloaded.[117] The Israeli government’s recent initiative to combine national digital medical records in a unified system is another example of centralised efforts to spearhead and support the development of national datasets for healthcare, including for applications of AI.[118]

However, we must acknowledge that healthcare data can be notoriously complex. They are often gathered by proprietary software and compiled in siloed databases that are part of largely incompatible systems – at times, even within the same hospital. This makes a large amount of the data in existence virtually useless in their current state. This is a key consideration for healthcare providers, who need to develop policies to promote interoperability within their own proprietary systems, as well as with those of external suppliers and other providers.

In order to make the most of the rich data available, healthcare systems need an interconnected data infrastructure, as well as standards for data formats, be they Fast Interoperability Resources or open EHRs, data exchange and semantic interoperability of medical terminologies to reduce noise in the data.[119] Such efforts have been successful in the past, for example in gene- and protein-naming conventions, in data-format standards for next-generation DNA sequencing data and the International Classification of Diseases codes.[120] They have often developed organically, proposed by groups of researchers or international committees of larger organisations and could offer an example of a potential path for similar efforts on AI.

4.4 Managing change

One of the most telling messages from healthcare provider leaders was that the implementation of new AI technology was not about the solution per se, but about how it was implemented and the success of the change process around its introduction.

Managing change while introducing AI is no different to managing change in complex institutions more broadly. Critical elements remain: defining and supporting the right champions within the organisation, clinical and nonclinical; developing a compelling narrative of change; enabling staff to understand and adopt change through communication, training and ongoing support; and linking change to mainstream processes to incentivise good performance. But, as everyone who works in clinician-led organisations will confirm, clinical leadership of change is key, as is being flexible to identify the right use cases that support rather than antagonise healthcare practitioners and truly augment, rather than substitute, their ability to deliver the best possible care to their patients. This, in turn, will lead to creating a critical mass of practitioners and patients who have experienced AI.

> *These projects are about 5 percent technology and 95 percent change management.*
> **Robert Freeman, Mount Sinai Hospital**

The success of any implementation depends on the time, energy, training and development of the staff who are affected by the change. Implementation of AI is no different, but there are some additional challenges that providers need to recognise and address in advance.

First is the lack of technology expertise and a degree of the fear of the unknown among both clinical staff and hospital executives. As AI solutions potentially replace processes and automate them at a scale and pace unseen in healthcare providers, some in the workforce will find this hard to comprehend. We have already discussed the need to upskill the healthcare workforce, but they also need to understand AI's potential and how it can help them improve the care they provide to their patients, as well as positively affect their working life.

This means healthcare providers need to develop a consistent narrative on why and in what way AI will be good for patients, practitioners and the organisation. Recognising this dual reality will be important: whilst AI may mean certain job roles change, staff should be reassured that their skills will still be required and in fact that these new technologies provide a great opportunity for developing new skills and transitioning into much-needed new roles. AI also has enormous potential to make healthcare staff's professional lives more rewarding and enjoyable, giving them more time with patients and reducing unnecessary waste and process duplication. Healthcare providers need to be transparent about the benefits and risks of AI and work with staff to harness the collective energy of their teams and capitalise on the opportunities AI can bring.

This may not be a rapid process, but it soon becomes increasingly rewarding for practitioners. And it is an important part of the overall adoption process, especially for clinicians. Professor Jens Lundgren from Rigshospitalet, University of Copenhagen explains: "Our skillset is to be very critical with anything new presented to us. It takes two to three years for clinicians to feel comfortable around AI. Initially, the physicians check everything manually all the time, but eventually they stop. Once clinicians are comfortable with one application, they are much more comfortable with the second round."

4.5 Investing in new talent and creating new roles

Healthcare organisations need to consider how they develop and recruit the new roles that will be critical to the successful introduction and adoption of AI, such as data scientists or data engineers.

Demand for such skills is heating up across industries and the competition for talent will be fierce, but many young professionals find a vocation in healthcare and its mission and are excited about the potential of digital health and AI. Developing flexible and agile models to attract and retain such talent will be a key part of these organisations' people strategy.

Most interviewees emphasised that scale matters when it comes to AI. Not every organisation needs to become a centre of excellence, but most can join one. Smaller organisations can work in clusters of innovation, digital health, biomedical research, translational medicine etc. to create attractive roles in networks for subject matter experts and ensure they can use their strengths to create the right scale for AI – in particular with regards to population-health management, where having access to large datasets at a population level is important.

Providers also need to consider how they can help clinical staff develop portfolio careers, working across clinical practice, R&D, innovation and digital transformation, so they can apply their clinical practice knowledge to the development of innovative AI solutions.

The traditional IT department in hospitals and the role of the chief information officer or chief technology officer will also change. Whilst ensuring the organisation has the appropriate hardware and IT infrastructure to deliver the day-to-day operations of the hospital, executive teams need strong leadership in technology and innovation from an expert who can keep track of developments and highlight potential solutions and disruptions that the organisation should be prepared for. SE Health in Canada (a community-based home healthcare provider) has recruited a board-level position of Future Strategist charged with bringing insights into new technologies, as well as sharing with staff the opportunities that these can present in how they care for patients. Such roles are far from the traditional C-Suite functional leadership positions and have a licence to roam across the organisation challenging the traditional hierarchy. Strong leaders who can translate complex, data-rich solutions into practical, on the ground delivery will be invaluable and organisations such as Cincinnati Children's Hospital and Mount Sinai already employ senior leaders to oversee the implementation of AI across their hospitals.

Finally, organisations should invest in the next generation who are starting their careers, and start bringing their enthusiasm, knowledge and technological abilities to a healthcare setting. These new employees will be the staff who will live through the next 30 years of technology developments, when solutions that are currently in their infancy become mainstream. Encouraging them to be ambassadors and advocates working with patients and other staff to support them through the implementation of new solutions and hand-holding those who are nervous of change, will be a critical part of the successful adoption of AI now and in the future.

4.6 Regulation, policy making and liability, and managing risk

The concepts of privacy, data ownership, data governance and access can vary widely around the world. Europe placed an early emphasis on citizens' ownership and control of their own data.

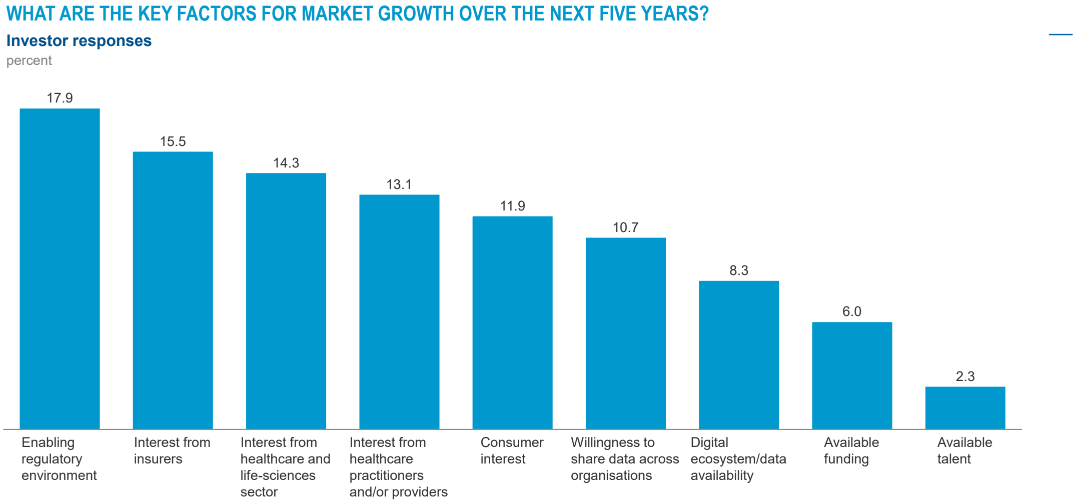
The EU's General Data Protection Regulation (GDPR) put in place binding regulations for its Member States around data protection and privacy, which is especially pertinent for healthcare due to the sensitive and highly personal nature of the data involved. The EC argues that the GDPR ensures a high level of personal-data protection, while allowing the free flow of personal data within the EU.[121] Even though the ethics of AI in healthcare have been extensively reviewed by EU bodies, interviewees highlighted the uncertainty around regulation as a particular barrier to the use of patient data for AI.

> *Europe is in the lead in reminding people about the importance of ethics and privacy and that is highly commendable. But if we get stuck only on that, without capitalising on the value of AI, it will fall behind as developments will continue in other parts of the world.*
>
> **Sudipto Srivastava, Mount Sinai Hospital**

Today, responsibility for AI solutions – both clinical and technical – is split between healthcare organisations and their staff, at times with a piecemeal approach to governance. Understandably this makes all the players in the health system nervous and does not help move AI forward so it can start delivering for patients. For investors and startups, the lack of familiarity with the regulatory process, long timelines and required fees, and the particularities of country-specific regulations in Europe add to the complexity of accessing the European market, and investors clearly responded in our survey that the most important factor for market growth in the next five years was an "enabling regulatory environment" (Exhibit 4.3).

> *We need policies that are flexible enough to protect the patient, but also allow innovation. We need open policies that allow for pilot testing and the active engagement of citizens. This would significantly improve and speed up the delivery and adoption of AI-based solutions.*
>
> **Federico Menna, EIT Digital**

Exhibit 4.3 – Investors identified a range of market-growth factors



SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

Ultimately, it is important to ensure trade-offs of different approaches are clear. According to Dr. med. Pförringer of TU Munich Hospital, "There has to be a balance: insisting on the strictest privacy laws may help but may also lead to preventable patient deaths. As a society, we will need to be more comfortable discussing trade-offs and the true value of our privacy."

4.6.1 Approving algorithms: Ensuring safety, efficacy and no bias

To get AI solutions into clinical settings, it is imperative to ensure their safety and effectiveness. AI solutions are not drugs or medical products and new policies are needed to allow for the appropriate regulatory processes. With an ever-increasing number of AI solutions, a challenge for practitioners (and patients) is to know which solutions meet the necessary standards.

> *There should be a debate on 'autonomous systems' from an ethical point of view, but also a technical debate, on how we should evaluate AI systems. Should we compare a machine versus a human operator? Or should we compare an AI system versus another AI system? Regulations and legal frameworks currently clearly lag behind technology.*
>
> **Dr. Emilio Gómez González, University of Seville**

A clear approach from the regulatory bodies can not only help guide that process, but open the door to innovation, removing the barriers created by fear. This is even more critical as the resources and expertise required to evaluate the safety and efficacy of AI often exceed the capabilities and capacity of any single organisation and add significant complexity. "We have instituted an AI board to develop a framework for the assessment and procurement of AI solutions," says Haris Shuaib from Guy's and St Thomas' NHS Foundation Trust. "A CE mark is a basic requirement, not nearly enough to help us decide what is actually useful. What we learned is that it takes a lot of subject-matter expertise across medicine, engineering and business to make these decisions."

AI solutions are typically classified by the type of algorithm employed. This is helpful for understanding the technical sophistication of the solution, its capabilities and limitations, but it is not always helpful in understanding the impact of the solutions and the risk involved from a provider or patient perspective. This is where regulation comes in.

The United States' FDA, in its effort to regulate AI-enabled software solutions, has developed a framework for classifying the risk associated with SaMD.[122] Its "Digital Health Innovation Action Plan" gives guidance for the approval process for software and introduces a precertification programme, which aims to replace the need for a premarket submission.[123] To address the challenges that arise from updating software (e.g., when does a software update require reevaluation of approval), the FDA has also published a discussion paper on which methods could help allow for controlled changes between premarket development and postmarket performance.[124] As a result, in recent years several AI solutions have received FDA approval as well as the CE mark.

