FUTURE OF SURGERY

Royal College of Surgeons
ADVANCING SURGICAL CARE

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FOREWORD

Mr Richard Kerr, Chair

This year we celebrate the 70th anniversary of the inauguration of the National Health Service, enabling patients from all over the UK to access treatment free at the point of delivery. During those 70 years, the NHS has seen enormous changes in health diagnosis and care for the benefit of all patients, the result of world leading innovation and research.

We are now entering the next and perhaps most exciting phase in the evolution of healthcare, driven by rapid advances in digital technology and molecular biology. At a time when the pressures experienced by both those in need of help and those providing care are higher than ever before, we must embrace the potential of the vast range of life changing advances under development.

This report, presented by the independent Commission on the Future of Surgery, sets out a compelling and achievable vision of the future of surgery in the UK. Sponsored by the Royal College of Surgeons, the Commission has considered the changes that are likely to occur over the next 20 years, in the delivery of surgical care.

With the patient at the heart of our work, the Commission has reviewed some of the most revolutionary future advances. As we move further towards minimally invasive surgery, robot-assisted procedures, nano-technology, genomic medicine, advanced data analytics, artificial intelligence, and augmented and virtual reality, this report considers the potential impact these and other changes will have on patients and their families. It then outlines the developments required in teaching and training the workforce to deliver these advances in surgical care.

The world of surgery is embarking on a time of innovation and change that promises to bring huge benefits to patients. The future careers of surgeons and the surgical team will change and become more flexible and diverse to facilitate these developments. However, the continuing crucial role of the surgeon and the surgical team will be to support, with empathy and compassion, all individuals and patients to become active managers of their own health and care, to review and assess the vast amount of information and knowledge available, and to assist them in making personalised choices about their plan of treatment.

The future of surgery is very exciting, ever evolving and full of innovation, yet also demanding of the core values of compassionate medical care to maintain and enhance the humanity behind the delivery of surgery.

I would like to thank all those who have contributed their time, knowledge and experience, and I would especially thank the Commissioners for their hard work and support. It is a great honour for me to present this report on 'The Future of Surgery'.

FOREWORD

Professor Stephen Powis, NHS England Medical Director

Technological and medical developments have had a profound effect on surgery over the last few decades. Patients now enjoy less invasive surgical techniques accompanied by even better outcomes and much shorter hospital stays. Procedures which might have taken a day and meant weeks in hospital recovering when the NHS was formed in 1948, can now be done in less than an hour, with the patient able to go home the same day.

The next couple of decades will see even more radical change. Developments in robotics, artificial intelligence, genomics, and digital technologies promise a future where healthcare is even less invasive and much more personalised.

And so the role of the surgeon will undergo no less a revolution. Increasingly, the boundaries that separate the current roles of different health professionals will be blurred, and other professionals, such as data analysts and bioengineers, will become part of teams as technology becomes even more sophisticated. In this future preconceptions must be left outside the operating theatre; what matters is who has the right skills to treat a patient, not whose 'right' it is to provide that treatment.

None of this should be seen as a threat to the role of the surgeon, or any other medical professional. No artificial intelligence or robot will ever replace the need for the human touch. Rather, future technologies underline the role of the surgeon as leader; spearheading the introduction of new techniques and helping patients to navigate a new range of treatments.

The NHS in England is well placed to incubate and exploit the full benefits of this future. We are already a world-leader in data collection and analysis, and the 100,000 genomes project has put the NHS at the cutting edge of genomic medicine. The centralisation of complex surgery continues to improve standards, and current IT systems will be overhauled to enable a world-class digital health service.

But innovation and technological advancement is not, and should never be seen as, an end in itself. While in the operating theatres of the future we might be reaching for the lasers instead of the scalpel, or welcoming artificially-intelligent robots as members of our teams, the recipient of these new types of care and treatment – the patient – will remain very much human.

As exciting as it is to look to what may be possible in the future, we must never lose sight of the goals of improving quality, safety and outcomes, and the wishes and best interests of each individual patient must remain central to everything that we do, whether as surgeons, leaders or any other member of staff.

If we stay true to those principles, the future of surgery, just like the history of surgery, will mean ever more people will be able to enjoy a greater quality of life, for longer.

THE COMMISSION

Mr Richard Kerr, Chair

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Professor Tony Young
National Clinical Lead for Innovation NHS England

The Commission on the Future of Surgery was set up in October 2017 by the Royal College of Surgeons to look at the future of surgical care and advise on how best to prepare for its opportunities and challenges.

It is an independent group of 14 experts who were tasked with identifying likely advances in medicine and technology in the next twenty years, and their implications for patients, the surgical workforce and the healthcare system.

The Commission received over 70 written contributions, held four days of oral evidence sessions and conducted several meetings with experts from numerous areas of medicine and technology.

EXECUTIVE SUMMARIES

Which technologies will deliver the greatest impact?

Surgery will be transformed over the next two decades. The Commission believes there are four areas of technological development that will make the greatest impact.

Minimally-invasive surgery

- In the short-term, alongside major developments in laparoscopic and endoscopic surgery, surgical robots will be more versatile, lighter and probably cheaper. The next generation of surgical robots – due in early 2019 – could be moved between hospitals and theatres, helping to make robot-assisted surgery more widely available.
- In the longer-term, there will be greater robotic autonomy and machine learning, although it seems unlikely that there will be fully autonomous robots in the next two decades. Nano-robotics for diagnosis and drug delivery may become a reality.
- The wider use of robotics is likely to reduce variation in surgical performance and the invasiveness of interventions. This may raise the possibility that skilled surgical technicians could undertake some procedures under the supervision of a surgeon.

Imaging, virtual reality, and augmented reality

- Advances in imaging and simulation, including virtual reality (VR) and augmented reality (AR), are already being used to complement surgical training and planning.
- The shift in imaging from static anatomical displays to showing dynamic organ function is likely to be extended across many areas of surgery.
- AR and VR technology platforms will enable multidisciplinary teams to connect and specialist surgeons to support complex procedures remotely.
- 3D planning and printing will advance and be used more frequently for teaching, training and surgical preparation for complex surgical interventions.

Big data, genomics and artificial intelligence

- Developments in big data analytics and genomics will improve understanding of disease profiles at patient-specific and population-based levels.
- Genomics – and potentially other ‘omic’ technologies – will help to predict the likelihood of disease, thereby influencing strategies for screening and surveillance, and early treatment. It will also continue to improve the understanding of the biology of cancers, enabling targeted treatment.
- Precision medicine will become more widespread, allowing patients and clinical teams to choose the most effective treatment based on the genomic data.
- Artificial intelligence (AI) mechanisms are likely to improve diagnosis and population-based risk assessment. Machine learning could prevent surgical errors by supporting surgical teams inside the operating theatre.
- Liquid biopsies from a variety of bodily fluids may make it easier for the population to be diagnosed earlier – eg for the presence or recurrence of cancerous tissue.

Specialised interventions

- A number of novel interventions may reach clinical application: some stem-cell therapies, 3D bioprinting of tissues and organs, artificial organs, animal-human transplants and neural prosthetics with adaptive control mechanisms.
- More advanced imaging could enable ‘nano-surgery’, where surgeons could use miniaturised devices to operate on individual cell clusters, potentially with revolutionary effects for cancer patients.
- Novel treatments are likely to become increasingly dependent on collaborative, highly specialised interdisciplinary teams.

What does the future mean for patients?

How surgery and healthcare will change

- Surgery is currently used to treat advanced disease and takes place after the display of symptoms. In the future, surgery will potentially prevent – and not just treat – illness.
- Healthcare will continue to shift towards establishing and maintaining good health, prevention and prediction of disease, early intervention and co-ordinated management of chronic conditions.
- Patients can confidently expect surgery to become gradually less invasive, more accurate, have more predictable outcomes, faster recovery times and lower risk of harm.
- The current unique relationship between the patient and the surgical team will become even more important, as technology allows greater access to information.
- Surgery is likely to increasingly focus on improving quality of life and operating on well people and older patients with the aim of prevention.

Who will undergo surgery?

- New drugs and the development of other non-invasive treatments may make surgery obsolete for some conditions. Advances in radiotherapy and immunotherapy may drastically reduce the need for cancer surgery. Vaccination programmes are likely to affect the incidence of virally-driven diseases, such as the vaccination against human papillomavirus to prevent cervical, anal and oral cancer.
- Less invasive technologies and advances in imaging will enable more patients, particularly frail and older people, and more diseases to be treated with surgery. For example, functional imaging of the brain is already enabling more radical but safer micro-surgery for some cerebral tumours.

How health will change

- The Commission does not anticipate any radical increases to life expectancy unless a significant breakthrough revolutionises prevention of the main causes of mortality. Societal attitudes to conditions like obesity might influence future longevity.
- Patients will continue to experience an increasing burden of non-communicable chronic diseases and multiple morbidities, such as diabetes or dementia.

Possible risks

- The ubiquity of healthcare information and personal data may help patients to become more informed about their own health, but may also lead to greater anxiety. For example, genomic information may inflate demand for risk-reducing surgery.
- The speed and variety of innovations and information available will be such that patients may need specialist advice and support to make decisions about their care. For example, greater access to data and medical knowledge may generate inequalities due to different levels of health literacy.
- New inequalities may be driven by the potential cost and availability of specialised treatments. Patients may turn to the independent sector if there is slow adoption or limited availability due to financial constraints within the NHS.
- Changes may have a different impact on individuals and groups within the population, and it will be important to promote access to worthwhile innovations equitably on the basis of need.
- On the other hand, greater access to and sharing of data, widespread availability of new technologies and remote support of experts may reduce inequalities and variation in treatment outcomes between different hospitals.

How will the delivery of surgery change?

Will surgery become more locally or centrally delivered?

- The recent history of complex surgery has been one of increasing centralisation to improve treatment results for patients by concentrating expertise and resources to make services more sustainable.
- Specialised treatments – such as stem cell therapies or tissue engineering – will continue to be delivered by multidisciplinary teams with specialist expertise. Such care will only be available in a small number of locations, which need to be carefully planned. Other digital technologies, such as 3D printing and planning, will also benefit from multidisciplinary hubs.
- Digital technologies and robotics could enable more types of routine surgery to be delivered locally if resources are available, thanks to platforms allowing for remote support and proctoring, and robotic platforms of smaller size and greater versatility.
- As the ageing population is expected to live increasingly outside of metropolitan areas, demand for care in those areas will also grow.

Inpatients and outpatients

- The current trend of an increasing amount of day-case and overnight stay surgery will continue. Preoperative and follow-up assessment will therefore acquire even greater importance, but they are likely to be undertaken in local settings through the use of telemedicine and digital platforms.

The future operating theatre

- Operating theatres are likely to look different with greater integration of digital technologies. In the long-term, AI could be used to schedule procedures, request instruments and monitor the environment. Digital systems will also provide guidance to the operating team and show enhanced anatomical imaging.
- Theatre space will become more flexible and dynamic, as equipment will be smaller and lighter.

Enabling and reviewing innovations

- In contrast to drugs, many surgical innovations are introduced without clinical trial data or centrally held evidence. This is a risk to patient safety and public confidence.
- Pathways need to be developed to assess digital devices, diagnostics and drugs, with compulsory registration of novel technologies and devices, utilising real time data. A 'one size fits all' approach for randomised control trials or a national registry will not work for all innovations.
- The surgical royal colleges could have a role in working with national regulators to support or oversee registries of innovations, and support the uptake of innovations that improve quality of life and patient safety.
- Submission of follow-up information to central databases is crucial to ensure patient safety.
- A framework should be in place to oversee this, comprised of appropriate regulators who have access to databases.

The future surgical team

The role of the surgical professional

- The evolution of the role of the surgeon is likely to depend on the best treatment option for the patient:
  - The current role is likely to remain unchanged for areas of surgery little affected by developments in alternative treatment options, such as joint replacement surgery;
  - However, the role of the surgeon is likely to become increasingly blurred with that of other clinicians in other areas of medical intervention where a vast array of other treatments may become preferable, such as in cancer surgery.
- The surgeon's role will become increasingly multifaceted and surgeons will need to become 'multi-linguists', understanding the language of medicine, genetics, surgery, radiotherapy and bioengineering. Leadership, managerial and entrepreneurial skills will become increasingly important attributes of the surgical professional.
- The surgeon will play a key role in genomics, acquiring and handling tissue samples and being the first healthcare professional to discuss genetic analysis with a patient.

The multi-disciplinary and multi-professional surgical care team

- The multi-disciplinary and multi-professional surgical care team will become increasingly important in developing and delivering care of the highest quality. They will be able to provide more aspects of care and may take over some areas of surgical care currently delivered by surgeons.
- The delivery of complex specialised interventions (eg stem cell therapies or regenerative medicine) will require a team with specialist training, including bioengineers, molecular biologists, data analysts and robotic engineers.
- There will be a continuing need for a large surgical workforce, given the rising demand for treatment. Patients will depend on them for the thousands of routine elective and emergency procedures. The surgical team will increasingly use digital technologies inside and outside the operating room, including simulation training, AI and 3D planning.
- Advanced robotics may allow other team members, with expertise in handling robots, to conduct some operations in the future under the supervision of a surgeon. Remote surgical assistance and training will also be possible.

Changes to training

- The content of the surgical training curriculum will need to change and be flexible to reflect the likely future career of a surgeon and innovations as they evolve. With flexibility will come options to be a clinical surgeon, scientist, entrepreneur, educator, innovator or manager, with the ability to move across different roles throughout a career.
- Training must incorporate knowledge of computing, engineering, molecular biology, data literacy, leadership, team building and communication. In an increasingly digitised health service, we must strive to ensure and enhance the humanity in surgery.
- New technologies such as data analytics, AR and VR will enhance training, with high-fidelity patient-specific simulation, and remote mentoring and proctoring.
- Entry requirements for medical school will need to reflect the diverse range of skills required and encourage students from other backgrounds, such as engineering or computing, to enter medicine.

SETTING THE SCENE

The future burden of disease

The health needs of future patients will be increasingly complex. Older and more numerous, the population will often live with multiple chronic conditions, such as diabetes or dementia. Health and social care systems will need to facilitate the management of long-term conditions, support the personal care needs of older people, and aim to extend mobility, cognitive capabilities and independence later in life.[1] Earlier intervention will become possible thanks to advances in disease prediction, data analysis, risk stratification and earlier diagnosis. The greater availability of vast and complex information about our health and of interventions that target previously unmet clinical needs will increase demand for healthcare services. The Commission expects demand for surgical care to continue to grow.

In high-income countries, the burden of disease will continue to be primarily the result of non-communicable diseases, provided threats such as new infectious epidemics or antimicrobial resistance (AMR) are adequately addressed. Key risk factors for chronic conditions, particularly obesity, are rising.[2] Public health policies may help to slow down the obesity epidemic, but its prevalence is projected to increase in the short to medium-term.[3,4] This will have an impact on surgical demand, as excess weight increases the risk for many cancers, contributes to the development of diabetes and heart disease, and potentially increases the complexity of surgical interventions and patient recovery. This may drive up the need for bariatric or metabolic surgery[I] as treatment options, despite the development of pharmacological alternatives. The prevalence of non-communicable chronic conditions will affect the demand for surgical care.

- **Cancer:** In 2016 one in four of all deaths in the UK were caused by cancer. Although the incidence of cancer is expected to increase by 2% between 2014 and 2035, mortality rates are projected to decline by 15% during the same period due to improvements in early diagnosis and personalised treatments.[5] However, UK cancer survival rates currently lag behind the European average.[6] For the UK to improve these rates, it will be necessary to ensure wide access to such improvements and their uniform implementation. The potential implications for surgical treatment are multifaceted, especially in the context of an ageing population with complex multiple morbidities. On the one hand, the rise in cancer incidence may result in higher demand for surgery. On the other hand, advances in science and medicine, and improvements in prevention, prediction of disease and early diagnosis may allow therapies other than surgery to become the preferred choice of treatment. What is clear, however, is that care pathways will be more complex and likely to integrate medical and surgical treatments, increasing the importance of a multidisciplinary team approach to cancer care.

> "Mortality rates are projected to decline by 15% due to improvements in early diagnosis and personalised treatments."

I For bariatric surgery, the report refers to a group of weight loss surgical procedures including stomach stapling, gastric bypasses, sleeve gastrectomy and gastric band maintenance.

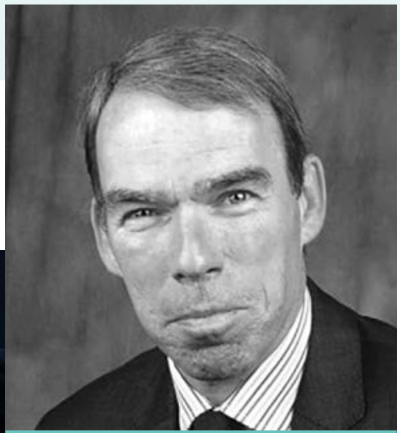
The paradigm of cancer surgery: an opinion

Cancer care has already undergone a revolution over the last 80 years. With limited treatment choices and delayed presentation, radical surgery was initially the only available option and surgeons developed increasingly extensive operations to try to control it. The emergence of chemotherapy and radiotherapy provided additional tools for its control. As these (initially) second line therapies have evolved, so combined treatments for advanced cancer have developed and required the emergence of multidisciplinary teams (MDTs) to decide on the best care.

What of the future? Early and even pre-cancer diagnoses are already changing the disease landscape. For many conditions - such as breast cancer, cervical cancer and more recently rectal cancer - organ preserving and minimal access surgery are becoming the norm.

Stratified cancer care employing genomics and gene-targeted therapy are set to change the landscape again. Complex pathways of targeted therapy, complimented by safer, more limited surgery are already emerging. New non-invasive monitoring such as circulating (tumour derived) DNA will improve monitoring of treatment and may even provide earlier diagnosis. It is clear that radical surgery will become a less frequent option in cancer care. However, treatment will involve more complex and prolonged pathways as new modalities are added to the armamentarium of therapy. History has also shown that screening and early diagnosis will increase the disease prevalence, as more cases are accounted for, and so increase the need for specialist care teams. Although the precise role of surgery in each cancer type cannot be predicted, we can be confident that the role will change away from radical resection and will increasingly focus on safer, organ preserving options.

Written by Commissioner Professor Dion Morton



Professor
Dion Morton

- **Neurodegenerative diseases**: The prevalence of neurodegenerative diseases such as Alzheimer's and Parkinson's disease increases with age. Dementia – a term used to describe symptoms such as memory loss, confusion and personality change caused by neurodegenerative diseases[7] – will become a bigger challenge in the future. This is due to the population growing older and the current lack of preventive or curative treatments. In 2015, dementia overtook heart disease as the leading cause of death in England and Wales.[8] More than two million people are projected to suffer from dementia by 2050.[9] Poor cognitive health has implications for informed consent, supported decision-making and risk assessment for surgery. Demand for current surgical treatments to alleviate symptoms – such as deep brain stimulation for Parkinson's disease – may increase, and advances in stem cell treatment for neurodegenerative diseases may in the future open new surgical avenues for treatment.

- **Musculoskeletal disease:** An estimated 28.9% (17.8 million) of the total UK population live with a musculoskeletal condition.[10] Chronic pain resulting from these conditions has a debilitating impact on every aspect of a patient's life. Painful musculoskeletal conditions are the largest single cause of years lived with disability (YLDs), and the third largest cause of disability adjusted life years (DALYs).[11] This figure is expected to grow, fuelled by physical inactivity and obesity. Immobility, pain and the need for strong analgesics make it difficult to address such risk factors, creating a vicious circle of multimorbidity. The number of people living with knee osteoarthritis – the most common site for the disease – is expected to almost double between 2010 (4.7 million) and 2035 (8.3 million).[12] This will drive up demand for joint replacement surgery.[13] While longevity of implants has improved in recent years, revision arthroplasty remains necessary, leading to the need for longer lasting implants.[14] Prevention of presumed 'degenerative' conditions such as osteoarthritis will become increasingly possible as the disease process is better understood.

- **Cardiovascular disease:** Recent improvements in smoking cessation rates and further advances in medical care have led to a meaningful decline[II] in deaths from cardiovascular disease (CVD).[11] However, there is little change in the prevalence of the disease, likely due to rising risk factors such as obesity, diabetes and air pollution.[15] Treatment for these conditions will remain necessary in future years. The scope of medical therapy and endovascular interventions for coronary artery disease will expand. In the long-term, drug therapy, life style changes or even stem cell therapies will reduce the need for interventional treatments. In the short and medium-term, less invasive cardiovascular procedures will increasingly be carried out as minimally invasive endovascular interventions. The same may be true of interventions for valvular heart disease. Surgical interventions, such as coronary artery bypass and valve replacement, will continue to be necessary. Cooperation between cardiologists, interventional radiologists and cardiovascular surgeons will remain key to managing the treatment of cardiovascular disease.

- **Diabetes:** Diabetes mellitus affects about 6%[III] of the population across all UK nations and its incidence is expected to rise.[16-17] Although mostly preventable, type 2 (adult-onset) diabetes accounts for approximately 90% of patients. Diabetes greatly increases the risk of cardiovascular disease, stroke, peripheral vascular disease, adult blindness and renal disease.[18,19] The risk of complications after surgery for patients with diabetes is also higher as they are more likely to suffer complications from surgical site infection and poor wound healing.[20]

II Between 2005 and 2016 in the UK there was an 18.9% reduction in ischaemic heart disease mortality and a 6.3% reduction in cerebrovascular disease mortality.

III This does not consider undiagnosed cases of Type 2 diabetes, currently expected to amount to 2 million people in the UK according to Diabetes UK.

Figure 1

New technological solutions, such as better cardiac monitors or digital platforms improving the emergency response, may help reduce the impact of CVD.

GoodSAM© is an app alerting a community of over 40,000 trained first-aiders to cardiac arrests near them, and mapping nearly 50,000 defibrillators in the area. Through the app, the public, even in remote areas, are more likely to get early CPR and survive cardiac arrest.

GoodSAM© also allows the use of mobile phone cameras remotely, allowing emergency services to be "instantly on scene". They can see the patient and dispatch the appropriate resources – from an ambulance to a helicopter, or simply give advice to the patient or caller.

Figure 1: GoodSAM© app (Image credit GoodSAM©)

GoodSAM

> "GoodSAM© also allows the use of mobile phone cameras remotely, allowing emergency services to be *instantly on scene*."

The growth of these areas of disease will mean surgical decision-making will require understanding and management of multiple conditions. Their possible interaction in the evaluation of risks and benefits of surgical procedures, and clinical outcomes will also need consideration, with consequences for informed consent and supported decision-making.

A larger population living longer with higher expectations

The UK population is predicted to increase in size, from 65.6 million in 2016 to over 74 million by 2039.[IV] Without a significant change to existing fertility rates and migration patterns, older people will increasingly outnumber people of working age. Projections by the Office for National Statistics (ONS) estimate that around a quarter of the population will be aged 65 and over in 2046.[21] Some of the changes outlined in this report may continue to drive average life expectancy upwards, but the Commission does not expect radical increases.[V]

While life expectancy increases modestly,[VI] the proportion of life spent in ill health or disability is projected to increase. A 2017 study into forecasted trends in disability and life expectancy in England and Wales found that the number of people living with disability will increase by 25% between 2015 and 2025, reaching 2.8 million, reflecting an ageing population.[22] There is great variation in healthy life expectancy in the UK across geographical areas and population groups, with healthy life expectancy at birth varying across local areas by 18 years and disability-free life expectancy by 20 years.[23]

Social changes and technology developments have led to the creation of digital platforms in sectors other than healthcare that cater with impressive speed for the needs of people. The public will expect the same access, openness and efficiency when it comes to their health and care. The launch of the NHS app – planned in England for 2019 – through which patients will be able to access their GP records, book appointments, order prescriptions and state their preferences, should improve the way patients access care. The increasing use of digital consultations will improve access to medical support.[24] Heightened patient expectations will not extend exclusively to systems and ease of access, but also to clinical outcomes. As more people will live into older age, with retention of good health-related quality of life, the demand to retain independence and physical and cognitive capabilities will grow.

IV These projections do not account for the possible effects of migration trends following the UK's exit from the European Union.
V Unless breakthroughs in stem cell technologies, genomics, regenerative medicine and other innovations or significant public health interventions reduce the prevalence and effects of chronic illness.
VI Despite the recently observed stalling of the rate of increase.

THE PATIENT JOURNEY

At present, surgery and most types of medical intervention take place after a patient becomes unwell and the presence of symptoms prompts medical investigation. Often medicine and surgery play 'catch-up' with disease, and surgeons currently play the role of firefighters. This section of the report follows the likely changes in the journey of a future patient with emphasis on prevention, prediction and early intervention to reverse this pattern.

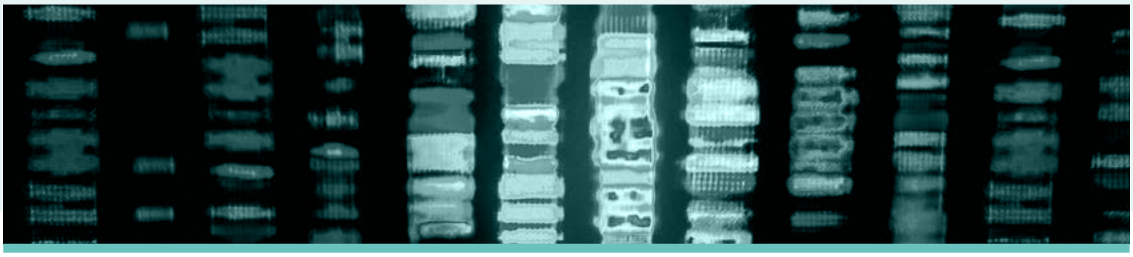
Prevention and prediction of disease

FICTIONAL FUTURE

It's 2035, *Lucas* is 40, he is a construction worker and a keen runner. As he moves and interacts in the world, his mobile devices collect data that contribute to an instantly updated digital picture of his health. When *Lucas* goes for a run, speaks with his doctor or collects his prescriptions, his 'digital twin'[25] learns a bit more about him. Once collected, the data are linked to other anonymised sources of medical knowledge and are analysed to predict *Lucas'* chances of developing disease and help him to prevent it or tackle it early.

Lucas has access to his data and can choose from a huge variety of digital services and platforms to manage his health. As anonymised data about *Lucas* are transferred and assembled in population-level databases, the chances of predicting and detecting disease early through artificial intelligence algorithms also improve for the population that shares with him similar characteristics. Information about *Lucas* also links with family data, helping to identify inherited diseases.

As part of regular checks, *Lucas'* genome is sequenced. He is found to have a defect in one of the DNA mismatch repair genes. This defect causes Lynch syndrome, leading to increased risk of colorectal and a number of other cancers. Alongside this key finding, genomic analysis identifies risk factors for increased blood pressure and osteoarthritis in later life.



Over the past few decades, healthcare policy and public health interventions have increasingly emphasised prevention and the promotion of wellbeing. Improving prevention and ensuring healthy lifestyles are likely to reduce the societal and economic burden of advanced disease.[VII] However, catering for previously unmet clinical needs and increased access to health data may further increase demand for care. The collection and analysis of data using new technologies will enhance prevention strategies by enabling more accurate prediction of disease, both at the patient and population level, and earlier preventive interventions tailored to the individual. For this to take place, however, prevention strategies and data analytics tools will need to be developed in partnership with the public, tailoring for the needs of the end-user.

Chronic diseases, and as a consequence a large proportion of surgical diseases, are often largely amenable to prevention. There is increasing awareness of the major role of risk factors such as smoking, nutrition, inactivity, pollution and abuse of alcohol and substances, through which social and environmental factors have an impact.[26-27] Surgeons can, therefore, help individuals, families, communities and organisations to be empowered to make better decisions.

VII We recognise that effective public health strategies and prevention of avoidable disease are enshrined in a whole government approach tackling the wider determinants of health and working with local communities. However, the analysis of such approaches and policies is beyond the scope of this report.

Data sharing and analysis

Unlocking the potential of data collection and analysis at an individual and population level will be of great importance to better prevent and predict disease. Various studies have already shown the potential of AI techniques to predict the probability of patients developing specific diseases, to discover effective cancer drugs or the rate of hospital readmission based on large electronic health records (EHR).[28,29]

These records, together with information from wearable, implantable or ambient sensors, imaging devices, digital platforms and social media outputs, all contribute to the collection of an ever increasing array of personal health data. Furthermore, from 2019 all seriously ill children, adults with certain rare diseases or hard-to-treat cancers will be offered whole genome sequencing in England. The NHS Genomic Medicine Service in England is planning to extend services included in the 100,000 Genomes project to one million whole genomes sequenced in five years.[30,31] As a result, genetic information will further contribute to patient datasets.

Several contributors suggested that the analysis of big data will bring some of the most innovative changes.[32,33] The term 'big data' refers to datasets with three defining characteristics, 'the three Vs': high volume, variety and velocity.[34] More recently, other attributes have also been considered, including variability (consistency of data over time), veracity (trustworthiness of the data obtained) and value.[40] Big data analytics tools will enable the development of effective prevention and prediction strategies that are patient-specific or differentiated across geographical areas.[35]

To reap benefits such as better prevention, patient empowerment, and world-leading research and innovation, the first key barrier to overcome is the ability to easily share data safely and securely across systems, and provide timely analyses that can improve the delivery of care. Although the UK is already a leader in public health data collection, numerous issues remain to be addressed, including the variable quality of the data collected, the coding of medical conditions and interventions, interoperability across healthcare organisations' systems, and ethical and data protection issues. While the market for digital healthcare is expanding, with digital giants and innovative start-ups developing new ideas every day, there remains a gap to be bridged between the safest and most effective innovations and their adoption in the system.

Against the backdrop of recent scandals over the misuse of data, attention must be paid to ensure that patient privacy, confidentiality and wishes over the use of their data are respected. As new European legislation, such as the General Data Protection Regulation (GDPR)[36] and the UK government's Code of Conduct for Data-driven Health and Care Technology,[37] are implemented and as awareness of data use increases, society is gradually adjusting to the necessary standards for the ethical use of this resource. To maintain the public's trust over the use of data in healthcare, patients must remain informed partners in the use of new technologies.

The Commission welcomes the guiding principles of user need, privacy and security, interoperability, and openness and inclusion, outlined in the Department of Health and Social Care's recent vision for digital, data and technology in health and care.[38] The Commission appreciates the complexities of achieving such aims, as demonstrated by the difficulties and pitfalls of previous national IT strategies. However, commissioners believe that achieving interoperability across NHS systems and providing standards to enable and encourage innovation from inside and outside the NHS are key priorities.