In Europe, the picture is different. In 2018, the EMA published a strategic reflection on its regulatory science through to 2025, emphasising the development and use of innovative technologies and AI, and the close collaboration needed with academic institutions. Specifically, the EMA cited:

- Catalysing the integration of science and technology in medicines development: "The ultimate public-health aim is to ensure that regulation can support the development of new medicines and innovative techniques, so that patients' needs can be better addressed with safe, effective and clinically appropriate treatments."
- Driving collaborative evidence generation and improving the scientific quality of evaluations: "[Exploiting] digital technology and artificial intelligence in decision making", through establishing "a dedicated AI test 'laboratory' to explore the application of innovative digital technology to support data-driven decisions across key business processes", and developing "capacity and expertise across the network to engage with digital technology, artificial intelligence, cognitive computing, and their applications in the regulatory system."
- Enabling and leveraging research and innovation in regulatory science: "Develop the existing interaction between the EU regulatory network and academia further, in order to be kept informed of relevant scientific innovations and research and identify solutions to regulatory needs and challenges," including "developing network-led partnerships with academia to undertake fundamental research in strategic areas of regulatory science," proactively engaging with EC Directorates-General (DGs), such as DG-Research and Innovation and DG-SANTE, the Innovative Medicines Initiative, and Member State funding agencies to establish research collaborations.

The Heads of Medicines Agencies (HMA) and the EMA have launched a joint Taskforce on Big Data to develop recommendations around "A path towards understanding the acceptability of evidence derived from 'Big data'" for medicines regulation.[125] Their February 2019 report develops a set of areas to be addressed, and their January 2020 report aims to provide concrete mechanisms by which these aims may be achieved.[126] One goal is to define how, and to what extent, big data and AI will affect the work of the EMA, especially when it comes to providing evidence for the approval of medicines or their pharmacovigilance work, and how the EMA may need to transform its operations to better understand and address the regulation challenges posed by a rapidly changing industry landscape.

Unlike the FDA, the EMA does not approve medical devices – in Europe, this is the responsibility of national authorities. EMA guidance mostly concerns instances where AI is used to develop medicines, for example as part of clinical endpoints.

Within individual EU Member States, there have been recent advances in developing processes to evaluate AI-related applications. For example, Dr. Thomas Senderovitz, Director General of the Danish Medicines Agency, spoke of the agency's new digital strategy, which includes a new data analytics centre being scaled up in 2020, with the ability to host data (e.g., clinical registers, adverse-event data, EHRs), analyse data on medical devices, including AI solutions, and offer scientific advice to industry. The agency is raising its digital and AI capabilities, doubling its medical device team and bringing in more capabilities in new technologies, and ensuring the whole leadership team attends masterclasses on the topics of digital and AI, while digital education classes are rolled out across the organisation.

Nonetheless, a clear challenge that stems from the absence of a pan-European process is that it is hard to know which algorithms may have been approved for use elsewhere in Europe. There has been an effort to spearhead a supranational database, Eudamed, which lists approved medical devices, but for now, its use is restricted to national competent authorities, making it harder for the public or healthcare practitioners to have a clear view of the AI in healthcare landscape in Europe.[127] To be approved in different European markets, medical devices typically have to undergo an assessment of compliance with legal requirements and safety standards, and of performance versus their stated purpose, which can result in them receiving the CE mark.[128] While the CE mark is a necessary step, as we have seen, healthcare providers still need further regulatory clarity on AI solutions.

As part of their big data taskforce, the EMA and HMA have, therefore, issued recommendations around the regulation of "innovative devices and those incorporating complex algorithms", whilst acknowledging that authorising such devices is outside the taskforce's remit (they fall primarily under the purview of the HMA). The main recommendations include ensuring effective coordination processes across multiple national bodies, especially those tasked with regulating medicines and medical devices, to establish common specifications and performance requirements; and closely monitoring the impact of updated EU medical regulation to determine whether it meets evolving needs. The recommendations have been presented and endorsed, along with initial estimates of the work required to implement them. Work is now underway to establish the funding and resources needed over the next few years.

Regulation of patient access to AI healthcare tools across Europe is another issue to be clarified. Do patients need prescriptions for AI-enabled health solutions? To what extent are companies required to explicitly and clearly inform patients of the effectiveness, caveats and contraindications of their solutions? This is an important issue, as showcased by the FDA-approved contraception app Natural Cycles, which resulted in several unintended pregnancies.[129]

The big data taskforce pointed out that there is uneven capability across Europe for assessing and regulating AI-enabled healthcare solutions and no routine knowledge sharing is taking place. An early solution could be to assign specific national regulatory agencies a pan-European role in some areas of AI evaluation, creating regulatory centres of excellence that can support others across the EU, for example, in deep learning, advanced analytics for pharmacovigilance, and so forth. The Danish Medicines Agency's Dr. Thomas Senderovitz concurs: "Centres of excellence may be the most practical way forward. Not all [EU] countries can do everything simultaneously. Similar to assessments for advanced oncology medications, which not all agencies have the capability to perform, we can have centres that specialise in assessing algorithms."

Last, although not constituting a formal part of the regulatory system, healthcare-practitioner associations are also important self-regulating actors in healthcare and are coming forward with a perspective on the future of AI. The American Medical Association has developed its own policy and recommendations on “Augmented Intelligence” in healthcare, stating its commitment to engaging in digital health to help set the priorities for AI, integrate physicians’ perspective into the development, evaluation and implementation, promote the development of clinically validated AI following predefined criteria, encourage critical appraisal skills among stakeholders and raise awareness for legal issues arising from AI – and similar efforts are underway among scientific societies in Europe.[130]

4.6.2 Liability: Who is the actor?

Patient safety is paramount, but healthcare practitioners may also have to think about their professional accountability and how they can protect their organisations from any potential reputational, legal or financial risk. The question of liability is undeniably important. Many interviewees gave examples of AI being used in hospitals, often to enhance traditional care models or clinical practice, while emphasising that the clinician is fully accountable for the patient’s care and ultimately, professionally responsible for them.

> *The tough part is where will the responsibility lies – will AI be just ‘decision support’, or ‘decision making’?*
> **Stefan Vlachos, Karolinska University Hospital**

One complication is defining who is liable when an AI solution, used to flag cases that require urgent attention and deprioritise less urgent ones, erroneously delays the review of an image by a clinician and leads to a worse outcome for the patient. Physicians are uncertain about the potential impact of AI on their patients and their own professional accountability and licence to operate. Healthcare lawyers interviewed as part of this report, whilst not having seen patients or caregivers bring action against organisations for incorrect diagnoses or treatment linked to AI, were also clear that the accountability ultimately rests with the clinician. As AI becomes more commonplace in healthcare and levels of automated decision making increase, providers will need clearer governance defining where professional responsibility begins and ends.

One physician in our survey suggested that AI-related liability should be regulated in a similar way to medical devices. There is a well-established approach for regulating devices driven by national bodies such as the FDA, or the UK’s Medicines and Healthcare Products Regulatory Agency. Registration with regulatory bodies provides assurance that the products have been tested, are effective and safe. Where AI solutions provide an element of diagnosis or treatment, they need to be registered with the relevant national body, but there was a view that this process is slow and cumbersome and not designed to meet the fast-moving and ever-changing world of AI development. According to this school of thought, if an approved medical device or AI solution is used correctly, physicians should not be liable if there is a mistake or error generated by that solution.

This also touches upon the distinction between AI as product vs. AI as a tool supporting professional decision making. For example, if an AI solution has received FDA approval as a device, product liability will apply. But in cases where the AI solution provides recommendations for the clinician, professional liability comes into play. This distinction could still lead to challenging situations, for example when AI solutions are used to increase efficiency by reducing reading times of medical images through AI-guided detection of abnormalities. If the physician is expected to be more efficient and read more scans in a given time, but will also be professionally liable with the consequent risk of losing their professional licence should they overlook an abnormal finding, this would be an additional, significant barrier to AI adoption.

There may not be a single answer to this problem but there needs to be a discussion at a national level with regulators, professional bodies and legal experts to define where responsibility and liability begin and end between the software company and the individual organisation or clinician. A common theme in our discussions with clinicians, lawyers and hospital executives, was that guidance in this area is limited, further guidelines and clarification are required and, in their absence, many physicians and healthcare organisations would be reluctant to introduce or significantly scale up AI applications.

The use of AI also affects what information practitioners need to disclose to enable patient consent. Patients should be told the extent to which AI is involved in their diagnostic or therapeutic process, or in cases where their data, even anonymised, may be used in clinical research. However, it less clear to what extent patients will be able to understand in detail what the AI applications do and how this level of understanding affects their ability to provide "informed" consent.

Having clear guidance on liability will be crucial in enabling the successful implementation of AI into clinical practice. Regulatory guidelines will provide the guardrails and professional bodies and associations should also guide their members on how to use AI in their daily clinical practice. Last, healthcare providers will need to consider how they work proactively with regulators and professional bodies to define the scope of responsibility and risk that sits with their organisations. Providers are also proactively putting new processes in place and ensuring a "compliance by design" approach is at the core of product development.

4.7 Funding: The most important enabler of all?

The reimbursement of medicines and medical devices across Europe is complicated with different rules. To start with, there is a significant variation between countries in the healthcare spend per capita and the share of devices as a proportion of the total.[131]

The responsibility for decisions on reimbursement of medicines or devices rests with national and local payors in different countries. This typically also covers what will be reimbursed and at what price.

> *We need to find ways to reimburse AI tools like we pay for medication.*
> **Felix Nensa, University Hospital Essen**

Clear criteria for the potential reimbursement of AI applications will be crucial for its adoption at scale. In Germany the Digital Supply Act, adopted in November 2019, has set a standard for Europe by making digital apps prescribed by the physician reimbursable by the statutory health insurance. The main requirement to be added to the list of reimbursable digital apps is for the solutions to prove to the Federal Institute for Drugs and Medical Devices (BfArM) that they can improve patient care.[132]

On a more practical level, it is unclear how solutions that reduce the number of patients seeking direct treatment from physicians will be financially incentivised and rewarded, especially in systems that rely on fee-for-service incentives. Mary Lou Ackermann from Canadian health provider SE Health believes this is a crucial issue: "Health systems need to consider new business models in order to introduce new service models. We are building solutions to shift from scheduled in-home visits to a model that ensures care visits are at "the right time". Today's fee-for-service model, which requires an in-home visit, is a major barrier to modernising our health system." Although SE Health itself has nonprofit status and the new solutions can help address the nurse shortage crisis, their wider impact in reducing at-home visits could provide a disincentive for other organisations. Similarly, in Europe, many payment models incentivise face-to-face interactions with doctors.

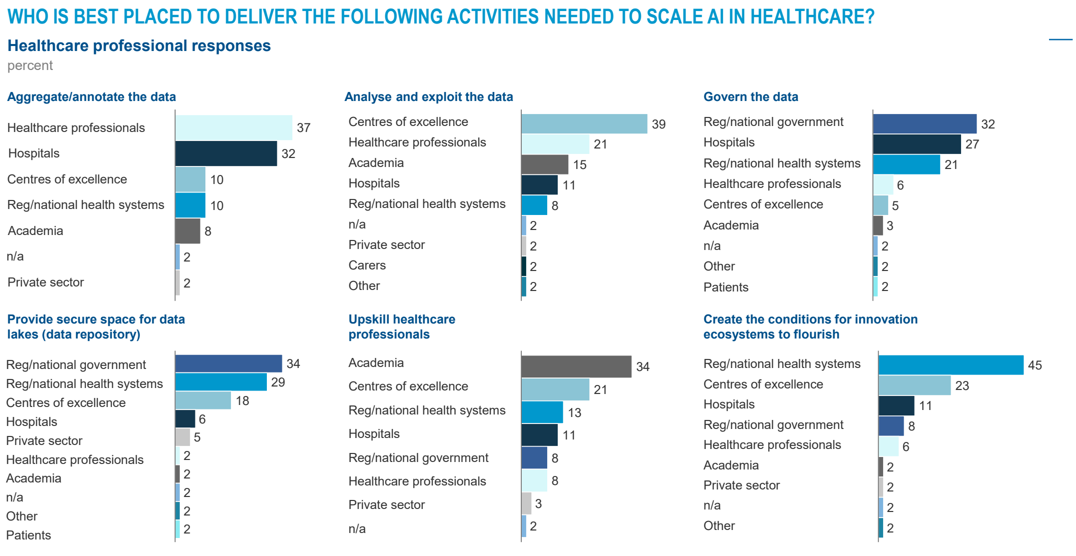
Some organisations, such as Mount Sinai in New York, Mehiläinen in Finland and HMOs in Israel, are starting to tackle this reimbursement issue by putting incentives in place. A shift to value-based healthcare and away from a fee-for-service model would go a long way towards providing the right incentive framework for the sustainable adoption of AI in healthcare.

4.8 Who should do what? The key roles to make AI happen

One of the most interesting discussions arising from our survey was the perspective of respondents, in particular the healthcare professionals, on who is best placed to deliver the key activities needed to scale up AI in healthcare, and what the implications could be for healthcare providers, health systems and the EU.

Healthcare professionals felt they were best placed to aggregate and annotate the data and reasonably well-placed to analyse them, potentially through scaled up efforts in centres of excellence. Governing the data and providing a secure space for data lakes (data repositories) was a role for regional or national governments or health systems, with hospitals and centres of excellence providing alternate options. Centres of excellence, alongside academic institutions, were seen as well-placed to improve practitioners' digital skills, while creating the conditions for the healthcare ecosystem to flourish was seen as primarily a role of the health system. The role of the private sector across these functions was seen as minimal: slightly higher in providing data repositories, low in other categories and nonexistent when it came to data governance (Exhibit 4.4). Global experience of creating dynamic, innovation-driven ecosystems has traditionally relied on private-public partnerships and, increasingly, VC startup funding, so this perspective from European healthcare professionals with a passion for innovation highlights the potential barriers and culture change needed to enable collaboration between public and private actors to grow AI in healthcare.

Exhibit 4.4 Most critical enabling activities have a clear natural owner



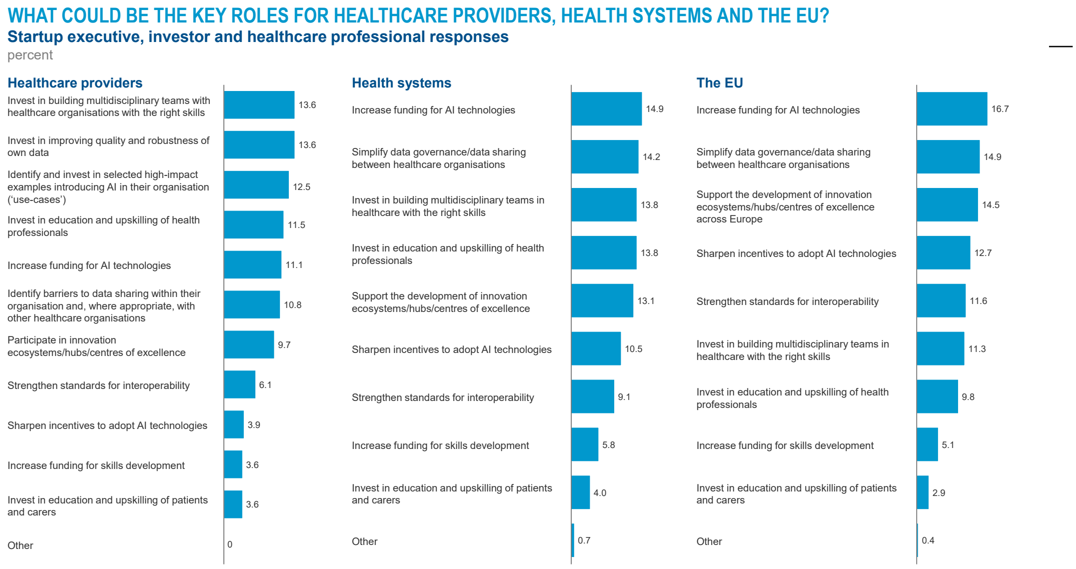
SOURCE: Survey of healthcare professionals, health investors and startup executives across European Countries, conducted between November 2019 and January 2020

Healthcare professionals had a clear wish list of what different parts of the ecosystem could or should do to help deliver AI's potential in European healthcare (Exhibit 4.5):

- For healthcare providers, respondents saw their most important role being to bring together multidisciplinary teams with the right skills, followed by improving the quality and robustness of their data, identifying the right use cases, upskilling their own professionals and increasing investment.
- For health systems, the most important role was to "increase funding for AI technologies", followed closely by simplifying data governance and data sharing between organisations. Other important roles included developing multidisciplinary teams, upskilling workers, and, crucially, supporting the development of innovation ecosystems or centres of excellence.
- Last, for the EU, the important roles were also to increase funding and simplify data governance and sharing, followed by supporting innovation ecosystems or centres of excellence, sharpening incentives for AI adoption and strengthening interoperability.

> *Some academic medical centres are going to take the lead in development, in cooperation with industry. The other 95 percent will adapt solutions that were developed elsewhere.*
>
> **Dr. Eyal Zimlichman, Sheba Medical Center**

Exhibit 4.5 – Each player in the system could assume important roles



SOURCE: Survey of healthcare professionals, healthcare investors and startup executives across European countries, conducted in December 2019 and January 2020

All in all, survey respondents and interviewees indicated there is significant willingness not only to engage fully with AI, but also to welcome a systematic and tiered approach in terms of actions and levers across Europe – at local, regional, national and EU level.

4.9 The potential role of the EU

Our early analyses of levels of VC investment and AI-related clinical trials,as well as the number of companies and M&A deals in digital health and AI, portray a fast-moving market, where the EU, as a group of countries, is starting to step into a leading role alongside the US and China.

The scale needed for effective rollout of AI in healthcare may place a toll on smaller EU Member States but could be easily reached through collaboration across Europe. Interviewees and survey respondents were clear on the potential role of the EU in the introduction or scaling of AI in healthcare, with five specific strands:

- **Consolidating funding against strategic AI priorities.** There are different EU funds that touch on AI and healthcare. Some relate to research and innovation, others to digital, and others still to the growth of small and medium enterprises, employment, or regional development. Defining a few concrete priorities for AI in European healthcare and consolidating funding to support them strategically could help fast-track promising developments in AI. Speed is of the essence in a market changing so rapidly and dismantling barriers to adoption would help deliver the true potential of AI to European health systems and their patients. Recent work underway in DG Grow also considers promoting private-sector investment, for example, by setting up a European AI VC Fund as a public-private partnership to support companies developing critical AI applications in their growth phase.

- **Creating a level playing field across European healthcare.** Common standards on data, access and governance, privacy or interoperability, and shared requirements on data exchange could enable innovators to scale AI solutions cost-effectively, while focusing their energies on entrepreneurship. They would also enable patients, practitioners and health systems to develop the same confidence in new AI solutions that they have in new medicines and devices that have undergone European approval. A priority would be improving access to public and publicly funded data, distributing data in easily accessible formats, encouraging open data in publicly funded research and public-private partnerships in critical AI areas. Accelerating the adoption of digital health data (e.g., EHRs) should also be a priority, as a precondition for the introduction of AI.
- **Clarifying key aspects of regulation around product approval, accountability and liability.** Providing clarity on approval processes across Europe, potentially creating regulatory centres of excellence for different aspects of introducing AI in healthcare, and setting expectations on accountability and liability – solving the AI as product vs AI as tool debate, would be significant in removing barriers to adoption.
- **Encouraging and supporting the creation of centres of excellence for AI in healthcare.** This can help concentrate AI healthcare talent in high-profile and agile networks that can move quickly from design to implementation and spearhead the introduction of new capabilities in national health systems. It would follow the examples of innovation hubs or clusters already growing in Europe, such as innovation parcs or technology centres. In many cases these centres would use existing capabilities and would help develop exciting career paths for new AI professionals.
- **Maintaining a leading role on introducing trustworthy AI that is ethical, technically robust and lawful.** Interviewees emphasised that the thoughtful European approach to ethics, health data and patient confidentiality could continue shaping the AI sector, in the same way that GDPR has reset standards for privacy protection internationally.

These priorities are reflected in how the different DGs work together. As an example, the DG for Communications Networks, Content and Technology (CONNECT), the DG for Research and Innovation and the DG for Food and Health Safety coordinate daily on AI in healthcare, working towards supporting the digital transformation. “We use funds to support Member States, connect them and help them scale up AI and for experimentation and testing”, says DG CONNECT’s Marco Marsella.

The Joint Research Centre (JRC) is one of the Directorates of the EC that supports scientific advice across all DGs. The JRC’s Massimo Craglia spoke about a new service of the Commission called AI Watch. He explained that it will monitor and assess the European AI landscape from driving forces to technology developments, from research to market, from data ecosystems to applications, providing advice and guidance to Member States. Other strands of work at the JRC are focused on ethics and the social impact of AI across industries.

Last, the JRC is also looking to provide advice and guidance on the study of different models of access to health data, the implications on efficiency of introducing machine learning, and the broader economic consequences of these models, such as who reaps the benefits of innovation and how benefits are distributed and shared. According to Bertin Martens at the JRC, examples could include:

- The Finnish model: Finland has put in place a system of centralised and controlled access to healthcare datasets. By law, data must be made available to a government operated data server run by the Ministry of Health, which researchers can access under certain conditions and typically with no data taken out of the system. Data are available to both private- and public-sector researchers. National coverage of the data, with all Finnish providers participating, makes it easy to benchmark the efficiency and productivity of the system as AI is being introduced.
- The British model: the UK has less centrally controlled access to healthcare datasets. NHS hospitals working with AI providers who are running and training algorithms on their data may allow them to remove data from the provider organisation, including outside the UK (as happened recently with Google DeepMind).

Interviewees and survey respondents are in broad agreement that the implementation of innovative digital health and AI solutions can best be achieved by working together at the EU level, sharing experiences in deploying, measuring impact and transferring innovation across Member States and regions. The active engagement of all parties is essential to succeed in creating the European Commission's "triple win" that benefits people, health systems and the market.[133]

Chapter 5

Key findings and recommendations

This work set out to answer the following questions:

- Why is AI in healthcare important and what is its potential to transform healthcare?
- What is the status of AI in healthcare today – where is it already transforming care both in Europe and further afield, and where is it heading?
- How will AI change the life of healthcare practitioners?
- What are the main barriers to expanding AI in healthcare and helping fulfil its potential, and how can they be overcome?
- What are the implications of AI for healthcare providers and healthcare systems?
- How can the EU draw on its collective strengths across Member States to help AI deliver its promise for European citizens?

5.1 AI's potential to transform healthcare

Healthcare is one of the success stories of our times. It is also in crisis. Huge advances in public health and prevention, biomedical knowledge, healthcare delivery and technology have all helped raised life expectancy, and expectations from healthcare itself. But as healthcare costs continue to rise exponentially, outpacing GDP growth, we need to deliver care that is better, faster and more cost-efficient, and provide more and better services to more people.

Not only do we not have the financial resources to deliver this promise but, increasingly, we do not have the human resources either. The WHO estimates that by 2030 the world will be short of 9.9 million doctors, nurses and midwives.

AI and automation have the potential to transform how care is delivered – addressing both the need for better and more cost-efficient care and helping fill some of that shortfall in staff. This is especially the case as populations age and their health needs become more complex. AI and automation are uniquely placed to help understand these needs and the complex interdependency between different factors that affect population health. In addition, the extraordinary shift from symptom-based medical practice to molecular- and cellular-based medicine is generating ever-increasing amounts of data. In such an environment AI can add value and help speed up new biomedical discoveries, the diagnosis process and access to treatment.

AI is still some way from delivering on all its potential, but the consensus among the healthcare leaders, AI companies and investors we spoke to is that the potential of AI in healthcare remains significant. This report reviewed the landscape of AI healthcare startups and applications and selected 23 that play a role at all points along a patient-centred healthcare framework and at various stages of the healthcare value chain and discussed the impact such innovations could have. It concluded that the potential of AI to transform healthcare holds true across the framework, whether we refer to self-care and prevention, triage and diagnosis, clinical decision support, care delivery in healthcare units or at home, chronic care management, population health, operational improvement, or advancing healthcare innovation, for example in R&D. There are also areas where AI in healthcare will increasingly do things faster, cheaper and, in some cases, better, which could lead to significant changes in care outcomes, patient experience and access.