Definitions

Term	Definition
Artificial intelligence (AI)	A field of computer science studying mechanisms that allow machines to perform tasks that would normally require human intelligence, such as the recognition of patterns, problem solving, decision-making, translation between languages and visual perception.
Machine learning	A form of AI that enables machines to learn from data and patterns they analyse, rather than prior programming.
Deep learning	A type of machine learning inspired by the functioning of neural networks in the human brain. It uses algorithms to analyse different layers of data, establishing hierarchical relationships between the outputs of one layer and the analysis of the next. It thus enables learning through the recognition of patterns and the interpretation of data and images.

The Danish digital health strategy

Denmark is often considered a world leader when it comes to digital health. The digitisation of the Danish healthcare sector started 25 years ago and today delivers innovative IT systems in primary and secondary practice, and effective digital communication between healthcare sectors. This means for example that the Shared Medication Record gives professionals and citizens full access to their medication record, and eHealth solutions such as telemedicine are used in municipal, regional and national healthcare settings.[39,40]

At the beginning of 2018, the Danish government launched a new Strategy for Digital Health to further prepare the system to reap the benefits of future developments in digital health. The strategy, accompanied by a dedicated investment to fund its implementation, consists of 27 initiatives focused on areas such as: engaging citizens as active partners through the digitisation and the use of health data; ensuring timely knowledge exchange; enhancing population health and prevention; delivering high data security and trust; and implementing a flexible digital healthcare infrastructure.

The engagement of citizens as active partners to take a more proactive role in their health and care through digital health is particularly important. The implementation of this stream of work will see initiatives aiming to ensure that more care takes place in the patient's own home through self-service options, sensors, greater use of telemedicine, and incorporation of the patient's own knowledge. Other initiatives include the use of an algorithm applied to Patient Reported Outcome data to calculate whether a patient needs to go to the hospital; and access to a complete digital overview of personal health data generated across different systems and institutions for patients and their relatives. Digitally supported rehabilitation through the use of sensors will also be implemented.

The strategy also aims to deliver digital solutions to track the health status of older people in care homes – thus ensuring early detection of any signs of deteriorating health – and to monitor patients with long-term conditions or at heightened risk of developing complications.[41]

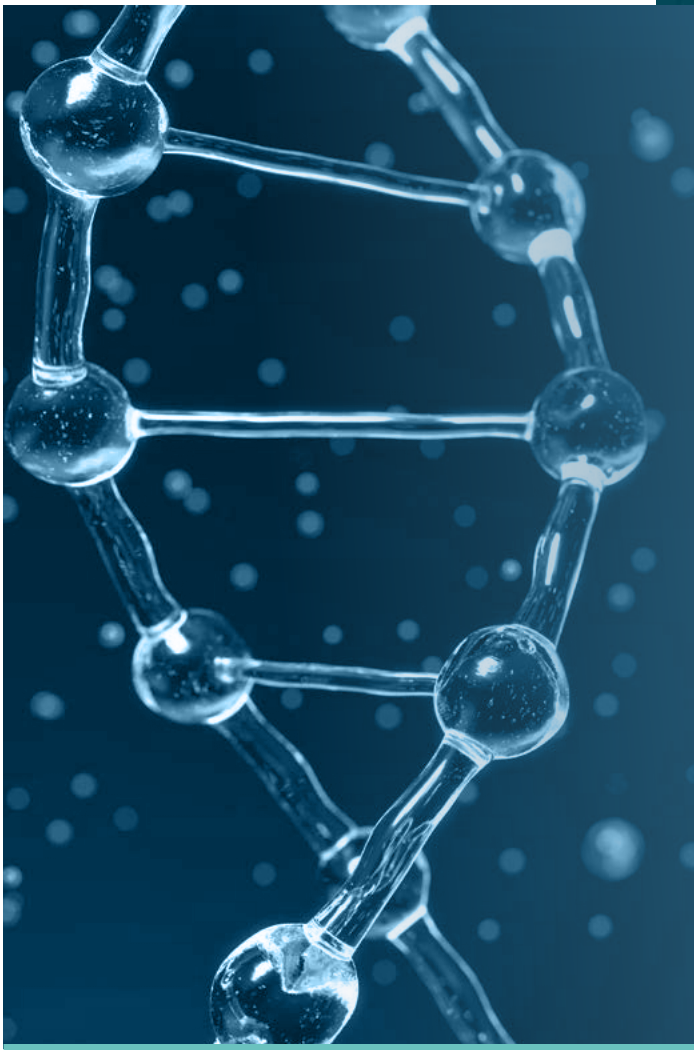
> "The engagement of citizens as active partners to take a more proactive role in their health and care through digital health is particularly important."

Genomics and risk-reduction surgery

Advances in the fields of genomics, pharmacogenomics and epigenetics will bring some of the most exciting changes to the understanding of disease pathways.

Many diseases have at least some inherited genetic predisposition, including cancer, arthritis, heart disease, diabetes and pancreatitis. Testing for these profiles will improve risk prediction and clinical decision-making.

With an extension of genetic and genomic testing to the wider population, preventive surgery will increase. There is a risk that genomic testing and the prediction or early diagnosis of conditions before symptoms appear may lead to overtreatment or overuse of risk-reduction surgery for patients who would not otherwise have needed any medical intervention. This could lead to an escalation of costs, without additional benefits. Estimating and contextualising risk accurately and communicating this information to patients, will assume even greater importance. Contributors to the Commission suggested that a multidisciplinary approach to risk estimation and decision-making should guard against such risks and aid effective supported decision-making.[35,42]



Genomics	Concerns the study of the genome, the entire sequence of DNA of an organism or tissue. Sequencing whole genomes improves understanding of disease processes, with benefits for disease prediction, early diagnosis and patient-tailored interventions.
Pharmacogenomics	Uses information from genomic sequencing to study the role of genomes in the individual response to drug treatments.
Epigenetics	Studies gene changes caused by mechanisms that do not alter the underlying DNA sequence – such as environmental or chemical factors – and are usually reversible over generations.

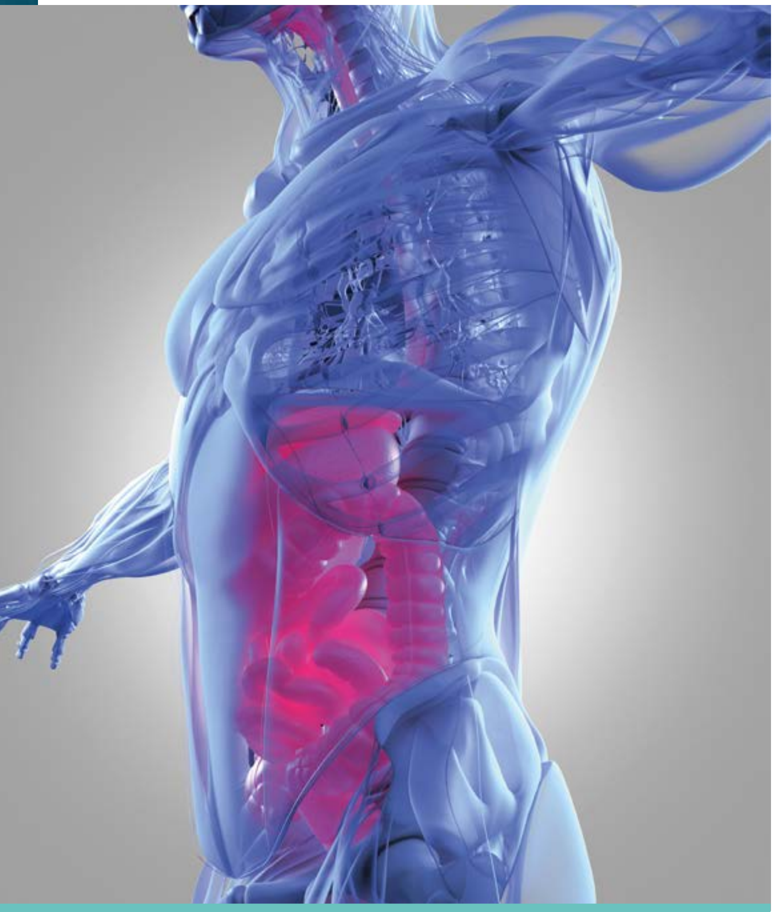
Definitions

Genetic testing and prophylactic surgery: some examples

Women carrying mutations in the *BRCA1* or *BRCA2* tumour suppressor genes have a high risk of developing breast and ovarian cancer and sometimes consider risk-reducing bilateral mastectomy and oophorectomy.

In individuals with familial adenomatous polyposis – a syndrome in which a defect in the tumour suppressor APC gene leads to developing premalignant polyps and colorectal cancer – colectomy is usually advised. Similarly, patients with multiple endocrine neoplasia – an inherited syndrome affecting endocrine glands – are, in some cases, advised preventive surgery, such as prophylactic thyroidectomy.[43]

For Lynch syndrome – a condition carrying a 20–60% lifetime risk of colorectal and a number of other cancers – surveillance with colonoscopy is usually employed, with chemoprevention being introduced.[44] However, if a patient develops cancer on a background of Lynch syndrome, the surgical approach may be modified, for example by performing an extended rather than segmental colectomy, and adding a prophylactic hysterectomy and oophorectomy for women.



> "If a patient develops cancer on a background of Lynch syndrome, the surgical approach may be modified, for example by performing an extended rather than segmental colectomy, and adding a prophylactic hysterectomy and oophorectomy for women."

Early detection and diagnosis

FICTIONAL FUTURE

Lucas is concerned about the results of his genome sequencing showing a DNA mismatch repair gene. Although regular colonoscopy can reduce the risk of colorectal cancer, surveillance does not protect against the other cancers he may develop, such as in the bladder, ureter, stomach or pancreas. He decides to have an implantable body sensor that can detect precancerous change in his body. In this way, a small and unobtrusive sensor will communicate information regularly to ensure its continued functioning, and will alert *Lucas'* doctor if cancerous cells are found well before the appearance of any symptoms.

The sensor aims to identify possible signs of diseases forming between his regular checks. As do the rest of the population, *Lucas* also goes to his local clinic once a year for a blood test to check for signs of cancerous cells in the body.

The development and deployment of new technologies are likely to lead to earlier and more accurate diagnoses. Developments in wearable and implanted sensors, genomics, imaging modalities and data analysis may deliver this result by making healthcare more pervasive, predictive, participatory and personalised.[45] Better and more tailored screening will result from enhanced understanding of inherited risks for each individual patient. The ability to mine and analyse the rich array of medical data collected from sensors, genomic testing and imaging could be of great importance for early and accurate diagnosis, which will ensure the right choice of treatment. Tackling disease at an earlier stage will most likely result in less invasive interventions and more preventive measures. In turn, this may make surgery unnecessary for a number of patients and result in fewer emergency patients, as disease is identified at an earlier stage.

The Commission believes that the existing collaborative process of diagnosis and choice of treatment, with the patient at the centre supported by the surgical and multidisciplinary teams, will increasingly move to include healthy citizens and intervene before illness strikes.

Multidisciplinary decision-making and risk-stratification allows the consideration of the effects and co-dependencies of different diagnoses and choices of treatment. This process should be personalised, taking into account individual definitions of quality of life and needs.[46] In the future, AI engines have the potential to aid the clinician to bring together all the 'best practice' pathways and personalise them. The clinician will therefore shift from the gatekeeper of knowledge to supporting the choices before each patient.

The use of digital technologies can have an impact on emergency surgery by enabling interventions to take place earlier more often in more emergency cases. For example, digital applications can connect trauma scenes and patients with clinicians, enabling earlier diagnosis and triage through the use of cameras and sensors on mobile devices. As a result, trauma patients may receive the right care at an earlier stage, with possibly less extensive or more targeted emergency surgery.

Sensors

In recent years, advances in computing and microelectronics have led to new generations of medical sensors that can continuously and unobtrusively monitor health parameters. These sensors can enable early disease detection, manage chronic disease, monitor medical devices and prostheses, and personalise implants or drugs. For example, implantable sensors are already being developed or in use to detect dangerous cardiac arrhythmias or changes in intraocular pressure indicating possible glaucoma, while devices to monitor glucose levels in the blood will be available on the NHS in England for type 1 diabetes patients from April 2019.[52,47] Ambient sensors are able to collect data about behavioural patterns and habits to help prevent and manage chronic conditions. In five to ten years, sensors implanted in the body to monitor the formation of cancerous cells could be possible.[52]

Blood tests for cancer

Evidence received from geneticists, clinical scientists and surgeons specialised in genomics suggests that in 20 years the population may be able to undergo annual testing for cancer through a blood sample, while similar tests are already being evaluated to monitor recurrence.[49] Although there is work yet to be done to extract the genomic signature from a blood test, the Commission anticipates that a 'liquid biopsy' might provide an even better view of a tumour, compared to a solid biopsy of the tumour itself, thus avoiding an invasive procedure for the patient. Several well-publicised studies have shown encouraging results for blood tests potentially able to detect signs of cancer years before the first symptoms appear.[50]

Smart devices supporting dementia patients at home

Smart devices and sensors are already being used in some pilot projects across the country, for example to support the care of people with dementia. A study run in partnership between the Surrey and Borders Partnership NHS Foundation Trust and Alzheimer's Society used smart devices connected via an Internet of Things – connecting devices to the internet or to each other – to improve the lives of those with limited to moderate dementia in Surrey or North East Hampshire.[48]

Smart devices were installed in the homes of patients affected by dementia who lived at home and were regularly visited by a carer. The devices enabled clinicians to monitor the individual's health, wellbeing and environment constantly and in real time. Any issues identified by the technology would be relayed to the carer, lead to a visit from an Alzheimer's Society Dementia Navigator or result in a call to the emergency services, according to the nature of the issue. Devices included sensors measuring a person's movement around their house and possible falls, GPS trackers to detect whether a person has wandered too far from their home, and sensors to measure weight, hydration and blood pressure.[55]

Artificial intelligence

The application of AI to patient data analytics, radiology, pathology and image analysis is also likely to deliver important changes in early detection and diagnosis of disease.[51] In particular, AI has the potential in the next five years to help improve the speed and accuracy of diagnoses. For example, a recent study demonstrated the potential value of AI in detecting eye disease. Attempts are being made with platforms using machine learning to analyse patient data, population-level data and medical knowledge to aid diagnosis and treatment choices for cancer patients. Opinions on the reliability of these instruments are, however, divided. Furthermore, assurances will need to be in place to prevent health inequalities generated by the use of AI mechanisms, for example by developing or learning bias and prioritising one ethnic group or gender over others.

Surgical treatment

FICTIONAL FUTURE

As he gets older, *Lucas* develops osteoarthritis. Due to the pain and impact on his mobility and life, *Lucas'* GP refers him for an orthopaedic opinion. At the time of his appointment, *Lucas* receives a full scan of his bones and joints. The imaging and the breadth of his medical and lifestyle data from past years – shared by *Lucas* with his local health centre through his personal identification – are immediately available to the surgeon, who discusses treatment options with him on the same day.

Before developing osteoarthritis *Lucas* ran marathons. He works in construction and his mobility is extremely important to his job. In discussion with the treating team, he asks that his joints are treated with a stem-cell based therapy.

Lucas' adult stem cells are taken at his local centre and are differentiated in the laboratory. The surgeon is then able to re-implant them in his joints. As a result, the inflammation in *Lucas'* joint is reduced, the pain eases and no further surgery is required.

At his local care centre, *Lucas* sees his neighbour, *Nova*. Unfortunately, she has been diagnosed with a particularly aggressive form of pancreatic cancer, which has quickly developed between her annual checks.

Nova is 78 and, although she has an active social life, she relies on the help of a carer for some everyday tasks.