5.2 Status of AI in healthcare internationally

The pace of change in healthcare AI has accelerated significantly over the past few years due to advances in algorithms, computing power and the increasing breadth and depth of data that can be used. In response, countries, health systems, investors and innovators are all now sharply focused on the topic.

Countries as diverse as the US, Finland, Israel, China, and Qatar, to name a few, have developed AI strategies that directly or indirectly affect healthcare. Global VC funding for AI in healthcare has reached $8.5 billion for the 50 best-funded healthcare AI companies, while clinical trials for AI-augmented healthcare applications are multiplying.

Europe, as a group of countries, is emerging as an important global player in healthcare AI, a sector where the US leads, but Asia – and China in particular – is catching up. The EU has already made early steps in regulation and setting standards around ethics, data security and confidentiality (e.g., GDPR), but has also sought to step up its AI efforts through broader initiatives and strategic investments, significant research contributions and growing, albeit from a small base, VC and other funding. However, our analysis suggests that VC funding and transactions in healthcare AI in Europe are dwarfed by investments in the US, while Asia is also the fastest growing region. While European countries (as a group) now match the US in terms of the number of healthcare studies with AI focus, China is stepping ahead and investing strategically in AI.

5.3 Impact on healthcare practitioners

The implications of AI in healthcare settings on the work of practitioners are starting to emerge. MGI research highlights that healthcare is one of the sectors least prone to automation.

While for the selected EU countries, 42 percent of time spent on current work activities across all industries are technically automatable today, for healthcare this is just 30 percent, and in the midpoint scenario of automation adoption just half that – 15 percent of time spent on today's healthcare activities.

Modelling the demand pressures on healthcare resources for a diverse set of European countries, even considering the potential impact of automation, reveals that by 2030, there will still be a significant shortfall in the healthcare workforce. For example, the expected additional demand for nursing professionals in 2030 could be as high as 39 percent.

Most healthcare practitioners are therefore unlikely to be displaced by AI, but their professional lives will change. They will be augmented, supported and in some cases, challenged, by the introduction of AI:

- **They can refocus their energy on their patients, spending less time on administrative tasks and more on direct delivery of care.** Activities that today occupy anything between 20 to 80 percent of physician and nurse time can be streamlined or even eliminated. This can be converted to additional capacity in resource-drained hospitals or gives staff more time to build stronger counselling relationships with patients and their caregivers – "bringing back more joy" to clinical teams. Streamlining routine tasks is a key priority for many of the physicians and nurses we interviewed, and the barriers to adoption are relatively low.

- **Some activities will be more efficient or deliver better outcomes (or both).** AI is improving the speed of diagnostics and in several cases, their accuracy. At the physician level, different specialties will be affected to different degrees, starting with the early adopters – radiology, pathology and ophthalmology – where AI is helping as the volume of clinical data explodes. With the potential to free up 20 percent or more of radiologists' time by handling processes and admin, AI solutions can let them focus more on what the image means and then how to work with patients and clinical teams to further personalise and improve care.
AI's ability to identify the risk of adverse outcomes in hospitalised patients, such as septic shock or acute respiratory failure, may allow teams to prioritise time better and deploy scarce specialist resources to where they are most needed, leading to better outcomes and lower costs. In emergency response, AI can allow for more precise detection of cardiac arrest, potentially saving lives.
- **Healthcare practitioners will increasingly undertake new roles for which they are neither prepared nor have been trained – moving from "oracle" to "counsellor".** Faced with AI-empowered patients who have a preformed view on their condition, practitioners will need to understand the context and constraints of direct-to-consumer solutions such as e-triage. They will need to explain these to patients and reach a shared diagnosis through a counselling relationship. Where an AI-enabled solution is an option for monitoring or treatment, clinicians need to define not only its appropriateness, but also patients' ability to use it. They will need to coach them on its use and monitor the impact, particularly for patients with chronic conditions who may be managing their disease with AI-enabled monitoring and decision support. As care moves from hospital to homes this requires skills not always taught, or prized, in healthcare systems, and a fundamental shift in the culture of how to engage patients. More broadly, as healthcare practitioners interact with ever smarter machines, the demand for soft skills will rise. Social and emotional skills are already becoming more important as intelligent machines take over more physical, repetitive and basic cognitive tasks.
- **Hospital patients may have more complex needs.** AI-augmented remote monitoring, e-triage and similar applications mean that the average patient coming to hospital may have more complex needs, while patients with less complex symptoms may choose to access care through other channels such as primary care, community-based specialists, urgent-care centres or digital consultations. To treat these patients with more complex needs, practitioners will need to work across disciplines far more than they have traditionally. They will need to know how best to use AI clinical decision support to navigate the growing amounts of information on treatments. And they will need to change their approach to education, seeing lifelong learning, digital and AI literacy as cornerstones of their practice.
- **New professionals will need to be welcomed and integrated into healthcare.** People with hybrid, clinical+data profiles, or even profiles completely unknown to the sector such as data scientists, will become intrinsic parts of the system. Working not in silos, but as a single team and speaking the same language will be imperative to improve patient care. In this AI-empowered workforce, the ability to solve problems together will become more important than the knowledge of each individual practitioner.

5.4 Barriers and enablers

This report takes a unique and balanced assessment of the views of healthcare professionals, healthcare investors, startup executives, and healthcare and AI leaders across regions, on what is holding us back from realising the full potential of AI in healthcare.

Despite the increasing attention on AI in healthcare, its introduction in Europe remains slow: 44 percent of healthcare professionals in our survey, a group disproportionately likely to be engaged in innovation as part of the EIT Health network, have never been involved in developing or deploying AI solutions in their organisation. Transparency and the collaboration of innovators and practitioners will be key to scaling AI in European healthcare. The introduction of AI follows on the coattails of digital transformation and there are significant parallels and learnings from this process that offer a cautionary tale on what it takes to adopt and scale innovation in healthcare.

Themes that affect adoption, identified in this work, include:

- **The quality and suitability of solutions.** Our survey reveals two worlds of practitioners and startups passionately striving to solve the same problems, but not necessarily talking to each other – at least not early enough. The result is a feeling that some offerings do not address the right clinical or operational need, are not suitably integrated into existing workflow, or simply do not work. Creating multidisciplinary teams that can work together from identifying use cases through to design, testing, implementation and scale-up appears to be critical, as is user-centred product design. This in turn will help create early the right evidence base for AI's effectiveness, removing the concern that it can be a black box and addressing issues around rolling solutions out to different populations, or error or bias in algorithms. Finally, AI research needs to heavily emphasise explainable, causal and ethical AI, which could be a key driver of adoption.

  Interviewees confirmed that a large part of the value of AI in their organisations could be linked to operational improvements in delivery of care rather than the more eye-catching examples of clinical support. Operational-focused solutions are more likely to be readily adopted as they do not directly affect practitioners' interaction with patients and in fact can free up clinical time.
- **Changing skills of healthcare practitioners and long-term medical education.** MGI analyses show Europe will see an increased demand for most types of skills in healthcare, but the need for technological skills will be the most significant. This includes digital literacy for all frontline staff, as well as the introduction of new skill areas (e.g., data science). It implies both a change in approach to learning for existing practitioners, focusing on lifelong learning and development, and a need to embed such skills into health-system training and education programs across Europe. AI-driven changes in patient behaviours also imply a change in the relationship between patients and practitioners, with the latter needing more focus on counselling and interpersonal skills. Despite some good examples, most higher-education institutions training the healthcare practitioners of the future are not yet addressing this problem and very few have plans to do so. If acquiring these skills is left to individuals themselves to address, it could lead to a wide variation in outcomes.

- **Data quality, governance, security and interoperability.** Issues around data will always be at the heart of successfully promoting AI solutions. Health systems need to take a systematic approach to developing common data standards and processes in order to maximise the value of existing data. This remains a challenge – healthcare is one of the least digitised economic sectors. Healthcare providers and AI companies need to put in place robust data governance, ensure interoperability and standards for data formats, enhance data security and bring clarity to consent over data sharing. Clear guidelines on the required levels of pseudonymisation or anonymisation, and on the linking and de-linking of records needed for certain applications, would be of particular value.
- **Change management.** Ensuring end-users understand the context, strengths and limitations of AI upfront is critical to implementation, as is ensuring they understand the processes used to remove bias from AI and deliver "ethical and trustworthy AI" solutions. A lack of understanding creates barriers to adoption, and these can be as challenging and time-consuming to overcome as developing new solutions in the first place. This understanding needs to be complemented by a clear narrative on the benefits of AI, co-developed with patients and practitioners.
- **Introducing new talent.** The new skills required in an AI-enabled healthcare sector are those most in demand across all sectors and countries. The social impact of working in healthcare is attractive for many new AI professionals, but healthcare needs to work hard to develop other more proactive elements of a value proposition in order to attract, retain and develop such talent. Developing more agile, inclusive and multidisciplinary working cultures will be key, as will be defining a structured path for professional advancement within healthcare.
- **Working at scale.** Health systems will need to recognise that not every hospital will be able to afford or attract all the new people it needs. The resources needed to develop robust AI solutions mean scale matters. Smaller organisations can benefit from working in innovation clusters that bring together AI topics with medical research. Larger organisations can develop centres of excellence that pave the way for regional and public-private collaborations to scale AI further.
- **Regulation, policy making and liability, and managing risk.** Interviewees emphasised strongly that defining the regulatory framework for AI in European healthcare is critical and urgent – especially to avoid bias in AI as it is scaled up.[134] At the moment, responsibility for AI adoption and its impact, whether clinical or in terms of data security, sits with healthcare practitioners or healthcare organisations. This creates uncertainty and delays adoption. Providers need assurance AI products are approved for use and clarity on who carries the risk. Many are also proactively putting new processes in place and ensuring a "compliance by design" approach is at the core of product development.
- **Funding.** Reimbursement of medicines and medical devices across Europe is complicated with different rules. Clear criteria for potential reimbursement of AI applications will be crucial for their adoption. In many European countries it is unclear how solutions that ultimately reduce the number of patients seeking direct treatment from physicians will be financially incentivised and rewarded. However, there is more scope for novel approaches to funding innovation. Some interviewees pointed out that health organisations or health systems could allow open access to specific databases under the right guidelines (i.e., data security and confidentiality, and ethical and trustworthy AI), in exchange for a share of intellectual property rights or a share of profits when AI solutions are eventually scaled up.

5.5 The implications for healthcare organisations and health systems

European healthcare providers and health systems need to assess what their distinctive role or contribution can be in introducing or scaling AI in healthcare. They need to take stock of their capabilities, level of digitisation, availability and quality of data, resources and skills to define their level of ambition on AI as it fits with their strategic goals.

They should also define the enablers they need to put in place. The precise list will vary, but for many these will include creating an AI ecosystem through partnerships to codevelop the right solutions for their population; codeveloping a compelling narrative on AI with patients and practitioners; defining and developing the right use cases jointly with end-users; defining and addressing skill gaps in digital literacy for their staff; refining their value proposition for AI talent; addressing data quality, access, governance and interoperability issues; and shaping a culture of entrepreneurship.

As scale matters, European providers could come together on a geographic or thematic basis. This could involve joining a geographic cluster of innovation such Cambridge University Health Partners or other UK Academic Health Science Centres, or a specialty-based collaboration, such as the disease-based AI collectives in Israel, and they could scale their impact with targeted collaborations across Europe.

European health systems can play a more fundamental role in catalysing the introduction and scale-up of AI. Six actions they could take are:

- Develop a regional or national AI strategy for healthcare, defining medium- and longer-term vision and goals, specific initiatives, resources and performance indicators
- Define use cases to support through targeted funding and incentives to enable scaling of AI solutions across the system; ensure these deliver against both clinical and operational outcomes.
- Set standards for digitisation, data quality and completeness, data access, governance, security and sharing and system interoperability; incentivise adherence to standards through a combination of performance and financial incentives.
- Redesign workforce planning and clinical education processes to address the needs of both future healthcare and AI-focused professionals; and invest upfront in upskilling frontline staff and designing lifelong-learning programmes through continuing professional development and degrees or diplomas for healthcare practitioners.
- Provide incentives and guidance for healthcare organisations to collaborate in centres of excellence or clusters of innovation at the regional or national level.
- Address AI regulation, liability and funding issues, creating the right environment for appropriate, safe and effective AI solutions to be adopted but minimising the risk to healthcare practitioners; ensure this is reflected in funding and reimbursement mechanisms for innovation in healthcare.