She and her family have been discussing different options with her surgeon, while the surgeon has been discussing with the rest of the multidisciplinary team the possible consequences of a surgical intervention on *Nova's* respiratory problems and diabetes.

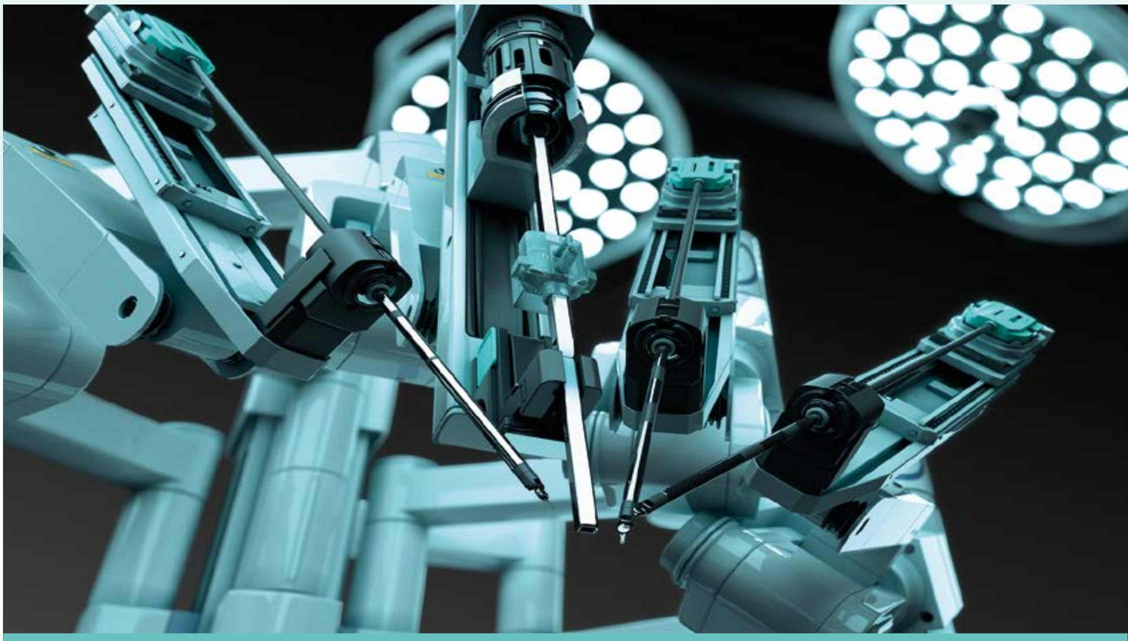
Data collected on *Nova's* health and genetic tests, as well as genomic testing of her tumour biopsies, are helping the surgeon illustrate to her possible outcomes and complications of a surgical operation.

Nova has grandchildren and doesn't want to risk her future with them. She therefore asks the surgeon to remove her cancer surgically.

In the days before the operation, a perioperative physician helps her to prepare for the surgery, discussing her expectations and preparing for her recovery.

Nova's surgeon removes her cancer with the support of a surgical robot. This type of intervention can be performed through a small incision in the abdomen, reducing the impact of the surgery and improving *Nova's* recovery time.

Through the use of imaging technology analysing in real time the molecular composition of the tissue excised, the surgeon is able to remove the entire cancer and reduce the risk of recurrence.



Minimally invasive surgery

Reducing the impact of surgical interventions on patients has been the direction of travel for surgery in the last few decades. From laparoscopic or keyhole to single-port robot-assisted surgery[VIII] and interventions through natural orifices,[IX] the discipline has increasingly shifted from 'saws and scalpels to robots and lasers'.[52]

We are progressively moving away from traditional open surgery, where surgeons need to make an incision large enough to see and feel the patient's organs with their eyes and hands. Minimally invasive surgery, such as laparoscopic and endoscopic surgery or robot-assisted surgery, is associated with reduced reported postoperative pain and faster recovery times, more effective use of resources, bigger savings for hospitals due to shorter stays and a reduced risk of wound infections, adhesion formation and postoperative hernias, as well as better cosmetic results.

Despite such benefits, access to minimally invasive surgery varies across the country and between different types of procedures. This may reflect long learning curves and variable access to training.[53,54] Advances in simulation technology over the next five years are likely to reduce learning curve times and increase accessibility. The pace of change will, however, remain the greatest challenge: for the service, to deliver patient benefits effectively and in a timely fashion; and for the surgeon, to ensure that such changes are professionally evaluated and the risks appropriately mitigated.

Advances in mechatronic devices[X] will continue to produce developments in minimally invasive surgery. Surgical tools are likely to become smaller, more dexterous and 'intelligent', thus allowing for a better synergy between surgeon and machine.

The drive for minimally invasive surgical procedures has led to the development of endoscopic techniques that reduce the number of access ports. Laparo-endoscopic single-site surgery (LESS) and Single Incision Laparoscopic Surgery (SILS) reduce the number of skin incisions to one.[55] Natural orifice transluminal endoscopic surgery (NOTES) goes a step further. Surgery without scars involves a planned incision through the wall of natural orifices to access the peritoneal cavity and perform a surgical procedure avoiding skin incision.[56] Yet, despite the appeal of scar-free surgery – including reduced risk of wound infections, hernia formation and adhesions – current technology and risks such as bacterial contamination from the access orifices limit its widespread use.[63]

VIII Surgery performed with the aid of a surgical robot through only one incision on the patient's body.
IX Natural Orifices Transluminal Endoscopic Surgery, NOTES.
X Technological devices developed in combination between mechanical engineering and electronics.

Robot-assisted surgery

The current picture: challenges and benefits

One type of minimally invasive surgery currently available at some UK hospitals is robot-assisted surgery. Most robot-assisted surgery is performed through the use of a master-slave system that allows the surgeon to sit at a console and control the movements of multiple robotic arms that can rotate and move in ways that human arms cannot. This surgery is currently used for a limited number of procedures, most commonly urological, gynaecological and some types of general surgery.

The main benefit of surgical robots is their improved accuracy and precision, and improved access to areas of the body that would otherwise be difficult to reach with other forms of surgery. Three-dimensional display, image magnification and the elimination of tremor reduce risk for patients. Elimination of the fulcrum effect at the body wall is a further advantage of robot-assisted surgery compared with laparoscopic surgery, where instead natural hand-eye coordination is more compromised, as the surgeon must move the instrument in the opposite direction from the desired target on the monitor to interact with the site of interest.[57] Similar to laparoscopic surgery, recovery times are faster with less reported postoperative pain compared with open surgery.

Despite the benefits, current robot-assisted surgery presents a number of limitations that need to be overcome for this technology to have far-reaching impact on surgical care.

- High costs: this includes the purchase of the robotic system, maintenance and the disposable instruments required for each procedure. Additional costs include those of training, technical support, insurance and potential litigation.[58]
- Size and weight: current robots are cumbersome and heavy, resulting in their lack of mobility and reduced availability around the country and in remote areas.
- Training time and associated costs: commentators quantify the learning curve as up to 200 robot-assisted procedures before achieving the best outcomes.[59-60]
- Insufficient evidence of the effectiveness of robot-assisted surgery: studies of robot-assisted procedures over a number of years are often unhelpful, due to rapid advances in the design of the robots.

What happens next?

The Commission believes significant changes in robot-assisted surgery are imminent, thanks to the confluence of a number of new technologies, with a likely higher uptake of this type of intervention.[60,61,62] Several companies are developing new robotic platforms or are about to launch new surgical robots on the market, including CMR Surgical© in the UK, Auris Health, Inc.© and VERB Surgical, Inc.© (a collaboration between Johnson & Johnson© and Google©), in addition to current market leader Intuitive Surgical®.

It is expected that the new generation of surgical robots will be significantly smaller and probably less expensive. As a consequence, surgical robots may be more easily located in smaller hospitals and moved between different theatres or sites. Their easier integration in the surgical workflow and their increased versatility will allow the use of a robot across several surgical specialties and types of interventions. Contributors to the Commission suggested that, as a result, gynaecological procedures, colorectal surgery and cardiothoracic surgery are likely to see a significant uptake of robot-assisted surgical techniques.[63] Emergency surgery, however, is likely to benefit less in the short-term from surgical robots than elective procedures, due to the time pressures involved in the delivery of emergency care.

New surgical robots will include systems to record the entire procedure, as well as capturing telemetric data from the robotic arm and associated instruments. This could allow better evidence-gathering and audit of robot-assisted surgery, and the refinement of surgical techniques, ultimately improving surgical outcomes.[71] Robots will deliver ever less invasive procedures. For example, the Intuitive Surgical® da Vinci® single-port platform aims to enable natural orifice and single-port approaches that are limited to only one small incision.[64]

Figure 2

Intuitive Surgical®

Intuitive Surgical® have been the leading provider of surgical robotic platforms with their da Vinci® robot. The master-slave system will be complemented by new platforms such as single-port systems to allow natural orifice surgery.

Figure 2: Intuitive Surgical® robotic platform (All material is proprietary to Intuitive Surgical®. The da Vinci® SP is not CE marked and cannot be placed on the market nor put into service.)

Figure 3

CMR Surgical©

CMR Surgical© are set to launch in 2019 their new surgical robotic platform, Versius®. Its slender arms and portable platforms will make it more versatile and easy to use across operating theatres.

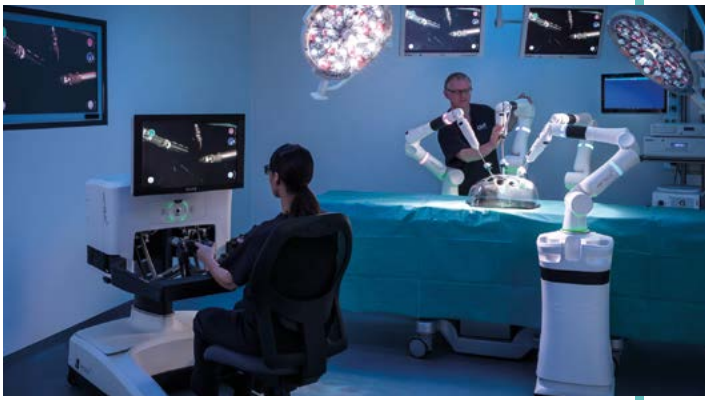


Figure 3: CMR Surgical© Versius®
(Image credit CMR Surgical©)

Figure 4

Corindus, Inc.©

The CorPath® system is a robotic platform that allows physicians to sit in a radiation-shielded workstation and use a set of joysticks and a touchscreen to control movements for precision vascular procedures.[65]

Figure 4: Corindus© CorPath®
(Image credit Corindus©)

The new generation of surgical robots may deliver other key benefits.

- **Improved access to minimally invasive surgery:** Smaller and cheaper devices should lead to increased uptake of robot-assisted surgery, with more hospitals purchasing the technology and more surgeons performing it.
- **Standardisation of surgical outcomes:** The use of robotic platforms may reduce variability of outcomes, through the analysis of data gathered during procedures, and further learning and refinement of surgical techniques.
- **Increased patient safety:** New robotic systems may use AI mechanisms and on-screen checklists to minimise surgical errors. Robotic systems will enable greater remote support from specialists.

The Commission anticipates that:

In the next five years

- There will be more surgical robots that are of smaller size and likely lower cost in the operating theatre, and more providers in the market. This will open access to robot-assisted surgery to more patients, including patients with complex co-morbidities, and most likely to a wider range of pathologies previously not approached with surgical robots, such as musculoskeletal surgery.
- Surgical robots will start undertaking a small number of more simple automated tasks, such as suturing, and may be used in diagnostic procedures (eg robot-assisted biopsies for the diagnosis of lung cancer).
- Simulation training using surgical robots will be more realistic with increased use of augmented reality.

In the next ten years

- Even smaller and smarter surgical robots could become available to deliver specific tasks.
- Smarter robots may make standardisation of procedures possible, enabling greater potential to employ skilled, but non-medically trained health professionals responsible for defined high volume procedures.
- With simple forms of machine learning, surgical robots could deliver some small levels of mediated control. For example, they could warn the surgeon about potentially dangerous dissection movements.
- Data collection through surgical robots could improve understanding of short and long-term outcomes, and improve training for the surgeon and the surgical team.
- The ergonomics of robotic systems could make surgery less physically onerous for the surgeon and lengthen careers.

In the next twenty years

- There might be a more established understanding of the conditions and procedures for which robot-assisted surgery could be effective.
- Robotic platforms might have more autonomous features, with surgeons directing the system to perform certain tasks, rather than performing tasks themselves through the system.
- There might be increasing use of micro and nano-robotics, combined with targeted drug delivery and new interventional procedures.
- Reduced cost and improved functionalities of robotics, with wider adoption of robotics in both specialist and non-specialist centres across the country.
- Robotic platforms might provide much greater guidance to the surgeon on how to perform procedures. Systems might incorporate preoperative imaging and information collected through sensors and display such information during the procedure.

Trusting robots and artificial intelligence

A 2017 survey investigated the public's attitudes towards AI and robotics in healthcare. The general findings of the survey showed a willingness to engage with AI and robotics, if this meant better access to healthcare with faster and more accurate diagnosis and treatment. Trust in the technology emerged as a key factor for its adoption and, most importantly, maintaining the 'human touch' was still considered vital as the basis of healthcare interaction.[66]

Key factors in building up trust in the use of AI in healthcare are likely to be the interpretability of its mechanisms and the transparency over the use of data by private companies. Caution must be exercised given our current inability to fully understand AI decision-making patterns, which complicates clinicians' and patients' reliance on the technology. As AI tools require access to data to learn and develop more effective solutions, there is a great opportunity to innovate and improve patients' lives through the use of a resource the NHS has abundance of: data. Patient confidentiality and their wishes over the use of data and personal information must be carefully understood and respected to ensure that negative examples do not detract from positive innovation. The Commission welcomes the Code of Conduct for Data-driven Health and Care Technology, recently published by the Department of Health and Social Care.[44] This represents a significant step towards the establishment of standards for companies for the responsible use of data and an initial framework to encourage digital innovation.

Interventional micro and nano-systems

The future technology of surgery is likely to be smaller. While nano-sensors are likely to have an impact on diagnostics and patient monitoring, nano-robotics is likely to have a specific impact for treatment.

The field of robot-assisted surgery has moved towards the use of ever smaller and smarter surgical robots. Micro-robots that are swallowed or otherwise implanted can navigate the body to 'fix' medical issues and are then expelled. They have so far been the subject of science fiction. Yet, the use of 'untethered micro surgeons' may be much closer to reality.[67] Surgical micro-robotics is an area of research where only a few systems have been analysed in living animals. The potential for high precision and minimal invasiveness might make them 'indispensable tools of future operating rooms, capable of treating pathologies with ultra-high precision at early stages of disease development'.[75]

Targeted drug delivery is a key area of development for surgical micro-robotics. The discovery of active ways to transport nanoparticles could allow the targeted delivery of pharmaceutical compounds to small regions of the body. Magnetic fields, light, ultrasound and chemical reactions are all methods that might be used to propel and direct particles inside the body.[68]

In the future, nano-robots will aim to decrease further in size to below 1mm and to find new applications, such as in gastrointestinal systems. More detailed preoperative imaging technology better able to target a location may lead to the delivery of ablative therapies.[69]

Micro and nano-particles still face a number of hurdles before they are fit for clinical drug delivery. These include ensuring their precise trajectory, biocompatibility, removal after use and long-term effects. These barriers mean that while nano-robotics is likely to have a significant impact on surgery, adoption into clinical practice should be viewed as a long-term outcome.[76,77]

Imaging

Advances in imaging technologies will have two important consequences:

- Advances in preoperative imaging and technologies will improve diagnosis, surgical planning and procedural simulation.
- Intraoperative or real-time imaging will improve the visual and guidance available to the surgeon, increasing the precision of surgical interventions.