5.6 What role could Europe play?

Europe's strength lies in its collective energy, compared to other leading players in AI such as the US or China.

Survey respondents were clear on the potential role of the EU, which could complement that of regional or national health systems and providers, and it could include:

- Defining a small core of **European AI funding priorities** and consolidate funding to support rapid testing and scaling of AI solutions in critical areas.
- **Creating a common playing field across Europe**, with common standards on data, regulation, access, privacy or interoperability, and shared requirements on data exchange. This would enable innovators to scale AI solutions in a cost-effective way and would increase user confidence.
- Encouraging and supporting the creation of **centres of excellence for AI in healthcare across Europe**, to help concentrate scarce AI talent in high-profile roles in agile networks, and to ensure talent creation and continuous learning are prioritised and enhanced at the European level.
- Finalising an approach on **data security and confidentiality**, leading the way internationally (similar to Europe's role with GDPR) and removing unnecessary barriers to using and scaling AI.
- Offering targeted support to **upskilling or reskilling healthcare practitioners** through tailored talent and educational programmes across Europe, potentially delivered by a diverse set of education providers and through diverse channels.

AI has the potential to transform how care is delivered in Europe and in some cases it is already doing so. Speeding up the pace, through the thoughtful and systematic introduction of AI, could deliver significant benefits to European patients and populations. Europe is distinctively placed to deliver the best of both worlds. It can build on the unique strengths of its national health systems and datasets, and on its innovation ecosystem to ensure that patients' rights to their data remain sacrosanct, while ensuring those same patients get the full benefit from the tremendous promise of AI in healthcare.

Appendices

Appendix 1: List of interviewees

Name	Position	Organisation
Mary Lou Ackerman	Vice President of Innovation	SE Health
David E. Albert, MD	Founder & Chief Medical Officer	AliveCor
Antoaneta Angelova-Krasteva	Director for Innovation, International Cooperation & Sport	DG EAC, European Commission
Peter Arlett	Head of Pharmacovigilance and Epidemiology Department	European Medicines Agency
Dr. Sarim Ather	Specialist Registrar in Clinical Radiology Topol NHS Digital Fellow	Oxford University Hospitals
Dr. Christopher Austin	Chief Medical Officer	Kheiron Medical
Dr. Yossi Bahagon	Managing Partner	Qure Ventures
Mike Berger	Chief Data and Analytics Officer	Mount Sinai Health System
Nathalie Bloch, MD, MPA	Head of Big Data and AI at ARC	Innovation Center at Sheba Medical Center
Claire Bloomfield	CEO, National Consortium of Intelligent Medical Imaging	University of Oxford
Dr. Kyra Bobinet	CEO, Physician, Behavioural Science Expert and Author	Fresh Tri
Eugene Borukhovich	Chairman & Founding Board Member	YourCoach Health
Vincent Buscemi	Partner and Head of Independent Health and Social Care	Bevan Brittan LLP
Josep Carbó	Director Global Business Development Vice-President	Mediktor Barcelona Health Hub
David Champeaux	Chief Growth Officer Advisory Council Member	Cherish Health HIMSS
Anthony Chang, MD, MBA, MPH, MS	Founder Chief Intelligence and Innovation Officer of the Sharon Disney Lund Medical Intelligence and Innovation Institute and Medical Director	AI Med CHOC Children's Heart Failure Program
Dr. David Cox	Consultant Neonatologist Topol Fellow in Digital Healthcare	Imperial College Healthcare NHS Trust, Health Education England and Great Ormond Street Hospital for Children NHS Trust
Massimo Craglia	Senior Expert, Digital Economy Unit	Joint Research Centre, European Commission
Adolfo Fernández-Valmayor	CTO	Grupo QuirónSalud
Stefano Fontana	Head of Unit Innovation Communities	EIT

Name	Position	Organisation
Robert Freeman	Vice President, Clinical Innovation	Mount Sinai Hospital
Zaide Frias	Head of the Human Medicines Evaluation Division	European Medicines Agency
Carolina Garcia-Vidal, MD, PhD	Principal researcher at Nosocomial Infections Group ESCMID fellow Professor	IDIBAPS Universitat de Barcelona
Dr. Emilio Gómez González	Director of the Group of Interdisciplinary Physics (GFI)	ETSI, Universidad de Sevilla
David Harlow	Healthcare Compliance Counsel, Compliance Officer & Privacy Officer	Insulet Corporation
Oliver Harrison	CEO	Alpha Health
Hans Hofstraat	VP, Innovation Program Manager	Philips Chief Technology Office
Dr. Marco Inzitari	Director of Intermediate Care, Research and Teaching President	Parc Sanitari Pere Virgili Catalan Society of Geriatrics and Gerontology
Julián Isla Gómez	Data and Artificial Intelligence Resource Manager	Microsoft EMEA
Saurabh Johri	Chief Scientist	Babylon Health
Zayna Khayat	Future Strategist Adjunct Professor	SE Health Rotman School of Management at the University of Toronto
Ossi Laukkanen	Business Unit Head, Digital Services	Mehiläinen
Rebecca Love	Nurse, VP	OptimizeRx
Prof. Jens Lundgren	Professor, Centre Leader, Senior Consultant	Rigshospitalet, University of Copenhagen
Marco Marsella	Head of Unit eHealth, Well-Being and Ageing	DG CONNECT, European Commission
Bertin Martens	Senior Economist	Joint Research Centre, European Commission
Federico Menna	Head of Operations	EIT Digital
Bertalan Meskó, MD, PhD	Director	The Medical Futurist Institute
Antanas Montvila, MD	Radiologist, Vice President	European Junior Doctors Association
Daniel Moreno Martínez, PhD	Head of Innovation	Hospital Universitari Germans Trias i Pujol

Name	Position	Organisation
Hiyam Nadel, MBA, RN	Director of Innovations in Care Delivery Johnson and Johnson Innovation Fellow	Massachusetts General Hospital
Felix Nensa	Radiologist, Head of Machine Learning	University Hospital Essen
Dr. Alexander Ng	Vice President	Tencent Healthcare
Bethany Percha	Assistant Professor, CTO Precision Health Enterprise	Mount Sinai Health System
Steven Petit	Medical Physicist and Assistant Professor	Erasmus MC Cancer Institute
PD Dr. med. Dominik Pförringer	Orthopaedic and Trauma Surgeon	TUM Hospital
Todd Ponsky, MD, FACS	Professor of Surgery Director of Clinical Growth and Transformation	Cincinnati Children's Hospital
Petia Radeva	Full Professor	Faculty of Mathematics and Computer Science, ICREA Academia, Universitat de Barcelona
Lars Roemheld	Director of Data & AI	hih (German Ministry of Health)
Michal Rosen-Zvi, PhD	Director of Healthcare informatics Visiting Professor	IBM Research Faculty of Medicine of The Hebrew University
Rasmus Rothe	Founder	Merantix
Nawal Roy	CEO	Holmusk
Eigil Samset	Chief Technology Scientist	GE Healthcare Cardiology Solutions
Dr. Thomas Senderovitz, MD	Director General	Danish Medicines Agency
Haris Shuaib	Senior Physicist in Magnetic Resonance	Guy's & St. Thomas' NHS Foundation Trust
Sudipto Srivastava	Senior Director for Digital Health	Mount Sinai Hospital
Lior Teitelbaum	Chief Business Officer	FutuRx
Paul Timmers	Chief Advisor Research Associate	EIT Health University of Oxford
Martijn van der Meulen, MD	Internal Medicine	Radboud University Medical Center
Monique van Dijk	Professor Nursing Science, Dep. Internal Medicine & Paediatric surgery	Erasmus MC
Stefan Vlachos, MSc, MBA	Head of the Center for Innovation	Karolinska University Hospital
Dr. Eyal Zimlichman	Deputy Director General, Chief Medical Officer and Chief Innovation Officer	Sheba Medical Center

Appendix 2: MGI methodology

The 2017-2019 MGI work on automation has involved a detailed look across 19 different economic sectors and 820 different occupations, 69 of which describe healthcare professionals and related occupations.[135]

During this process, more than 2,000 distinct activities were mapped to 25 skills that fold into five skill categories: physical and manual skills, basic cognitive skills, higher cognitive skills, social and emotional skills, and technological skills.[136]

The time spent on these activities for all 800 occupations was calculated by MGI and then used to assess the overall occupational level potential for automation by 2030 for each occupation, based on today's technological capabilities, and the potential impact on the projected 2030 labour force.

Beyond technical feasibility, four main factors were identified as affecting adoption, i.e., the extent and pace of automation. These factors are economic and social and, although they are common across countries, their relative impact on adoption varies according to local context and conditions. They include:

- The cost of developing and implementing automation solutions
- Local labour supply, demand and wage rates
- Net economic benefits of automation, which can go beyond labour substitution, such as increased quality and safety
- Regulatory and social acceptance

Labour-market dynamics and wage rates can particularly affect adoption rates, since wages can vary widely between countries even for similar occupations. The relative cost of labour and automation will affect the business cases for deploying automation solutions: if qualified workers are abundantly available and automation much more expensive than overall wages, automation may be considered less favourably. Equally, where a qualified workforce is scarce and expensive, adopting automation solutions may be more attractive.

Although automation can reduce the hours of work needed by some types of workers to varying extents across sectors, and often transform the nature of work across occupations, in the next decade new and additional work will also be created. Predicting the exact extent of these changes is not possible, but the analysis has identified factors that will shape future labour demand in parallel to any reduction in demand by automation, giving an indication of potential net job growth.

The analysis has modelled seven specific global trends that are expected to be significant drivers of job creation, leading to 555 million to 890 million new jobs worldwide net of automation, created by 2030 as incomes rise. These include caring for others in ageing societies, raising energy-production efficiency and meeting climate challenges, producing goods and services for the expanding consumer class, especially in developing countries, investment in technology, infrastructure, and buildings as well as the marketisation of unpaid household work. The impact of these factors on job creation – either directly or indirectly – is sized and the work also accounts for other trends affecting the workplace, such as the globalisation of work and reductions in hours worked per person. For each occupation, 2030 incremental labour demand is compared with a potential reduction in labour hours required due to automation and AI and as such, the analysis offers a snapshot of potential labour demand that could be created.

See https://www.mckinsey.com/featured-insights/future-of-work for a more thorough discussion of the methodology employed.

Appendix 3: Survey

Here we describe the survey participants who helped us evaluate the impact of AI on healthcare resources and healthcare organisations, now and in the future.

The survey of 175 participants was undertaken in December 2019 and January 2020. It targeted three groups of stakeholders: healthcare professionals, the founders and executives of AI startups and healthcare investors. The survey sought to understand the view from the front line on the impact AI technologies will have on the healthcare workforce and on organisations within healthcare.

The survey was distributed among a targeted diverse group of stakeholders in the EIT Health Network. The participants were not selected to form a representative cross-section of Europe but reflect the membership of the EIT Health partnership. Due to the increased likelihood of having included more participants with a stated interest in innovation and technologies, we expect results to reflect this bias. We also shared the survey with key contacts in hospitals and other healthcare providers within the EIT Health network to disseminate to their staff.

We received responses from 78 healthcare professionals, 60 startup executives and 37 investors.

Survey demographics

Healthcare professionals

Most of the respondents were medical doctors, a quarter had roles related to management and IT and some were nurses. The medical doctors that answered the survey had different specialties, with radiology and surgery the two most common. More than two-thirds of them had at least 11 years' experience in their profession. Alongside medical doctors and different nursing practitioners, respondents included allied health professionals (e.g., surgical assistants, prosthetists), CEOs, chief information officers, managers of IT, innovation and clinical solutions, medical informatics consultants, clinical scientists, researchers and others.