X-ray imaging, computed tomography, ultrasound, endoscopy and magnetic resonance imaging are widely used techniques for diagnostic purposes. Future developments in medical imaging techniques will enable a more accurate, reliable and timely view of internal structures from the molecular to the organ level, while minimising the negative impact on the patient, including the avoidance of harmful radiations.

The future of imaging lies in the development of novel methods capable of producing images of the body with unprecedented detail and reliability, while minimising impact. Future imaging will make breakthroughs in resolution and function, from the current hundreds of microns to cellular and sub-micron levels. At the same time, experimental imaging systems will enhance our understanding of disease progression, aetiology and biological function.

New techniques to display a patient's medical information, such as 3D images, virtual reality and augmented reality, have improved the surgeon's interpretation of the tissue or organ of interest. Procedure rehearsal incorporating novel imaging will facilitate the introduction of new procedures and enhance training.[71] For example, evidence received highlighted the advantages of 3D imaging to support planning of personalised surgical interventions, and creating personalised implants using 3D printing techniques. These are now being used for complex facial reconstruction after cancer operations, to correct inherited conditions and following trauma.[72,73]

Advances in imaging techniques and digital platforms using virtual and augmented reality can also help the provision of earlier emergency care in remote areas. For example, these digital platforms can facilitate remote specialist support and proctoring in the operating room if patients cannot be transported to central locations in time.

A key goal of computerised medical imaging analysis will be to automatically detect, identify and delineate anatomical and pathological structures on 3D medical images, to guide the surgical procedure and influence the extent of the surgery, thus merging diagnostics and therapeutics.[79,74] However, real-time tissue characterisation requires integrating different images and models acquired preoperatively and intraoperatively to guide the surgeon in real time, which still present some significant technical challenges. Although research is available on solutions that would allow modelling of the motion of the organ or tissue of interest, at present the use of image-guidance technology in surgery is mostly limited to applications where data on rigid structures (such as bones in orthopaedic surgery and neurosurgery), which are less impacted by organ or tissue motion, are available.[75]

Contributors suggested that 3D mapping may represent a solution to delivering real-time imaging. This technology – used in the development of driverless cars – calculates the camera's position relative to the object in the field of view, with a much higher potential for scalability compared with 3D imaging, which requires images to be taken constantly and huge amounts of data to be stored.[76] 3D endoscopes are also increasingly used in surgical practice.

The development of ultra-high definition stereo endoscopes and microscopes combined with automated processing, tissue characterisation and decision-making support may represent the future of real-time imaging in surgical practice. Finally, the integration of imaging data with other patient data may allow the development of 'more comprehensive personalised patient models' guiding the surgeon during a procedure.[77]

The Commission anticipates that:

In the next five years

- Remote surgical teams will increasingly be able to access expertise and conduct multidisciplinary team meetings through digital technology.
- Outpatient appointments will more frequently occur through a digital platform.
- Imaging of organs will move from static anatomical displays to showing how an organ is functioning.
- 3D planning and printing will advance further and be used more frequently for teaching, training and surgical preparation for complex surgical interventions. The use of 3D models will increasingly become the norm for major hospitals.
- 3D models will also be used by patients to help improve their understanding of a procedure, illness or injury.
- Operating theatres will continue to incorporate imaging facilities such as x-ray, CT and MRI scans, with more hybrid theatres.
- Enhanced imaging technologies incorporating fluorescence will allow surgeons to identify more readily blood vessels, lymphatic channels, tumour bearing tissues or specific organs.
- Advances in imaging and simulation will continue to be used on a wider scale to complement surgical training and planning. More trainees will use mobile apps to supplement their training curricula.

In the next ten years

- AR will make a bigger impact, with surgeons able to overlay data and visuals over a patient's body during surgery.
- VR will become a standardised aspect of surgical training, with training centres and teaching hospitals needing to invest in VR suites.
- Digital applications providing training will be more commonly used and provide surgeons and medical students access to global knowledge and standards.

In the next twenty years

- Ultra-high definition stereo endoscopes and microscopes will be in use, making further improvements to the accuracy of diagnosis and surgery.
- Imaging data will increasingly be combined with other patient data, providing powerful information to the surgeon undertaking an operation.
- Surgeons will more frequently be able to conduct surgery from a remote console, enabling more patients around the world to gain access to expert surgeons. This will likely happen on a small scale.

Genomics

Following the successful 100,000 Genomes project, a new NHS Genomic Medicine Service will soon be delivered in England, aiming to extend genomic testing for different cancer types and rare diseases.[35,36] Similar plans are likely to be reflected in devolved nations. A 100,000 Genomes project is underway in Wales, and the Welsh Government's recent Genomics for Precision Medicine strategy sets the direction for future genomic services responsive to patient needs and the transfer of genomic data across the nation.[78] The Scottish Genomes Partnership is also undertaking a 100,000 Genomes project in Scotland in a collaboration between Scottish universities and the NHS.[79] With wider access to genetic testing, surgical care planning for cancer surgery will incorporate better personalisation of treatment.

Implications for the treatment of cancer patients will include:

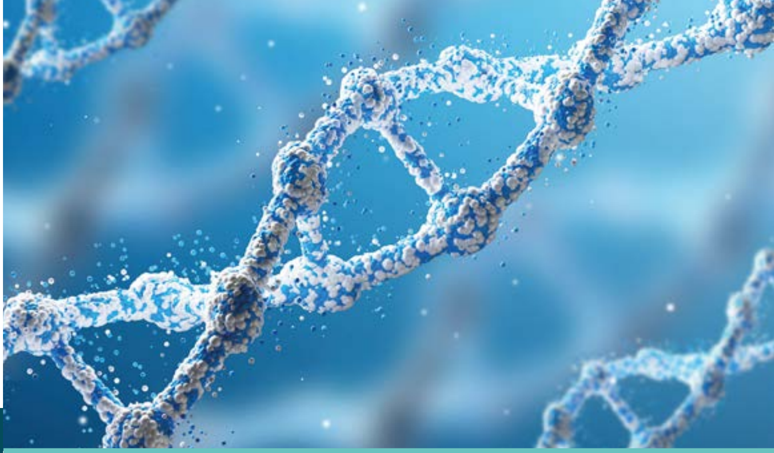
- Better prediction of inherited disease risk and therefore an increased potential for risk-reduction interventions, including surgery to prevent or delay occurrence.
- Use in diagnostics, particularly the detection of cell-free tumour DNA, allowing a 'blood test for cancer'.[56]
- Better precision medicine and the identification of treatment targets appropriate to the individual patient, rather than relying solely on outcomes data based on population averages. This may result in:
  - Avoiding invasive treatments in patients for whom they bring no benefit. In some cases, surgery may be avoided altogether, as alternative therapies may be more effective. Advances in pharmacogenomics could help tailor drug therapy to each patient, improving success rates and avoiding ineffective chemotherapeutics, adverse reaction or suboptimal dosing.
  - Molecular analysis in real time may guide more accurate surgical excision, possibly improving success rates, and reducing recovery times and recurrence rates.
- Multidisciplinary interpretation of genomic analyses and improved planning of patient care – taking into account risk of future disease, as well as prognosis of current disease – will become routine for most cancers.

Understanding molecular testing and genetic risk for a broader range of conditions, such as cardiovascular disease or connective tissue disease, will improve in five to ten years, both among the medical profession and the public, leading to improvements in clinical outcomes and mortality rates. Once again, better prevention and prediction of various disorders may result in fewer emergency surgical procedures and ultimately fewer operations for advanced disease.

The translation of genetic testing into routine clinical practice is not without risk. This testing may create an overestimate of risk leading to unnecessary preventive surgical interventions. Patients using commercially available genetic testing kits may be misled to believe surgical or other medical interventions are necessary. Decision-making at the multidisciplinary team level and regulation of diagnostic devices will be crucial to help mitigate such danger. Targeted efforts to raise public awareness and knowledge about genetic risks and the benefits of genomic medicine will be essential.

Improved understanding about the ethical implications from both the medical profession and the public will also be important. DNA testing may identify previously unrecognised inherited conditions, with implications for the patient and their family beyond immediate cancer care. There are also concerns about avoiding discrimination based on genetic testing especially for insurance and employment purposes.

Plans are in place in England for the launch of a national genomic consent process, to allow patient data to be stored in one location and for clinicians across the country to access anonymised data and to help contextualise their patients' results.[35] Appropriate consent mechanisms will need to be in place to enable the use of patient genetic data. For example, patients involved in the 100,000 Genomes project were all asked to give fully informed consent for their data to be held centrally and to be shared in a de-identified format for research purposes.[35]



The Commission anticipates that:

In the next five years

- The NHS Genomic Medicine Service will be extended to more patients undergoing genomic testing for different cancer types and rare diseases. Similar schemes will be in place in the devolved nations.
- There will be ongoing public debates about the ethical implications of collecting and analysing genome data.
- More licensed drugs that target a molecular signature will be available.
- Surgical training will need to better reflect the need for the surgical team to understand genomics, including correctly acquiring and handling tissue for DNA testing and supporting patients to understand their data. Existing surgical teams will need to be urgently upskilled to deal with this new genomic era.

In the next ten years

- Greater use of genomics in diagnostics. Surgeons will play an important role within the multidisciplinary team and established role in acquiring tissue to analyse DNA and being the primary health professional, discussing the implications of the diagnosis with patients.
- More demand for risk-reduction surgery for patients at heightened risk of developing cancer and other diseases.
- Treatments will begin to be targeted at patients based on their genome types through better access and analysis of population-level data.

In the next twenty years

- Use in diagnostics will be established. Likely use of cell-free testing on an annual basis for patients at risk of cancer (and potentially other diseases). This may allow cancers to be detected earlier, facilitating less invasive surgery.
- Greater use of precision surgery based on an improved understanding of the impact of specific interventions on genome types, for example understanding which patients are more likely to develop infections or heal more slowly.
- Greater adoption of non-surgical treatments based on genomic sequencing, likely making some types of radical cancer surgery less frequent or unnecessary.

Transplantation and regenerative medicine

Due to population ageing, increasing multimorbidity and greater population size, the need for transplantation is likely to increase. As the population grows older, treatment will expand to higher-risk patients. The incidence of obesity, fatty liver disease and diabetes is likely to increase demand further for transplantation of the liver, pancreas, kidney and heart. Transplantation might increasingly become an option to treat different types of cancer.[80]

For transplantation to expand, however, current hurdles need to be overcome. The most significant challenge affecting transplantation is the shortage of organs available. In the UK there are currently around 6,000 people on the national Transplant Waiting List and last year 400 people died while waiting for a transplant.[81] Another great challenge is organ rejection requiring life-long immunosuppression, with impact on the patient's quality of life.

The Commission anticipates that in the short-term these challenges will be tackled by:

- **Improving the supply of organs:** Attitudes and behaviours towards organ donation may change through public awareness campaigns and changes in policy.
- **Better management and assessment of donor organs:** New organ perfusion technologies will allow us to accurately identify organs that can be safely transplanted, and potentially improve the condition of 'marginal donor' damaged organs out of the body before transplantation.[82,83] Ex-vivo perfusion will increase the numbers of organs that are suitable for transplantation.
- **Re-programming the immune system:** Rather than aiming to ablate the immune system, it may be possible to re-programme it through a combination of drugs and cell therapies, such as stem or regulatory cells.

Within five years, new types of transplant could be offered more widely,[XI] including face, limb or uterus.[88,90,91] In the next ten to twenty years, a range of other techniques and technologies could be possible – such as xenotransplantation, 3D and 4D bio-printing, artificial organs and cell therapies – solving some of the current challenges in transplantation. Developments in stem cell and gene therapies together with perfusion technology could allow us to recondition organs inside the body, potentially reducing the need for some forms of transplantation.[84]

Advances in transplantation will bring benefits to patients by reducing mortality rates and increasing the life span of grafts. However, transplantation is currently an invasive intervention that can have a negative impact on the patient's quality of life, such as the life-long use of immunosuppressive drugs. This impact needs to be considered, especially when operating on an increasingly older patient cohort.

Xenotransplantation

Xenotransplantation – the use of animal grafts for transplantation in humans – may finally be close to delivering on its potential. Porcine heart valves and tissues have been used in cardiac, orthopaedic and general surgical procedures for decades. However, these xenografts comprise structural tissues from which porcine cells have been removed. Implantation of solid organ xenotransplants still presents a number of substantial difficulties, such as overcoming the immunological response of the recipient. Unmodified xenotransplants incite a very powerful rejection from the recipient's immune system. Such transplanted organs may also demonstrate physiological incompatibilities and carry a risk of transmissible infections (zoonoses) affecting humans.

XII We refer here to transplant on offer from the NHS, not from private providers.

Considerable research efforts have gone into establishing the feasibility of genetic manipulation of the porcine donor, not only to reduce the severity of the rejection response, but also to eliminate endogenous retroviruses within porcine DNA.[85] Another possible solution could be the development of bioengineered composite organs, in which a scaffold is derived from animals and the cells that repopulate it are of human origin. This might have advantages with respect to both immunology and physiology, as well as it being potentially easier to control quality.[86]

Organ bioengineering and 3D bio-printing

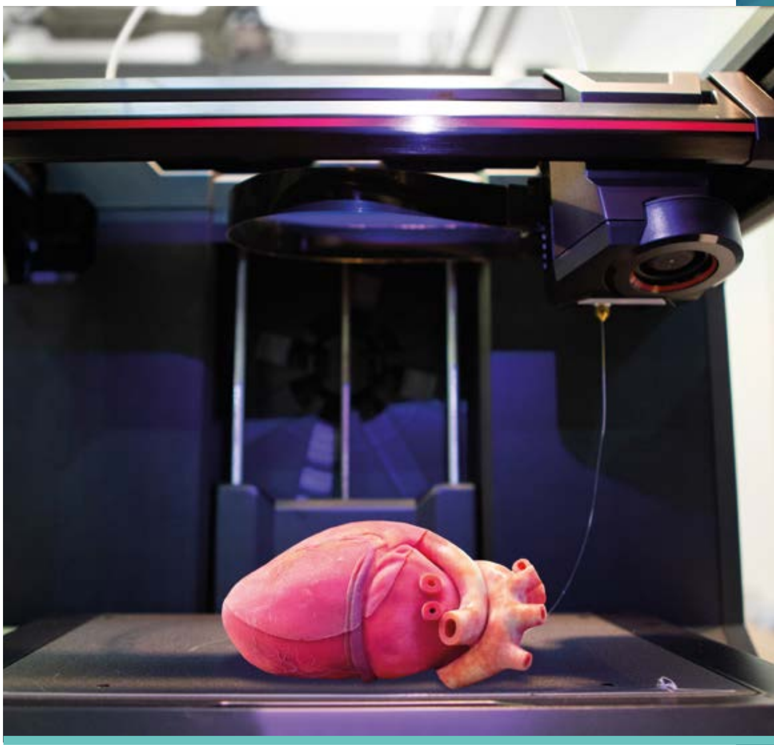
In ten to twenty years, organ bioengineering and 3D bio-printing could bring exciting changes to healthcare, from providing organs for patients waiting on the transplant list to restoring form and function in patients who have sustained trauma or burns.[87]

Advances in regenerative medicine could improve the quality of organs currently unsuitable for transplant and provide an inexhaustible source of organs and tissues, eliminating the need for life-long immunosuppressive drugs.[95,88] Advances in 3D bio-printing have the potential to personalise cell and drug testing and remove the need for animal and human participants in drug trials. In the future, 3D printed scaffolds that dissolve over the years may become available. For example, researchers at Queensland University of Technology are developing scaffolds based on MRI reconstruction of the breast, which will dissolve in a two to three year period as the fatty breast tissue regenerates.[89]

Contributors suggested that in five years it could be possible to bio-print mesenchymal tissue – cells from the mesoderm that can differentiate into structures such as connective tissue, blood, cartilage and bone – thus aiding stem cell therapy. The ability to implant cartilage, bone, blood vessels and small grafts could be later developed, while in the long-term it might be possible to 3D bio-print organs – such as skin or pancreas – or even one day have the potential to bio-print limbs.[90] 4D printing might also be developed: printing tissue that over time responds to stimuli and changes its form (eg a liver that might regenerate itself).

Bioengineered organs pose enormous technical and institutional challenges:

- Vascularising bioengineered organs remains difficult. To date, the most successful bioengineered organs used in clinical settings have been simple structures not requiring reconnection to a vascular supply, as providing an adequate supply of oxygen until the organ's integration with the body remains an issue.
- Printing and growing organs can be extremely costly and time consuming.
- The NHS may not be ready to implement such innovations.
- Concerns about the long-term safety and outcomes of bio-printed tissues and organs need to be addressed through long-term studies and adequate monitoring and surveillance.[95]



3D planning and printing for guides, implants and prostheses

3D printing has been one of the most innovative technologies seen in recent times, with an impressive uptake in surgery. 3D printing software has been used to extract data from patient imaging technologies and print personalised and custom-made guides for surgery and implants replacing resected body parts or anatomical structures affected by congenital diseases.

3D planning and printing technologies are likely to become widely available in major hospitals, reaching more medical specialties.[92-93] The field of 3D printing is expected to grow exponentially, with the healthcare sector projected to be the fastest growing segment of the market.[94]

3D printing technologies have been used to yield personalised facial and cranial implants using a variety of materials for people who have sustained traumatic injuries, or to repair skull or congenital defects. As 3D printing template surgical guides and custom-made implants have now become common in many places across the country, the next step will be printing with materials that are better tolerated by the human body, as a precursor to the ability to grow or print tissue.

Developments in 3D printing are making surgery safer and more precise, and are opening avenues for surgical procedures that are currently too complex or have poor outcomes. These innovations will lead to an increase in patient choice, expectations and a demand for bespoke care. The provision of 3D models to patients could improve patient understanding and facilitate more informed consent.

Despite the growth and potential of the sector, there remain hurdles to overcome for this technology to be further adopted. Technological and biological challenges include improving imaging, the speed of printing, and the compatibility and variety of materials. Contributors suggested that the regulatory environment and the reimbursement process could adapt more easily to innovations by involving experts from different disciplines – including clinicians and engineers – in the design of such processes.[98]

Figure 5

Figure 5: Planning of 3D cutting guides for removal of an aggressive tumour of the mandible in a 50 year-old female, using CT scan in 3D software, Mimics® Innovation Suite from Materialise, and Freeform® from 3D Systems. Image credit CARTIS

Centre for Applied Reconstructive Technologies in Surgery

Maxillofacial and head and neck surgery have seen numerous applications of 3D printed implants and prostheses. For example, in Wales, the Centre for Applied Reconstructive Technologies in Surgery (CARTIS) has been one of the leading innovators in applying 3D printing technology to reconstructive surgery and facial and oral prosthetic rehabilitation.

In their contribution to the Commission, CARTIS argued that 'the way 3D planning and printing is used has evolved away from making patient-specific anatomically based plastic models from computer tomography data to the production of metallic transient use devices/guides and long term biocompatible implants'.[91]

Surgery by Consultant Maxillofacial Surgeon, Madhav Kittur.
Planning Peter Evans, Heather Goodrum, Madhav Kittur Morriston Hospital, Swansea

Challenges to further adoption could also be tackled by investing in the creation of multidisciplinary specialised hubs where not only the equipment but also the expertise and collaboration of clinicians, engineers, technicians and industry would be centralised.

Artificial organs and robotic limb prostheses

The use of robotic prosthetics has increased in recent years, with electrodes placed on muscles to control movement, such as the digits in a robotic hand. While such devices can improve a patient's function, they are still very limited in terms of the sensory feedback they can provide.

Although prosthetics and implants are currently well embedded in surgery, the most advanced prostheses available only have some degree of neurological control and no sensory feedback.[97] The future of organically controlled prosthetic limbs is far away and is not likely to have an impact on surgery immediately in the NHS.[98] In the long-term, prosthetics and artificial organs might be used not only to improve organs and body parts that are underperforming, but also to augment function beyond normality. Demand for these performance-enhancing procedures might increase and the resulting ethical issues, such as possible inequalities generated by the offer of such interventions in the private sector, should be considered.

Sensitive prosthetics

Research at the University of Chicago and Johns Hopkins University is attempting to restore the sense of touch to prosthetic limbs. By putting sensors into prosthetic hands, the researchers have shown it is possible to feed back information about objects to the somatosensory cortex, enabling patients to adapt the way they hold an object according to how it feels.[95] Similarly, researchers at Newcastle University made the news in 2017 for developing an 'intuitive hand' that can react automatically to the external environment and assess the force to apply in gripping objects.[96]

Stem cells and gene editing

Given their unique ability to proliferate and regenerate, stem cells have the potential to offer revolutionary solutions to fix damage to the body, grow tissue and organs for transplantation and bring benefits to patients affected by diseases for which no cure currently exists, such as Parkinson's, motor neurone disease or dementia.

At the time of writing, there are only a few approved clinical uses of stem cell research for cell-based therapy. Bone marrow transplant to treat diseases of the blood and immune system is the most widely established stem cell treatment. Skin stem cells have also been used to grow skin grafts for patients with severe burns. Recently the first advanced therapy medicinal product containing stem cells, aiming to repair damage to the cornea after an injury, has received conditional marketing authorisation by the European Commission.[99] Other clinical applications of stem cells are currently being evaluated in a vast number of clinical trials, but are yet to fully demonstrate their outcomes and validity.

The cost, complexity and time required for stem cell treatment remain high, as well as the difficulties in acquiring or producing the large quantities of stem cells needed. The long-term effects of stem cell treatments remain unclear, as currently there is no way to monitor stem cells after they have been implanted. Concerns therefore remain regarding their long-term behaviour, such as the risk that pluripotent stem cells could mutate and become cancerous.

Gene editing, the alteration of a specific sequence of DNA in specified genes to modify the gene function, has been developed in the last decade. Current use is mainly limited to research in the laboratory. However, the ease and availability of gene editing methods, such as clustered regularly interspaced short palindromic repeats (CRISPR) methods, make applications for therapeutic interventions a real possibility that is already being explored in rare inherited blood disorders. Gene editing can be used to correct mutations in human DNA that cause inherited diseases, make the use of animal grafts for transplantation safer by ridding the animals of possible viruses or treat conditions through the use of edited cells.[101]

Research in the use of stem cells and gene editing has raised a number of ethical controversies. The use of embryonic stem cells has divided opinions and gene editing raises questions about when modifying DNA to cure and prevent disease is desirable, and when it might risk becoming a selection mechanism. The Commission refers to the 2016 Nuffield Council on Bioethics report on genome editing for further details on the ethical considerations of the use of gene editing in medicine.[111]

CRISPR/Cas9 gene editing

This is a powerful method to edit genes by cutting and joining the DNA. The method uses a self-defence mechanism that bacteria use to fight viruses, to cut DNA and change specific letters of the DNA code of an organism.[100] Bacteria use this tool to kill viruses, but applied in human genetic conditions it could be developed to correct inherited mutations that underlie some genetic diseases. It has the potential to allow abnormal genes to be removed or repaired.

Definitions

The Commission anticipates that:

In the next five years

- It is likely that there will be more applications of stem cells across different conditions. Chronic inflammatory conditions like osteoarthritis, macular degeneration and neurodegenerative diseases will be the next areas of target.[102]
- Research in the use of stem cells may be directed towards treating diseases such as diabetes, thus reaching an even wider population.
- New types of transplant could be offered more widely – eg for face, limb or uterus.

In the next ten years

- Stem cells could be used to reconstruct or engineer tissues or organs in the laboratory. Access to engineered tissue will therefore be open to more patients and more diseases.
- 3D bio-printing could help achieve this goal as a tool to deliver scalability, reproducibility and a reduction in cost.
- Xenotransplants could begin to be used in the UK.
- Robotic prosthetics could become more readily available.

In the next twenty years

- Stem cells may improve organ function and longevity.
- Gene editing could be in use, albeit limited.
- Robotic prosthetics could have more neurological control and sensory feedback.
- Potential development of some limited artificial organs and body parts – probably for those areas that are easier to replicate such as the bile duct.
- 3D printing could be used to manufacture artificial organs.
- More advanced imaging could facilitate ‘nano-surgery’, with surgeons operating on individual cells.

Shift to peri-operative care and supported decision-making

A peri-operative approach to surgical care following the patient before, during and after the procedure is already in use, but could be further optimised with new technologies monitoring patients and further emphasis on pre and post-habilitation as part of the surgical team's role.[103] This will ensure that:

- Pre-habilitation is in place and patients undergo interventions at their best possible physical and mental state;
- Pre-intra and postoperative procedures are tailored to their needs with advice and support from surgeons;
- And patients are followed through recovery and rehabilitation to ensure that the outcomes of the procedure are evaluated on the basis of what matters to patients and their quality of life.[53,103,104,105]

Patients should be encouraged and enabled to take a more proactive role in their care and take increased responsibility over maintaining their health and wellbeing, choosing their treatment and managing their long-term conditions. However, levels of health literacy and patients' ability to manage their own health differ among different people and groups.

Methods have been identified to measure a patient's ability to manage their own health. For example, the Patient Activation Measure (PAM) is a tool used by over 60 sites in England to measure levels of patient activation – namely the ability of patients to manage their own health and conditions.[106] Similar tools can help healthcare professionals tailor care approaches to individual patients. Surgical teams, together with other health professionals, have a role in enabling people to take on a more proactive role over their health and care by tailoring their communication and support to the ability of each individual.[107]

Supported decision-making and management of an individual's health should therefore take place as a partnership between patients and their healthcare teams. Decisions about tests, interventional care and management of conditions should result from a personalised and case-by-case analysis, based on patient-specific and population-based data, patients' preferences and self-defined quality of life, as well as the clinician's knowledge and expertise.[108]

The necessity for supported decision-making was affirmed in the law by the Montgomery vs Lanarkshire Health Board judgement in 2015. The judgement argues that 'the relative importance attached by patients to quality as against length of life, or to physical appearance or bodily integrity as against the relief of pain, will vary from one patient to another […] The doctor cannot form an objective, "medical" view of these matters, and is therefore not in a position to take the "right" decision as a matter of clinical judgment'.[53]

> "Patients should be encouraged and enabled to take a more proactive role in their care and take increased responsibility over maintaining their health and wellbeing, choosing their treatment and managing their long-term conditions."

Follow-up and rehabilitation

FICTIONAL FUTURE

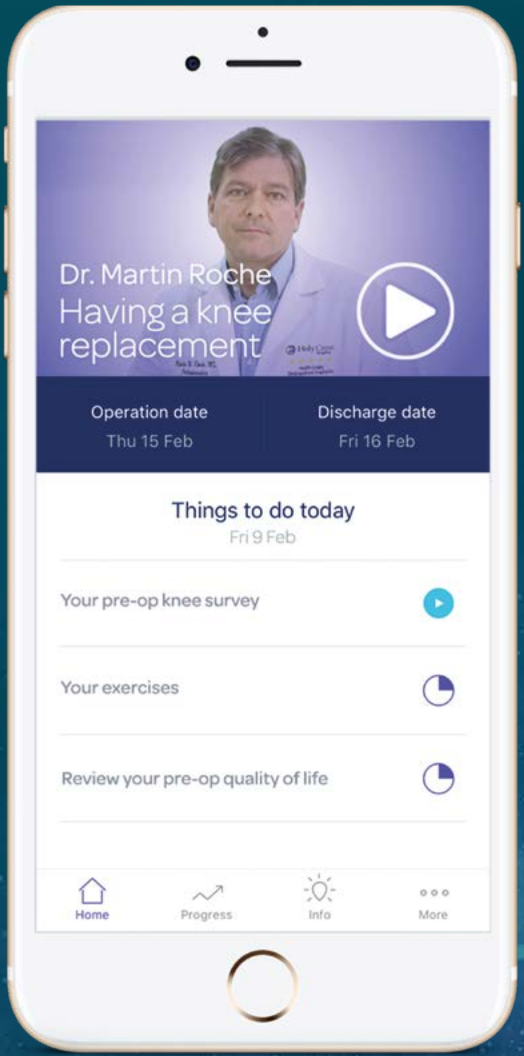
After a few days in the hospital, *Nova* can go home to recover from her cancer surgery. Ingestible degradable capsules monitor *Nova's* risk of developing a post-surgical infection and alert her surgeon to any such instances. AI algorithms analyse these data, further information coming from other sensors and *Nova's* tests to alert her surgeon of possible signs of deterioration.

Nova has weekly appointments with members of her surgical team to check her progress. These appointments often take place as electronic consultations through her smartphone. Through the camera on her phone, she can show the healing of her wound to her physician. Health apps help her understand what to expect at each stage, suggest increasing tailored levels of physical activity each day and track her subsequent progress.

Wearable and implantable sensors are likely to have important applications for follow-up after surgery. Short-term wearable, implantable or ingestible sensors could help monitor patients' vital signs and detect any postoperative infections, for example by measuring the body's core temperature or detecting bacteria in a wound.

Digital applications already exist that collect data, track symptoms and, through algorithms, are able to alert doctors of deteriorating conditions such as sepsis or acute kidney injury.[109] Surgical care does not stop when the patient exits the operating theatre and needs to follow their recovery, rehabilitation and long-term outcomes.

The use of telemedicine and digital apps has a great potential in this section of the patient journey. Following surgical procedures, consultations can take place digitally. Devices incorporated in, or transmitting data to, smart phones can send information about the patient to the physician. For example, cameras on smartphones can take pictures of wounds and wrist devices can monitor pulse pressure. Digital apps inform the patient about what to expect at each stage of their recovery so they can monitor progress on physical rehabilitation or offer interactive physiotherapy sessions.[110]



MyRecovery.AI

Digital platforms and telemedicine are already playing an important role in peri-operative care. MyRecovery.AI, a London-based start-up, has created an app that guides patients through preparation and recovery from their operation. Using data analysis, the process is personalised to each patient, who can watch videos of their own surgeon talking through each stage of their pre and post-habilitation, access exercise videos and track their progress through graphs and self-care tools. The use of the app enhances informed consent, enables remote support and provides a means to collect patient data. The app currently focuses on providing support to people with musculoskeletal injuries or conditions, but MyRecovery.AI is working to expand its remit to help patients undergoing other types of surgery.

Figure 6: MyRecovery.AI app (Image credit MyRecovery.AI)

myrecovery

Figure 6

Prevention of recurrence and management of long-term conditions

FICTIONAL FUTURE

Nova has now recovered from her operation and regained her function. However, she continues to use sensors and digital apps to keep healthy and help her doctor to detect any signs of disease recurrence. Her data are linked with her health records and shared with her GP to monitor the long-term outcomes of her surgery in the next few years.