Startup executives

Startups that participated in this survey came from 14 different EU Member States, with France the best represented (18.6%). Most of the solutions represented are already in the market (44%), in a prototype phase (28%) or in clinical validation (26%). Most (70%) are at an early stage of their development and have not yet raised more than €1 million, while just over a fifth have already raised between €2 million and €5 million.

Investors

The vast majority of the respondents invest mainly in Europe (89%). Just over half have a fund exceeding €50 million. Of the investors that participated, 82 percent are currently investing in AI. However, these investments represent between no more than 20 percent of the total portfolio in w71 percent of cases (normally one or two ventures per firm).

[1] *Global Strategy on human resources for health: Workforce 2030*, World Health Organization, 2016, https://www.who.int/hrh/resources/pub_globstrathrh-2030/en/.

[2] *Artificial intelligence: Potential benefits and ethical considerations*, European Parliament Legal Affairs briefing, Policy Department C: Citizens' Rights and Constitutional Affairs, PE 571.380, 2016, http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/571380/IPOL_BRI(2016)571380_EN.pdf. Our working definition of AI in healthcare in this work is deliberately broad; it includes a functional continuum from the application of rules-based systems through to cutting-edge methodologies that include classic machine learning, representation learning and deep learning.

[3] "A future that works: Automation, employment and productivity", McKinsey Global Institute, January 2017; "Artificial intelligence: The next frontier", McKinsey Global Institute, June 2017; "Jobs lost, jobs gained: Workforce transitions in a time of automation," McKinsey Global Institute, December 2017; "Skill shift: Automation and the future of the workforce", McKinsey Global Institute, May 2018; "'Tech for good': Using technology to smooth disruption and improve well-being", McKinsey Global Institute, May 2019. See https://www.mckinsey.com/featured-insights/future-of-work.

[4] *Global strategy on human resources for health: Workforce 2030*, World Health Organisation, https://www.who.int/hrh/resources/pub_globstrathrh-2030/en/, 2016; Healthcare personnel statistics - nursing and caring professionals, Eurostat, 2019, https://ec.europa.eu/eurostat/statistics-explained/index.php/Healthcare_personnel_statistics_-_nursing_and_caring_professionals#Healthcare_personnel.

[5] *Life expectancy at birth in the EU*, Eurostat, July 2019. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20190725-1.

[6] *2019 Revision of World Population Prospects*, United Nations, 2019 https://population.un.org/wpp/. Suzman R., Beard J., Boerma T., Chatterji S., "Health in an ageing world – what do we know", *The Lancet*, Vol. 385, Issue 9967, pp. 484-486, 7 February 2015.

[7] Prince, M., et al., "The burden of disease in older people and implications for health policy and practice", The Lancet, Vol. 385, Issue 9667, pp. 549-562, 7 February 2015.

[8] Porter makes the same point about the growth of healthcare spend in the US. Porter, M., *Value-based health care delivery: Core concepts*, Value-Based Innovation Summit, Cleveland, OH, 22 October 2019, https://www.isc.hbs.edu/Documents/pdf/10.29.2019_ClevelandClinicVBSummit_v4.1_DB_RefUpdate_FINAL.pdf.

[9] *Health at a Glance: Europe 2018*, OECD, February 2019, https://www.oecd-ilibrary.org/docserver/health_glance_eur-2018-en.pdf.

[10] *Global Strategy on human resources for health: Workforce 2030*, World Health Organization, 2016.

[11] *Artificial intelligence: Potential benefits and ethical considerations*, European Parliament Legal Affairs briefing, Policy Department C: Citizens' Rights and Constitutional Affairs, PE 571.380, 2016, http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/571380/IPOL_BRI(2016)571380_EN.pdf. Our working definition of AI in healthcare in this work is deliberately broad; it includes a functional continuum from the application of rules-based systems through to cutting-edge methodologies that include classic machine learning, representation learning and deep learning.

[12] *AI and the Health Care Workforce*, American Hospital Association, September 2019.

[13] *The Topol Review: Preparing the healthcare workforce to deliver the digital future*, Health Education England, NHS, February 2019.

[14] Colclough, G. et al. *Harnessing data science and AI in healthcare from policy to practice*, World Innovation Summit for Health, 2018 http://www.wish.org.qa/wp-content/uploads/2018/11/IMPJ6078-WISH-2018-Data-Science-181015.pdf.

[15] *Ethics guidelines for trustworthy AI*, European Commission, April 2019. This report listed seven key requirements for trustworthy AI: Human agency and oversight; technical robustness and safety; privacy and data governance; transparency; diversity, non-discrimination and fairness; societal and environmental well being; and accountability.

[16] *AI and Ethics in the Health Innovation Community*, EIT Health, 2019; AI Now Report 2019, AI Now Institute, 2019. Open AI research laboratory, https://openai.com/about/. CLAIRE - Confederation Of Laboratories For Artificial Intelligence Research In Europe, https://claire-ai.org/.

[17] "A future that works: Automation, employment and productivity", McKinsey Global Institute, January 2017; "Artificial intelligence: The next frontier", McKinsey Global Institute, June 2017; "Jobs lost, jobs gained: Workforce transitions in a time of automation," McKinsey Global Institute, December 2017; "Skill shift: Automation and the future of the workforce", McKinsey Global Institute, May 2018; "'Tech for good': Using technology to smooth disruption and improve well-being", McKinsey Global Institute, May 2019. See https://www.mckinsey.com/featured-insights/future-of-work.

[18] France, Germany, Hungary, Italy, Portugal, Sweden and the UK. The full MGI methodology is described in detail in the appendix of this report.

[19] *FDA approvals for smart algorithms in medicine in one giant infographic*, The Medical Futurist, June 6, 2019, https://medicalfuturist.com/fda-approvals-for-algorithms-in-medicine/.

[20] *Artificial intelligence: Potential benefits and ethical considerations*, European Parliament Legal Affairs briefing, Policy Department C: Citizens' Rights and Constitutional Affairs, PE 571.380, 2016, http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/571380/IPOL_BRI(2016)571380_EN.pdf.

[21] A simple and clear definition of AI offered by the University of Helsinki and Reaktor, "Elements of AI", https://course.elementsofai.com/.

[22] Colclough, G. et al., *Harnessing data science and AI in healthcare from policy to practice*, World Innovation Summit for Health, 2018 http://www.wish.org.qa/wp-content/uploads/2018/11/IMPJ6078-WISH-2018-Data-Science-181015.pdf.

[23] Mesko, B., "A Guide to Artificial Intelligence in Healthcare", The Medical Futurist, 2019; P. Densen, "Challenges and opportunities facing medical education", Transactions of the American Clinical and Climatological Association, vol. 122, pp. 48-58, 2011.

[24] Liat Clark, "Illumina announces landmark $1,000 human genome sequencing", *Wired*, January 15, 2014, https://www.wired.co.uk/article/1000-dollar-genome.

[25] https://www.projectbaseline.com/; https://healthynv.org/.

[26] S. Dodge and L. Karam, "Understanding how image quality affects deep neural networks," International Conference on Quality of Multimedia Experience (QoMEX), 2016 http://image-net.org/challenges/LSVRC/2010/results; http://image-net.org/challenges/LSVRC/2017/results.

[27] Daniel Nelson, "Baidu Beats Out Google And Microsoft, Creates New Technique For Language Understanding", *Unite.AI*, 28 December 2019, https://www.unite.ai/baidu-beats-out-google-and-microsoft-creates-new-technique-for-language-understanding/.

[28] "Can science be automated?", ScienceDaily, April 2019, https://www.sciencedaily.com/releases/2019/04/190418105730.htm.

[29] Hinton, G., Deep learning—a technology with the potential to transform health care. Jama, 2018, 320(11), pp.1101-1102; Gottesman, O., et al., "Guidelines for reinforcement learning in healthcare". Nature Medicine, 2019, 25(1), pp.16-18.

[30] Holzinger, A. et al., "What do we need to build explainable AI systems for the medical domain?", arXiv:1712.09923, 2017.

[31] US reports include, *National artificial intelligence research and development strategic plan: 2019 update*, a report by the Select Committee on AI of the National Science and Technology Council, June 2019; *Proposed regulatory framework for modifications to AI/ML based software as a medical device (SaMD)* – US Food & Drug Administration, discussion paper, May 2019, https://www.fda.gov/medical-devices/software-medical-device-samd/artificial-intelligence-and-machine-learning-software-medical-device. EU Member State reports include, Joshi, I., Morley, J.,(eds) *Artificial intelligence: How to get it right. Putting policy into practice for safe data-driven innovation in health and care*, NHSX, 2019, https://www.nhsx.nhs.uk/assets/NHSX_AI_report.pdf; *AI sector deal*, UK Government, Policy Paper updated May 2019, https://www.gov.uk/government/publications/artificial-intelligence-sector-deal/ai-sector-deal; *Germany: Artificial Intelligence Strategy*, German Federal Government, April 2019, https://ec.europa.eu/knowledge4policy/publication/germany-artificial-intelligence-strategy_en. *Finland's age of artificial intelligence Turning Finland into a leading country in the application of artificial intelligence. Objective and recommendations for measures"*, Finnish Ministry of Economic Affairs and Employment, December 2017, https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/160391/TEMrap_47_2017_verkkojulkaisu.pdf. And in China, *New Generation of Artificial Intelligence Development Plan"*, Chinese State Council, Document 2017, no 35, in Foundation for Law and International Affairs, https://flia.org/notice-state-council-issuing-new-generation-artificial-intelligence-development-plan/.

[32] https://ec.europa.eu/jrc/communities/en/node/1286/document/eu-declaration-cooperation-artificial-intelligence.

[33] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on Artificial intelligence for Europe (COM(2018) 237 final) https://ec.europa.eu/digital-single-market/en/news/communication-artificial-intelligence-europe.

[34] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions on a Coordinated plan on artificial intelligence (COM(2018) 795 final) https://ec.europa.eu/digital-single-market/en/news/coordinated-plan-artificial-intelligence.

[35] *Draft ethics guidelines for trustworthy AI*, High-Level Expert Group on Artificial Intelligence, https://ec.europa.eu/digital-single-market/en/news/draft-ethics-guidelines-trustworthy-ai. Other core EU publications on AI include: *Artificial intelligence: Potential benefits and ethical considerations*, European Parliament Legal Affairs briefing, Policy Department C: Citizens' Rights and Constitutional Affairs, PE 571.380, 2016, http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/571380/IPOL_BRI(2016)571380_EN.pdf; *Artificial Intelligence: A European Perspective*, JRC, December 2018, https://publications.jrc.ec.europa.eu/repository/handle/JRC113826; *The European AI Landscape*, European Commission Workshop Report, April 2018, https://ec.europa.eu/digital-single-market/en/news/european-artificial-intelligence-landscape; *Artificial intelligence: Challenges for EU citizens and consumers*, European Parliament Committees Briefing Notes, January 2019, http://www.europarl.europa.eu/RegData/etudes/BRIE/2019/631043/IPOL_BRI(2019)631043_EN.pdf. *Communication on building trust in human-centric AI*, European Commission, April 2019, https://ec.europa.eu/digital-single-market/en/news/communication-building-trust-human-centric-artificial-intelligence; and *Policy and investment recommendations for trustworthy AI*, June 2019, https://ec.europa.eu/digital-single-market/en/news/policy-and-investment-recommendations-trustworthy-artificial-intelligence.

[36] *Communication on enabling the digital transformation of health and care in the Digital Single Market*, European Commission, April 25, 2018, https://ec.europa.eu/digital-single-market/en/news/communication-enabling-digital-transformation-health-and-care-digital-single-market-empowering.

[37] *Digital Europe Programme: a proposed €9.2 billion of funding for 2021-2027*, European Commission, June 26, 2019, https://ec.europa.eu/digital-single-market/en/news/digital-europe-programme-proposed-eu92-billion-funding-2021-2027; Digital education action plan, European Commission, https://ec.europa.eu/education/education-in-the-eu/digital-education-action-plan_en.

[38] "Here's how Qatar is investing in AI research and advanced technology", Business Insider, 16 October 2019, https://www.businessinsider.com/sc/how-qatar-is-investing-in-ai-research-and-advanced-technology-2019-10.

[39] "Israel Prepares to Unleash AI on Health Care",*Wall Street Journal*, September 15, 2019.

[40] PitchBook Data, Inc., https://pitchbook.com/research-process.

[41] "Ping An Good Doctor has become the first online healthcare platform with more than 300 million registered users", PR newswire, September 2019, https://www.prnewswire.com/news-releases/ping-an-good-doctor-has-become-the-first-online-healthcare-platform-with-more-than-300-million-registered-users-300923026.html.

[42] European Society of Cardiology (ESC), Press release, 6 June 2019, https://www.escardio.org/The-ESC/Press-Office/Press-releases/Atrial-fibrillation-set-to-affect-more-than-14-million-over-65s-in-the-EU-by-2060.

[43] Heaven, D. "An algorithm that can spot cause and effect could supercharge medical AI", MIT Technology Review, February 5, 2020, https://www.technologyreview.com/s/615141/an-algorithm-that-can-spot-cause-and-effect-could-supercharge-medical-ai/.

[44] Smith, N., et al., "AI-Driven Automation in a Human-Centered Cyber World", In 2018 IEEE International Conference on Systems, Man, and Cybernetics, October 2018, (SMC) (pp. 3255-3260). IEEE.

[45] https://www.khealth.ai/post/how-k-delivers-free-personalized-healthcare-information.

[46] Ping An Good Doctor "Ping An Good Doctor Launches Commercial Operation Of One-Minute Clinics And Signs Contracts For Nearly 1,000 Units, Serving More Than 3 Million Users", January 4, 2019, http://www.pahtg.com/en/news/in-the-news/ping-an-good-doctor-launches-commercial-operation-of-one-minute-clinics-and-signs-contracts-for-nearly-1-000-units-serving-more-than-3-million-users/.

[47] "Ping An Good Doctor has become the first online healthcare platform with more than 300 million registered users", PR newswire, September 2019, https://www.prnewswire.com/news-releases/ping-an-good-doctor-has-become-the-first-online-healthcare-platform-with-more-than-300-million-registered-users-300923026.html; https://www.babylonhealth.com/blog/business/10-things-we-did-in-2019/; https://ada.com/milestones/; https://www.mediktor.com/en-us; https://www.khealth.ai/post/k-health-two-million-users-and-just-getting-started.

[48] McKinney, S.M., Sieniek, M., Godbole, V. et al. "International evaluation of an AI system for breast cancer screening". *Nature*, 2020, 577, 89–94.

[49] See: *Healthcare resource statistics - technical resources and medical technology"*, Eurostat, Statistics Explained https://ec.europa.eu/eurostat/statistics-explained/pdfscache/37388.pdf, https://ec.europa.eu/eurostat/statistics-explained/pdfscache/37388.pdf.

[50] https://www.marketresearchhighlights.org/industry-reports/blood-testing-market/.

[51] *DeepMind* blog "Using AI to give doctors a 48-hour head start on life-threatening illness", July 31, 2019, https://deepmind.com/blog/article/predicting-patient-deterioration; Tomašev N., et al., "A clinically applicable approach to continuous prediction of future acute kidney injury". *Nature*, 2019 572(7767) pp116-9.

[52] "How IBM Watson overpromised and underdelivered on AI health care", *IEEE Spectrum* April 2, 2019, https://spectrum.ieee.org/biomedical/diagnostics/how-ibm-watson-overpromised-and-underdelivered-on-ai-health-care.

[53] "Moorfields and DeepMind Health research partnership latest update", November 2018, https://www.moorfields.nhs.uk/node/2558; "Google-backed DeepMind Creates Deep Learning CDS for Eye Diseases", *Health Analytics*, 14 August 2018, https://healthitanalytics.com/news/google-backed-deepmind-creates-deep-learning-cds-for-eye-diseases.

[54] https://digital.nhs.uk/data-and-information/virtual-data-assistant.

[55] https://www.diabetes.co.uk/diabetes-prevalence.html (accessed January 8, 2020).

[56] https://www.ibm.com/case-studies/karantis360-ibm-cloud-watson-iot-care.

[57] https://ec.europa.eu/eurostat/cache/infographs/elderly/index.html (accessed January 13, 2020).

[58] "Elderly care and housing demand in the EU - Golden opportunities, but mind the cultural gap", ING Economics Department, May 2019, https://think.ing.com/uploads/reports/ING_-_Elderly_care_and_housing_demand_in_the_EU_-_May_2019_1.pdf.

[59] Yamada, M., et al, "Development of a real-time endoscopic image diagnosis support system using deep learning technology in colonoscopy", Scientific reports, 2019, 9(1), pp.1-9; https://www.bowelcanceruk.org.uk/news-and-blogs/campaigns-and-policy-blog/the-future-of-artificial-intelligence-(ai)-in-the-nhs/.

[60] "Icahn School of Medicine at Mount Sinai to establish world-class center for artificial intelligence", *Newswise*, June 11, 2019, https://www.newswise.com/articles/icahn-school-of-medicine-at-mount-sinai-to-establish-world-class-center-for-artificial-intelligence-hamilton-and-amabel-james-center-for-artificial-intelligence-and-human-health.

[61] "Emergency hospital admissions in England", The Health Foundation, May 2018, https://www.health.org.uk/publications/emergency-hospital-admissions-in-england-which-may-be-avoidable-and-how.

[62] Causes of death-standardised death rate, EU-28, 2016, Eurostat, http://ec.europa.eu/eurostat/product?code=hlth_cd_asdr2&language=en&mode=view; https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Causes_of_death_statistics (Accessed January 13, 2020).

[63] Published in zu Putlitz, Jasper (ed.) et al., *The future of Medicine: disruptive innovations revolutionise medicine and health*, (in German), Medizinisch Wissenschaftliche Verlagsgesellschaft, May 2019.

[64] Kalis, B. et al., "10 promising applications of AI in healthcare", *Harvard Business Review*, May 10, 2018, https://hbr.org/2018/05/10-promising-ai-applications-in-health-care.

[65] "Qventus for perioperative units – streamlining patient flow for perioperative care", Qventus. https://www.qventus.com/content/uploads/2019/01/Qventus-OR-Solution-Brief.pdf.

[66] "NHS performance and waiting times", *The Health Foundation*, 22 November 2019, https://www.health.org.uk/news-and-comment/blogs/nhs-performance-and-waiting-times.

[67] Roche, "This is personalised care", https://www.roche.com/about/priorities/personalised_healthcare.htm.

[68] Darino, L., Knepp, A., Mills, N., and Tinkoff, D., "How pharma can accelerate business impact from advanced analytics", McKinsey & Company, January, 2018, https://www.mckinsey.com/industries/pharmaceuticals-and-medical-products/our-insights/how-pharma-can-accelerate-business-impact-from-advanced-analytics.

[69] https://www.novartis.com/news/novartis-and-microsoft-announce-collaboration-transform-medicine-artificial-intelligence; "BMS signs deal with Concerto Health AI", *Pharma Times*, March 29, 2019, http://www.pharmatimes.com/news/bms_signs_deal_with_concerto_healthai_1282903; "AZ to accelerate drug discovery with BenevolentAI partnership", *Pharma Times*, April 30, 2019, http://www.pharmatimes.com/news/az_to_accelerate_drug_discovery_with_benevolentai_partnership_1286156.

[70] David Shaywitz, "Novartis CEO who wanted to bring tech into pharma now explains why it's so hard", *Forbes*, January 16, 2019, https://www.forbes.com/sites/davidshaywitz/2019/01/16/novartis-ceo-who-wanted-to-bring-tech-into-pharma-now-explains-why-its-so-hard/#402f02957fc4.

[71] https://www.sanofi.com/en/about-us/our-stories/real-world-evidence-turns-experience-into-knowledge.

[72] https://www.navify.com/tumorboard/.

[73] Kalis, B. et al., "10 promising applications of AI in healthcare", *Harvard Business Review*, May 10, 2018, https://hbr.org/2018/05/10-promising-ai-applications-in-health-care.

[74] "A future that works: Automation, employment and productivity", McKinsey Global Institute, January 2017; "Jobs lost, jobs gained: Workforce transitions in a time of automation," McKinsey Global Institute, December 2017; "Skill shift: Automation and the future of the workforce", McKinsey Global Institute, May 2018.

[75] The European countries analysed are France, Germany, Hungary, Italy, Portugal, Sweden and the UK.

[76] Mark Britnell, *Human: Solving the global workforce crisis in healthcare*, Oxford University Press, 2019.

[77] *Global strategy on human resources for health: Workforce 2030*, World Health Organisation, 2016, https://www.who.int/hrh/resources/pub_globstrathrh-2030/en/; *Healthcare personnel statistics - nursing and caring professionals*, Eurostat, 2019, https://ec.europa.eu/eurostat/statistics-explained/index.php/Healthcare_personnel_statistics_-_nursing_and_caring_professionals#Healthcare_personnel; Eurostat cites approximately 2.8 million practicing nursing professionals in EU Member States: 200,000 practicing midwives, almost 1.2 million practicing nursing associate professionals and around 4.4 million practicing nursing assistants, as of 2017.

[78] *The health care workforce in England – Make or break?*, The Kings Fund, 2018, https://www.kingsfund.org.uk/publications/health-care-workforce-england.

[79] Westbrook, Johanna I., et al., "How much time do nurses have for patients? a longitudinal study quantifying hospital nurses' patterns of task time distribution and interactions with health professionals", *BMC health Ser Res*, 2011, vol. 11, No. 319.

[80] EU 28 average birth rate: 1.6 children per woman in 2019, from 2.5 in 1960. *See Demographic outlook for the European Union*, 2019, European Parliament May 2019, http://www.europarl.europa.eu/RegData/etudes/IDAN/2019/637955/EPRS_IDA(2019)637955_EN.pdf.

[81] See also "Rads who use AI will replace rads who don't", *Stanford University*, November 2017, https://aimi.stanford.edu/news/rsna-2017-rads-who-use-ai-will-replace-rads-who-don-t.

[82] Woolhandler, S., Himmelstein, D.U., "Administrative work consumes one-sixth of U.S. physicians' working hours and lowers their career satisfaction"; *Int J Health Services 2014*; vol. 44; No. 4; Sinsky, C., et al., "Allocation of physician time in ambulatory practice: A time and motion study in 4 specialties", *Ann Intern Med 2016*; vol. 165, p.753-760; Donnelly, Laura, "Junior Doctors 'spend up to 70 per cent of time on paperwork'", *The Telegraph*, 8 December 2015, https://www.telegraph.co.uk/news/health/news/12037469/Junior-doctors-spend-up-to-70-per-cent-of-time-on-paperwork.html. Westbrook, Johanna I., et al., "How much time do nurses have for patients? a longitudinal study quantifying hospital nurses' patterns of task time distribution and interactions with health professionals", *BMC health Ser Res*, 2011, vol. 11, No. 319.

[83] "The impact of clinical speech recognition in the Emergency Department at South Tees Hospitals NHS Foundation Trust", *Digital Health*, 27 February 2018, https://www.digitalhealth.net/2018/02/impact-clinicalspeech-recognition-emergency-department-south-teeshospitals-nhs-foundation-trust/.

[84] Dr. Taj Hassan, President of the Royal College of Emergency Medicine, quoted in "NHS England urgently needs 2,200 more A&E consultants", *The Guardian*, July 19, 2017.

[85] "NHS Trust Saves £150,000 a Year Using Clinical Speech Recognition", The Journal of mHealth, November 29, 2018, https://thejournalofmhealth.com/nhs-trust-saves-150000-a-year-using-clinical-speech-recognition/.

[86] *The Topol Review: Preparing the healthcare workforce to deliver the digital future*, NHS, February 2019.

[87] "The Johns Hopkins Hospital Launches Capacity Command Center to Enhance Hospital Operations", *Johns Hopkins Medicine*, October 26, 2016, https://www.hopkinsmedicine.org/news/media/releases/the_johns_hopkins_hospital_launches_capacity_command_center_to_enhance_hospital_operations (accessed 6 January 2020).