Nova already uses an 'intelligent' sensor to manage her diabetes. The sensor is able to detect the levels of glucose in her blood, transmit her data to her 'digital twin' and automatically inject insulin accordingly, making the management of her condition throughout the day much easier.

Commission contributors highlighted the importance of tracking outcomes beyond the short-term and redefining the notion of success of surgical procedures on the basis of the patient's recovery and the impact on their quality of life.[115] Linking data from GP practices following surgery will allow the analysis of long-term outcomes of procedures, better inform what works best for which patients and produce a further shift towards personalised medicine.[111]

As a result of such a shift, information obtained through DNA testing is also likely to help to predict the recurrence of disease and, as a consequence, allow it to be potentially prevented or tackled. Once again, the ubiquity of data at an individual and population level, and its analysis, can enable predictive strategies and personalised interventions. In the next few years, sensors, telemedicine and digital apps will become more common in the management or self-management of chronic conditions.

Emphasis should also be placed on exercise and activity therapy, with further consideration to the impact of surgical treatments on mental health, and indeed their impact on surgery.

Some of the most frequent surgical interventions and projected changes

Procedure	Finished Consultant Episodes, England (2017-18)	Changes in the next 5 years	Changes over 5–20 years
Cataract surgery	390,563	• AI supporting diagnosis • Improved smart lens design • AR and VR continuing to aid training • Delivery by increasingly specialised ophthalmologists	• Demand expected to increase by at least 50% • Potential use of lasers to assist surgery depending on assessment of cost • Smaller incisions • Robots starting to be used in procedures • Cataract surgery delivered by fewer but highly specialised surgeons
Excision of skin lesion	202,824	• AI, coupled with improved datasets, will play the biggest role, aiding diagnosis by identifying suspicious and non-suspicious lesions. This may reduce the need for excision • Earlier diagnosis leading to better outcomes • AI aiding pathology	• Demand rising with ageing population • Routine use of AI for diagnosis • Public awareness for prevention • Likelihood of blurred professional boundaries of who does excisions with possible delivery by trained allied health staff
Tooth extraction	99,929	• Improved imaging: wider use of 3D CT scans for a higher number of extractions. This will especially help with planning of extractions close to a nerve • Unlikely decrease in the number of extractions, but more completed on older patients • Fewer extractions taking place under general anaesthetic ,with more taking place in primary care settings • Earlier intervention to avoid untreated dental disease and spreading infections often leading to emergency surgery • Public health awareness	• Public expectation of restoration, not extraction • Use of piezo electric surgery, a technology used to cut through bones with reduced trauma compared to drills • Use of platelet rich plasma into extraction sockets and wounds to accelerate healing • More extractions followed by replacing teeth with implants • Fewer extractions following improved oral health in children • Increased prevention • AI increasingly used for assessment and evaluation of teeth

Caesarean section	**100,067**	• Commonest procedure globally[XI] • Performed by obstetricians	• Rising global demand • Likelihood that specifically trained surgical assistants will carry out planned non-emergency caesareans in future
	Operation on a fracture		
	Operation within the fracture site to correct the position		
	40,253	• Activity therapy to improve joint and muscle health • Increasing demand due to older population • New treatments for osteoporosis	• Improved screening and prevention • Potential for less surgery • Improved medical care and rehabilitation for frail patients undergoing surgery
	Manipulation of the limb to reduce the fracture into a good position		
	42,454	• Expansion in fracture liaison clinics, which will help identify people at highest risk of fractures	
Cholecystectomy (gall bladder surgery)	**73,069**	• Metabolic modification to prevent gallstones • The management of obesity to reduce prevalence • Advances in endoscopic techniques for stone removal • Possible development of natural orifice minimally invasive surgery	• Robot-assisted surgery • Greater use of minimally invasive surgery, enabling less hazardous revision interventions • Application of AR to support remote surgery • Nano-technology to dissolve stones

XI Debate is ongoing however about the clinical value of maternal choice for caesarean section procedures and this might change the volume of procedures in the future.

Knee replacement	**80,627**	• Increasing need due to older population • Joint preserving surgery • Improved osteotomy techniques, meniscus transplant and articular cartilage repair • New materials aiding longevity of implants • Improved analgesia and recovery times leading to shorter stays (day-case for partial knee replacement) • Activity therapy, including weight loss	• Arthroscopy delivered by surgical assistants with AI analysis • Early medical and surgical preventive therapy, eg stem cell cartilage repair
Inguinal hernia repair	**63,650**	• Minimally invasive surgery using laparoscopic techniques • Robot-assisted surgery • Material advances for mesh implants and improved monitoring of mesh outcomes following recent controversies • Use of AR for teaching / training	• Mesenchymal stem cells for repair • Advances in endoscopes
Spinal surgery	**58,042**	• Activity therapy • AI aiding diagnosis • Endoscopic minimally invasive surgery • Robot-assisted surgery	• Earlier diagnosis/disc repair • Disc repair with stem cells • Use of AR to support surgery • Reduction in surgical intervention, increased early treatment of causes, such as inflammation

Mastectomies and breast conserving operations	**59,117**	• Less radical individualised surgery with combination of oncoplastic techniques and neoadjuvant treatments • Risk stratified breast screening • Genetic profiling of tumour for personalised treatment • Increased use of ultrasound scan by surgeons to facilitate clinical diagnosis and intra-operative techniques • Widespread introduction of novel methods of localising impalpable screen-detected cancers (eg radioactive seeds, magnetic seeds, radio-isotope injections) • AI aiding diagnosis in both radiology and pathology • More preventive surgery following genetic profiling • 3D printing aiding reconstruction • Advances in chemotherapy regimens and drugs	• Nanotechnology aiding diagnosis and treatment • Liquid DNA analysis for early diagnosis and screening • Non-surgical treatments (eg laser)

Coding was based on: Abbott T E F, Fowler A J, Dobbs T D et al. Frequency of surgical treatment and related hospital procedures in the UK: a national ecological study using hospital episodes statistics. British Journal of Anaesthesia 2017; 119 (2): 249–257 https://academic.oup.com/bja/article/119/2/249/4049141#94514166

Data sources: NHS Digital. Hospital Admitted Patient Care Activity, 2017-18. https://digital.nhs.uk/data-and-information/publications/statistical/hospital-admitted-patient-care-activity/2017-18 (Accessed November 2018)

In summary: implications for the patient

The patient's role in a new system

- Healthcare is likely to shift further towards prevention and prediction of disease, early intervention and self-management of chronic conditions.
- Fewer patients will have to undergo major invasive surgery. Those that do will have better outcomes, with reduced trauma and complications.
- On the other hand, more patients will undergo smaller procedures, as better tolerated by frail patients and yielding marginal benefits for patients with premorbid conditions.
- Patients will be supported and enabled to assume greater responsibility for their own health, from maintaining good health to making choices about their care.
- Consent and supported decision-making about treatment options will be centred more around the patient's preferences and self-defined quality of life, in partnership with the surgical team providing support to patients to make sense of complex information.

The patient journey

- Further emphasis on peri-operative care across patient pathways, and new technologies improving rehabilitation and recovery, will help support patients before, during and after surgery.
- The use of data analytics, wider access to genomic testing and better imaging will enhance predictive and personalised medicine, enabling more preventive and earlier interventions.
- Better diagnostics and less invasive interventions could shorten the patient's journey with more one-stop appointments.
- An expansion in multimodality clinics can be anticipated.

New technologies

- A new generation of surgical robots that are cheaper, more agile and versatile is likely to increase the uptake of robot-assisted surgery, standardise its outcomes, improve transparency through better data collection mechanisms and provide greater remote support from specialists.
- Although AI tools are likely to be increasingly used to find patterns in data and support tasks such as diagnosis and monitoring patient vital signs, robots performing surgery in full autonomy are unlikely to emerge in the next 20 years. However, elements of surgical procedures might become increasingly semi-automated.
- The 'human touch' and the human interaction with the surgeon and their team will remain fundamental.
- Treatments previously considered impossible or limited to a younger and healthier patient cohort will become possible for more patients.
- Advances in transplantation will improve mortality rates for conditions resulting in organ failure and increase the number of eligible patients and treatable diseases.
- Xenograft transplants will become more available, if the ethical issues can be addressed.
- In the long-term, it might be possible to bio-print or bioengineer tissues and organs for patients in need of a transplant or patients who have suffered burns and trauma.
- Stem cell therapies and gene editing could bring benefits to patients with inherited and currently untreatable diseases.

PREPARING THE SURGICAL WORKFORCE

FICTIONAL FUTURE

Today, *Rohan* will be removing a tumour from a patient's pancreas. Before leaving his house in the early morning of a normal working day in 2035, he turns on his mobile device, accesses the file of *Nova*, his patient, and puts on his VR headset. He enters a reality where 3D images of *Nova's* pancreas and the surrounding organs glow and rotate in front of him. He can see the tumour, the vessels around it and where the healthy tissue starts. He video-calls the other members of the team and, sharing the file with *Nova's* images, they finalise together and rehearse one last time the steps of *Nova's* surgery.[112]

When *Rohan* is finally in the operating theatre that afternoon, he is sitting comfortably at a console and controlling the arms of a surgical robot, while looking at 3D images on his screen. On the other side of the operating theatre, other members of the team check the machine and work around its slender arms. The digital operating theatre reminds the whole team about each step of the procedure and answers questions about Nova's tests and health parameters.

Real-time diagnostic tools integrated with the robot analyse the tissue and confirm the resection. All the cancerous tissue is removed and a surgical assistant staples *Nova's* small incision in her abdomen. Members of the surgical team focusing on peri-operative care follow *Nova* to the Intensive Care Unit, where AI mechanisms will alert them of any postoperative complications. Data about *Nova's* procedure is shared with her GP and national databases to monitor long-term outcomes. *Rohan* can now video-call *Nova's* family and tell them the good news.

Surgery can be a life-changing and emotional time for patients. For the surgeon performing the procedure, it is the culmination of years of study and supervised practice to provide the very best care possible. It is also a rewarding career, as surgeons are trusted by patients to support them and help them understand their condition and the options available. It is a role dedicated to patients, and one that fulfils and challenges, demanding of dedication and determination.

Over the next 20 years, surgical teams can expect to spearhead the transformation of surgical practice with the introduction of new technologies and new ways of working. To maximise the benefits of the future of surgery, the training of the surgeon and the surgical team needs to change. Medical professions and the healthcare system must prepare for the future, and nurture innovation in current and new generations.

The future surgical professional

Some might imagine a future where an array of more sophisticated treatments will make surgeons redundant. The evidence received by the Commission suggests that the need for surgical professionals will not disappear. No technology will eliminate the importance of the surgeon's 'human touch' and the relationship with the patient, and new therapies will continue to require surgical skills for their delivery. The therapeutic toolbox of the surgeon will become larger and extend across different disciplines, while knowledge, humanity and empathy must guide its use.

At present, the public generally consider a surgeon to be a trained professional with great specific skill and experience who performs a difficult intervention that usually involves making an incision in the body. This traditional role is likely to remain unchanged over the next 20 years for areas of surgery little affected by direct technological change. For example, a surgeon performing joint replacements is unlikely to see their role significantly changed, even with evolution in instruments or techniques.

In other areas of medical intervention, however, the role of the surgeon is likely to become increasingly blurred with that of other clinicians and health professionals. This will particularly be the case in conditions or anatomical areas where non-surgical interventions become increasingly preferable.

This is already happening in some surgical specialties like cardiothoracic surgery, neurosurgery, vascular surgery and urology. In such circumstances, the surgeon may perform surgery less often, with more time spent on diagnosis, non-surgical interventions and the care of the patient before and after an intervention.

Case study: urology in 2018

The modern day urological surgeon provides a useful challenge to the public perception of a surgeon as someone who simply performs an intervention that cuts the human body. A urological surgeon may spend the majority of their time involved in diagnosis, using non-surgical interventions and performing surgical operations on a relative minority of patients.

A patient with prostate cancer for instance may opt for different forms of radiotherapy, surgery (radical prostatectomy), high intensity frequency ultrasound treatment, cryotherapy, chemotherapy, hormone deprivation, combinations of these treatments or no intervention at all – often depending on how much their cancer has spread. Modern day urological surgeons can be involved in all of those options, as well as providing care before and after the intervention.

However, other health professionals may also be well placed to deliver some of these treatments. For example, an oncologist can prescribe or deliver drug treatments, while an interventional radiologist can deliver radiotherapy or ultrasound treatment. Similarly, a physician or a non-medical professional could follow the patient before and after any intervention. Uncertainty may ensue in some hospitals as to which professional is to deliver each intervention.

This blurring of the boundary of the surgeon's role raises a number of questions:

- What exactly will be the role of the future surgeon and what interventions will they perform?
- How will surgical training best be delivered?
- To what extent will surgeons be involved in the pre and post-operative care of a patient?
- Is it necessary for a surgeon to perform every type of intervention, or can some procedures be delivered with the same clinical quality and more cost-effectively by another health professional?

The Commission believes such questions will need to be carefully considered across different specialties. There are no easy answers. However, the important clinical issue is what will most benefit patients, and not whose professional territory it should be.

What is clear is that the role of the surgeon will become increasingly multifaceted and blurred with that of other professionals. The future surgeon will need to be prepared to adapt to what the patient needs, and the nature of their role may change markedly over the lifetime of their career. Surgeons will, therefore, need to become 'multi-linguists', speaking the language of medicine, surgery, radiotherapy and bioengineering, but also possess leadership, managerial and entrepreneurial skills. In some cases, the surgeon may coordinate interventional care and act as the conductor of the surgical team, but in other instances they may play the role of the first or second violin, or perhaps may not be on stage at all.

For example, the extension of genomic medicine will add more dimension to the role of the surgeon. With genomic testing available to more patients for a wider proportion of conditions, surgeons will assume an even greater role in acquiring tissue for testing, in diagnosing disease and assessing risk within the multidisciplinary team and as the primary health professional to discuss the implications of genomic testing and diagnosis with patients.

Greater collaboration across medical disciplines will be necessary to plan and deliver the best interventions for the patient and support them through recovery. The Royal College of Anaesthetists suggested that anaesthetists will increase their focus on peri-operative care and become peri-operative care physicians, following patients before, during and after a surgical intervention using a range of new technologies to collect data to track and monitor progress.[113] Patients would therefore benefit from even closer collaboration between surgeons, anaesthetists and other team members in planning interventions and ensuring the delivery of the best care and follow-up after surgery.

> "The future surgeon will need to be prepared to adapt to what the patient needs, and the nature of their role may change markedly over the lifetime of their career."

A multidisciplinary team approach to the delivery of surgical care

The demand for surgical interventions will remain high, whether these are similar to existing operations in an ageing population, risk-reducing procedures or entirely novel interventions. As a result, members of the wider surgical team are likely to take on a greater role in the delivery of small procedures and diagnostic interventions, and in their relationship with the patient. The Commission believes that the role of the wider surgical team[113] will increase in importance for three main reasons:

1. Some technologies will make it easier for selected team members to perform an increasing range of tasks, including some types of diagnostic interventions or operations. These are likely to be performed under the coordination of the surgeon, providing roles and appropriate regulations are defined.
2. The increased attention to pre and postoperative care, as our understanding of their impact on a patient's outcomes improves, and more patients will present increasingly complex clinical needs.
3. Financial constraints, increased demands from an ageing population and limits on the number of surgeons available due to length of training time will necessitate a wider range of staff.

Roles and responsibilities within the wider surgical team will need to be defined and established, with frameworks for supervision, regulation and accountability. To deliver multidisciplinary interventions that are personalised and focused around the patient, it will be important to break down the historic barriers across disciplines.