[88] Basu, M., and Rohaidi, N., "Exclusive: Tan Tock Seng Hospital builds 'artificial brain' to manage services", *GovInsider*, https://govinsider.asia/smart-gov/exclusive-tan-tock-seng-hospital-builds-artificial-brain-to-manage-services/ (accessed January 6, 2020).

[89] Saver, C., "How will artificial intelligence impact surgical patient care? Part 2", *OR Manager*, May 17, 2019, https://www.ormanager.com/will-artificial-intelligence-impact-surgical-patient-care-part-2/.

[90] "What the radiologist should know about artificial intelligence – an ESR white paper", Insights into Imaging, European Society of Radiology 2019, vol. 10, No. 44; McKinney, S.M., Sieniek, M., Godbole, V. et al. "International evaluation of an AI system for breast cancer screening". *Nature*, 2020, 577, 89–94; Hosny, A. et al., "Artificial intelligence in radiology", *Nature*, May 17, 2018, vol. 18, p. 500-510. https://www.nature.com/articles/s41568-018-0016-5.

[91] Remedios, D., et al., “Collaboration, campaigns and champions for appropriate imaging: feedback from the Zagreb workshop”. *Insights Imaging 2018*, vol. 9, No. 2, p. 211–214; Choy, G. et al., “Current applications and future impact of machine learning in radiology”. *Radiology 2018*, vol. 288, No. 2, p. 318–328; Hosny, A. et al., “Artificial intelligence in radiology”, Nature, May 17, 2018, vol. 18, p. 500-510. https://www.nature.com/articles/s41568-018-0016-5.

[92] *The Topol Review: Preparing the healthcare workforce to deliver the digital future*, NHS, February 2019.

[93] Rubin, D.L. and Kahn, C.E. Jr “Common Data Elements in Radiology”. *Radiology 2017*, vol. 283, No. 3, p. 837–844; Hong, Y., and Kahn C.E. Jr “Content analysis of reporting templates and freetext radiology reports”. *J Digit Imaging*, 2013, vol. 26, No. 5, p. 843–849.

[94] McKinney, S.M., Sieniek, M., Godbole, V. et al. “International evaluation of an AI system for breast cancer screening”. *Nature*, 2020, 577, 89–9.

[95] Codari, M., et al., “Artificial intelligence for breast MRI in 2008-2018: A systematic mapping review”. *AJR Am J Roentgenol*, 2019, vol. 212, p. 280–292 https://doi.org/10.2214/AJR.18.20389; Wang, J., et al., “Machine learning-based analysis of MR radiomics can help to improve the diagnostic performance of PI-RADS v2 in clinically relevant prostate cancer”. *Eur Radiol*, 2017, vol. 27, No. 10, p.4082–4090; Rajpurkar, P., et al., “Deep learning for chest radiograph diagnosis: A retrospective comparison of CheXNeXt to practicing radiologists”. *PLoS Med*, 2018, vol. 15, No. 11; Yasaka, K., et al., “Deep learning with convolutional neural network for differentiation of liver masses at dynamic contrastenhanced CT: A preliminary study”, Radiology, 2018, vol. 286, No. 3, p. 887–896.

[96] Alaa, A M, et al., “Personalized risk scoring for critical care prognosis using mixtures of Gaussian processes”, *IEEE Transactions on Biomedical Engineering*, 2018, vol. 65, No. 1.

[97] *When data meets disease head-on: new trends in treating and managing epilepsy*, IBM Research, October 2018, https://researcher.watson.ibm.com/researcher/files/au1-sharrer/EpilepsyWP_Nov2018.pdf.

[98] “AI that detects cardiac arrest during emergency calls will be tested across Europe this summer”, *The Verge*, April 25, 2018, https://www.theverge.com/2018/4/25/17278994/ai-cardiac-arrest-corti-emergency-call-response.

[99] “Germany introduces Digital Supply Act to digitalise health”, *Healthcare IT News*, November 13, 2019, https://www.healthcareitnews.com/news/europe/germany-introduces-digital-supply-act-digitalise-healthcare. Providers will have to prove to the federal Institute for Drugs and Medical Devices (BfArM) that their apps can improve patient care.

[100] *Muro*, Mark et al., *Digitization and the American workforce*, Brookings Institute, November 2017.

[101] France, Germany, Hungary, Italy, Portugal, Sweden and the UK.

[102] *The Topol Review: Preparing the healthcare workforce to deliver the digital future*, NHS, February 2019.

[103] *AI and the Health Care Workforce*, American Hospital Association, 2019, https://www.aha.org/system/files/media/file/2019/09/Market_Insights_AI_Workforce_2.pdf.

[104] *Artificial Intelligence* https://ec.europa.eu/digital-single-market/en/artificial-intelligence, European Commission (accessed on 15/01/2020).

[105] Liz Szabo, “Artificial intelligence has come to medicine. Are patients being put at risk?”, *Los Angeles Times*, January 3, 2020, https://www.latimes.com/business/story/2020-01-03/artificial-intelligence-healthcare.

[106] Vidal-Garcia, C., et al., “Artificial intelligence to support clinical decision-making processes”, *EBioMedicine*, 2019.

[107] See also “Healthcare, Artificial Intelligence, Data and Ethics – A 2030 Vision”, *Microsoft*, December 2018, https://www.digitaleurope.org/wp/wp-content/uploads/2019/02/Healthcare-AI-Data-Ethics-2030-vision.pdf.

[108] Challen et al. “Artificial intelligence, bias and clinical safety”, *BMJ Quality and Safety*, 2019, Vol. 28, Issue 3 (https://qualitysafety.bmj.com/content/28/3/231.

[109] *ibid*.

[110] *2014 eHealth Stakeholder Group Report: eSkills and Health Workforce*, European Federation of Nurses Associations, 2014.

[111] “Biomedical Computation Major Program”, Stanford University, https://ughb.stanford.edu/majors-minors/major-programs/biomedical-computation-major-program (accessed January 9, 2020); “Medicine and Computer Science (Double degree)”, Technion – Israel Institute of Technology, https://admissions.technion.ac.il/en/medicine-and-computer-science/ (accessed January 9, 2020).

[112] “MIT delta v”, Martin Trust Center for MIT Entrepreneurship, https://entrepreneurship.mit.edu/accelerator/ (accessed January 9, 2020); “Biodesign Innovation Fellowship”, Stanford Byers Center for Biodesign, http://biodesign.stanford.edu/programs/fellowships/innovation-fellowships.html (accessed January 9, 2020).

[113] Shvartzman, P., et al., “Continuing medical education for primary care physicians in Israel: A cross-sectional study”, *Journal of Biomedical Education*, 2013.

[114] “Digital Europe: Pushing the frontier, capturing the benefits”, McKinsey Global Institute, June 2016.

[115] “Royal Free breached UK data law in 1.6m patient deal with Google’s DeepMind”, *The Guardian*, July 3, 2017, https://www.theguardian.com/technology/2017/jul/03/google-deepmind-16m-patient-royal-free-deal-data-protection-act.

[116] Brunak, S., et al., “Nucleotide Sequence Database Policies”, *Science*, 2002, vol. 298, No. 5597, pp. 1333.

[117] “Data and data access”, Genomics England, https://www.genomicsengland.co.uk/about-gecip/for-gecip-members/data-and-data-access/ (accessed January 10, 2020).

[118] “Israel Prepares to Unleash AI on Health Care”, *Wall Street Journal*, September 15, 2019.

[119] Lehne, M., et al., “Why digital medicine depends on interoperability”, *npj Digital Medicine*, 2019, vol. 2, No. 79.

[120] *Report of the International Committee on genetic symbol and nomenclature*, Hugo Gene Nomenclature Committee (HGNC). Union internationale des sciences biologiques, international committee on genetic symbol and nomenclature, Paris: Secrétariat de l’U.I.S.B., Laboratoire de physiologie végétale, Pan Pacific Press, Tokyo, 1957; “European Nucleotide Archive – Genome Standards Consortium”, EMBL-EBI, https://www.ebi.ac.uk/ena/about/gsc-collaboration (accessed January 10, 2020); WHO, “History of the development of the ICD”, https://www.ebi.ac.uk/ena/about/gsc-collaboration, (accessed 10th January 2020).

[121] “Digital Single Market: Communication from the Commission to the European Parliament, the European Council, the Council, The European Economic and Social Committee and the Committee of the Regions on Artificial Intelligence for Europe”, European Commission, April 2018.

[122] *Proposed regulatory framework for modifications to AI/ML based software as a medical device (SaMD)* – US Food & Drug Administration, discussion paper, May 2019, https://www.fda.gov/medical-devices/software-medical-device-samd/artificial-intelligence-and-machine-learning-software-medical-device.

[123] *Digital Health Innovation Action Plan*, US Food & Drug Administration, 2017, https://www.fda.gov/media/106331/download.

[124] *EMA Regulatory Science to 2025*, European Medicines Agency, 2018 https://www.ema.europa.eu/en/documents/regulatory-procedural-guideline/ema-regulatory-science-2025-strategic-reflection_en.pdf.

[125] *Role of big data for evaluation and supervision of medicines in the EU”*, European Medicines Agency, February, 2019, https://www.ema.europa.eu/en/news/role-big-data-evaluation-supervision-medicines-eu.

[126] *Summary Report*, HMA-EMA Joint Big Data Taskforce, 13 February 2020, https://www.ema.europa.eu/documents/minutes/hma/ema-joint-task-force-big-data-summary-report_en.pdf.

[127] *European database on medical devices* (EUDAMED), European Commission, https://ec.europa.eu/growth/sectors/medical-devices/new-regulations/eudamed_en (accessed January 10, 2020).

[128] “Medical Devices”, European Medicines Agency, https://www.ema.europa.eu/en/human-regulatory/overview/medical-devices (accessed January 10, 2020).

[129] “The assessment of Natural Cycles is completed”, Läkemedelsverket, September 2018, https://lakemedelsverket.se/english/All-news/NYHETER-2018/The-assessment-of-Natural-Cycles-is-completed/; Sudjic, Olivia, “’I felt colossally naïve’: The backlash against the birth control app”, *The Guardian*, July 21, 2018 – The app which markets itself as the ‘first digital birth control’ was investigated in 2018, after a number of unintended pregnancies from users of its solution. Although the app performed within its stated effectiveness, the episode highlighted issues around AI and patient empowerment, especially the extent to which users can use AI tools without guidance from a licensed physician and the extent of the responsibility of technology companies for results from such use.

[130] *Augmented intelligence in health care*, American Medical Association, 2018. https://www.ama-assn.org/system/files/2019-08/ai-2018-board-policy-summary.pdf.

[131] *Medicines Reimbursement Policies in Europe*, WHO Regional Office for Europe, http://www.euro.who.int/__data/assets/pdf_file/0011/376625/pharmaceutical-reimbursement-eng.pdf.

[132] "Germany introduces Digital Supply Act to digitalise healthcare", *Healthcare IT News*, November 13, 2019, https://www.healthcareitnews.com/news/europe/germany-introduces-digital-supply-act-digitalise-healthcare.

[133] *Communication on enabling the digital transformation of health and care in the Digital Single Market*, European Commission, April 25, 2018, https://ec.europa.eu/digital-single-market/en/news/communication-enabling-digital-transformation-health-and-care-digital-single-market-empowering.

[134] 14 tech trends to watch closely in 2020, *CBInsights*, January 16, 2020, https://www.cbinsights.com/research/report/top-tech-trends-2020/.

[135] As this analysis forms part of a global comparison across geographies, using the Standard Occupational Classifications (SOC) terms used for occupations it makes use of the US Bureau of Labor Statistics (https://www.bls.gov/soc/). This may present differences in nomenclature used understood across international systems, which may differ slightly by country. While terminology may affect classification across specific health systems (e.g., for different types of nursing professionals), it does not affect the analysis in terms of defining the adoption potential for automation, but may in practice mean that specific professionals are classified differently to what may be prevalent within an individual country.

[136] Where an activity may use more than one skill, the analysis relied on the predominant skill used.