Using AR to enable real-time multidisciplinary team collaboration in the delivery of surgical care – Proximie©

Using digital platforms inside the operating room can help connect clinical experts and trainees across distant locations. Proximie© is a digital platform that enables the delivery of improved care, irrespective of the patient's location, by connecting all of the experts in one place at one time, enabling them to collaborate via visual and auditory tools.

Using the telesurgical collaboration platform with AR, surgeons and multidisciplinary teams – including the radiologist, trainee surgeons and oncologists – can discuss a case in real time. This approach can save time, travel and resources, while enabling surgeons in training to learn and engage with the surgery and review it after the event for further training.

Figure 7: Proximie© platform (Image credit Proximie©)

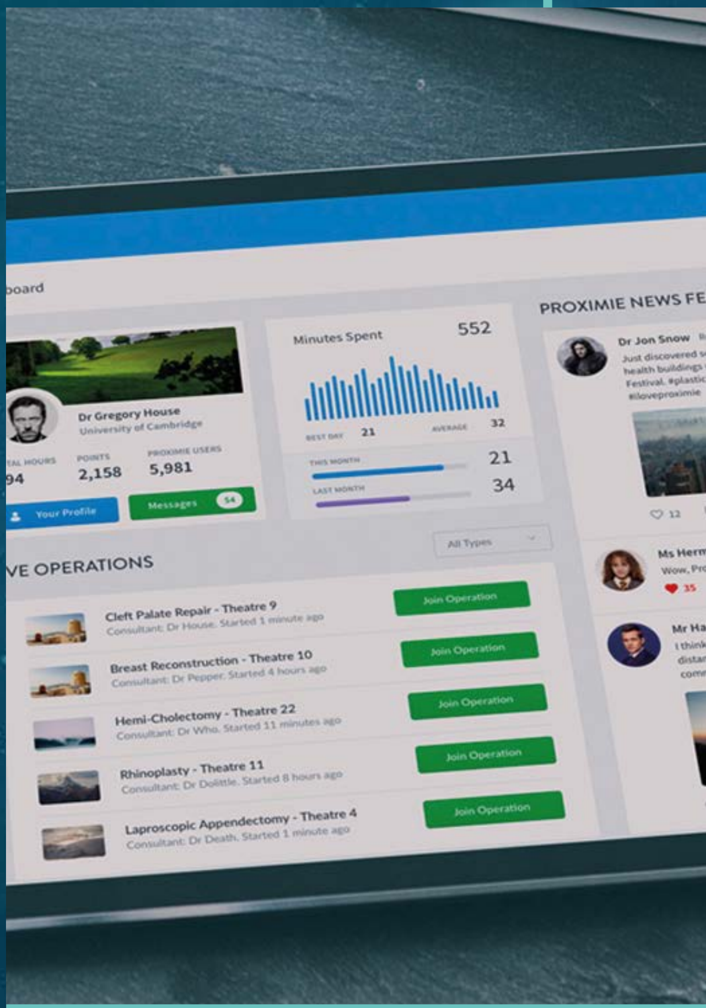


Figure 7

If a greater role for members of the wider surgical team is part of the answer to meeting increasing patient demands while maintaining high standards, two aspects will need consideration: training and regulation. The Commission believes that there is immediate scope for the education and training pathways of members of the wider surgical team to share some commonalities with the general training of medical professionals, including not only clinical skills, but also professional behaviours and human factors. For example, integration of the Generic Professional Capabilities framework into healthcare training could provide a baseline. This framework was developed by the General Medical Council in partnership with the Academy of Medical Royal Colleges in 2017 and signifies the move towards outcomes based curricula.[114] Similarly, simulation training should involve all members of the extended surgical team at the same time, with feedback offered to the whole team encouraging team building and commonality of purpose.[115]

> "Operating theatres are already changing to incorporate new technologies. For example, 'hybrid theatres' incorporating imaging facilities – such as x-ray, CT and MRI scans – are already being introduced across the UK."

If surgeons and members of the wider surgical team are to perform some of the same interventions, it is essential that such roles be appropriately regulated, both to protect patients and to enable some of these procedures to occur. For example, physician associates are currently unable to order x-rays or prescribe medications due to lack of regulation. The Commission welcomes the recent announcement by the Secretary of State for Health and Social Care of the introduction of a regulatory framework for roles that are currently not regulated. However, greater clarity is still needed in the definition of the roles that fall under the new regulatory framework, including extension of these regulations to surgical care practitioners.

The surgical team in the digital age

The surgical team of the future will use new technologies in a digitally integrated operating room. Operating theatres are already changing to incorporate new technologies. For example, 'hybrid theatres' incorporating imaging facilities – such as x-ray, CT and MRI scans – are already being introduced across the UK. The digitisation of surgery will result in the ongoing need to re-design operating theatres to integrate digital technologies such as new imaging systems and robotic devices, account for new dynamics among the surgical team and accommodate a modified flow of work inside the operating theatre.

Imaging

More advanced pre and intraoperative imaging systems will enable the delivery of less invasive interventions with greater support. Live telesurgical support with AR platforms and intra-procedural guidance could superimpose over the patient images taken before and during the procedure to guide the surgical team. The integration of 3D imaging and patient data will also enable the creation of more accurate patient-specific models for surgical planning.

Digital platforms

Digital tools using AR and simulation training can already help the surgical team to train together and rehearse the steps of a procedure before entering the operating theatre. Advanced simulation platforms could collect data about learners and tailor subsequent areas of education and training, with the potential to improve future teaching and learning techniques and tools. Digital platforms could also help to avoid skill deterioration and re-train established surgeons according to emerging need or changes in surgical treatment. Furthermore, digitally integrated operating rooms could soon include systems providing medical knowledge and information in real time. Whole-team simulation training may be of particular interest for trauma surgery by simulating scenarios such as mass casualties or war zone settings. Remote mentoring and specialist support through the use of AR and enhanced imaging digital platforms may have an impact on emergency surgery, by enabling patients to undergo specialist emergency surgery in remote areas.

AI and data

The use of AI mechanisms incorporated in the digital operating theatre and delivered through visual or auditory cues will advise the surgical team about steps to follow during the procedure or warn them of possible risks. Access to data and data analytics platforms will enable the surgeon to deliver more personalised interventions.

> "The use of AI mechanisms incorporated in the digital operating theatre and delivered through visual or auditory cues will advise the surgical team about steps to follow during the procedure or warn them of possible risks."

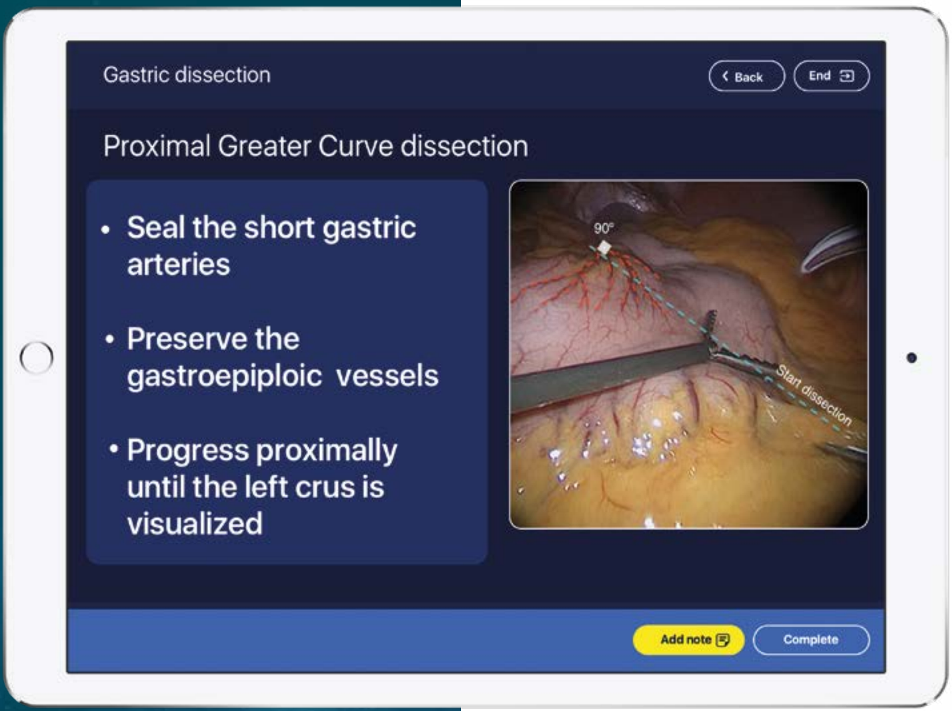


Figure 8

Digitally integrated teams and operating rooms – GoSurgery

The flow of information during a surgical procedure is critical for many reasons. Multiple studies have shown that team communication, or lapses thereof, is the root cause of sentinel events in surgery.[116] Aside from the quality and safety perspective, optimised information flow can help to make surgeries and time in theatres more efficient. Every minute in the theatre per surgery is estimated to cost the NHS £20.[117]

GoSurgery, from Digital Surgery™, uses AI to ensure that the right surgical process information is displayed to the right surgical team member, at the right time, during the procedure. Advanced AI algorithms interpret and understand surgical phases, automating the delivery of crucial information, tailored specifically for the end-user to ensure consistent surgical delivery and teamwork.

Early data collected by Digital Surgery™ at some NHS sites showed that surgical teams, including scrub nurses and agency staff, felt more prepared and better able to anticipate coming steps as a result of having access to GoSurgery, while surgical trainees deemed it an invaluable part of their training process.[118]

Figure 8: GoSurgery app (Image credit Digital Surgery™)

Will the machines take over? AI and surgery

Recent technological developments and breakthroughs in machine learning and robotics often leave us wondering whether machines will replace humans, or which tasks machines will take over and when. AI has the power to transform different areas of human activity.

A recent McKinsey report[119] on the potential for automation across different sectors and activities found that health and education are the sectors where machines are least likely to take over from humans soon, due to the applied expertise and crucial need for human interaction. A study in 2013 on jobs susceptible to computerisation argued that perception and manipulation – two key skills for surgeons – remain the biggest challenges to robotic computerisation and are unlikely to be solved in the immediate future.[120]

Although AI will be increasingly used to find solutions to specific replicable problems, it seems highly unlikely that it will entirely replace surgeons in the near future. A robot able to perform an entire surgical procedure autonomously and handle the unpredictability of its possible complications appears as a distant possibility.[121] The direction of travel is more likely to be one where robots and surgeons work in closer partnership, one making up for the limitations of the other. Of course we must not forget that a surgical robot is simply a tool to improve delivery of surgical therapies.

In the more distant future, AI could undertake low-level surgical task automation and high-level recognition of macro trends. Furthermore, it might be possible for surgical robots to learn directly from surgeons. If a system could be created to observe how skilled surgeons operate and gather accurate data, semi-autonomous robots could start simple operations from these data sets. Learning from increasing amounts of data would then be a matter of time.[122]

Robots learning from surgeons

The proof of concept for such mechanisms is not distant. For example, Professor Guang-Zhong Yang and his team at the Hamlyn Centre at Imperial College London are investigating new techniques for providing synergistic control between the surgeon and the robot. In 2006 they pioneered the concept of 'perceptual docking', a novel approach aiming to achieve a seamlessly shared control between the surgeon and the robot, with the latter gaining knowledge from the surgeon's motor and perceptual behaviour through location-specific sensing.[123]

The centre is also exploring safer ways to provide cooperative control between the surgeon and the robot. If robots are able to perform certain surgical tasks autonomously under the supervision of the surgeon, they can gain knowledge through the use of learning-by-demonstration, rather than pre-programming. This might also help to create dynamic active constraints to prevent the surgeon from reaching forbidden anatomical regions.[133]

Genomics in surgical practice

With routine access for patients to a genomic medicine service, it will become increasingly important for surgical professionals to have the knowledge to interpret and contextualise genomic information, and understand the ethical implications of genetic testing. Surgical skills could be refocused earlier in the cancer pathway, as more disease is prevented, predicted or subject to intervention at an earlier stage.[56]

Surgeons will have a fundamental role in:

- **Correctly acquiring tissue for DNA testing:** Several contributors raised concerns about the lack of knowledge of correct methods to acquire and store tissue to allow accurate testing.
- **Understanding and interpreting the results of genomic testing:** Although more collaboration with geneticists is likely to take place, surgical teams will still need a good understanding of molecular analysis and genomic medicine to interpret test results correctly, and understand the differences between acquired genetic alterations in tumours and inherited genetic variations.
- **Stratifying risk:** Surgeons will need to be able to assess risk accurately, to contextualise it and stratify the population according to it, with the aim of aiding surgical decision-making within the multidisciplinary team.
- **Communicating risk to the patient:** Surgeons will have an important role in discussing genetic risk with patients in a manner that is easily understandable, as well as its interaction with environmental factors associated with somatic mutations and epigenetic changes. Information uncovered by genetic testing will have implications on the consent process and a surgeon's duty of care, not only towards their patients but also towards patients' families.
- **Supporting patients' decisions about treatment:** Surgeons will have a role in supporting patients in decisions about their care by helping them to make sense of a complex array of information.
- **Working within the multidisciplinary team:** Surgeons will need to work as part of a multidisciplinary team to assess risk, diagnose patients and advise them about treatment or prophylactic interventions. Caution should be exercised to avoid advertising genetic medicine and prophylactic surgery as a panacea for cancer until a comprehensive evidence base has been built.[35,56]
- **Leading in the integration of genomics in surgical practice:** As more action will be taken centrally to increase the reach of genomic medicine, further connection will be needed in the short-term between more advanced centres – often resulting from the leadership of individual surgeons – and centres that have been slower in uptake.[35,56]

Although some resources are already available for the delivery and planning of genomic medicine education,[XIII] the Commission believes that genomic medicine should be further embedded in medical education, surgical training and continued career development.

Impact of new technologies on transparency and litigation

Individual consultants' outcome data are already published for many surgeons and some procedures. Transparency about outcomes should increase, as more data become available to surgeons, hospitals and patients. The increased availability of data, the enhanced role of patients as managers of their own health and the ability of digital platforms to collect data about procedures will result in increased transparency about surgical outcomes and therefore enhanced audit.

The use of AI, however, could muddy accountability, with risks for patients if surgeons were to blame mistakes on technology, or for surgeons if patients blamed them for the outcomes of untraceable decision pathways of AI technologies or technical issues. This may generate momentum towards explicable AI mechanisms as opposed to the current concept of 'black box', defining the lack of interpretability of some AI decision-making pathways.

The use of new technologies may present a heightened risk for litigation that will need to be managed. In particular, the supported decision-making and consent process will require to take into account the impact and role of the technologies used, while guidance will be important to help patients interpret the vast array of data that will become available about surgeons and procedures. At the same time, the data analysis may help to reduce mistakes, lowering the risks of litigation.

> "Blockchain technology, if combined with AI mechanisms, might have the potential to present a solution to transparency, data security and accountability issues."

Blockchain technology, if combined with AI mechanisms, might have the potential to present a solution to transparency, data security and accountability issues. Blockchain, initially invented as a ledger to record economic transactions of digital currency, is a shared, decentralised and open ledger that records transactions in a verifiable way, as these cannot be altered retroactively without permission of the entire network.

Developments of such a system and its application to healthcare might detail a clear pattern of accountability and ensure the integrity of transactions of healthcare data. By making healthcare data transactions more transparent across the entire network, the network itself could become the shared authority monitoring the use of data. Nonetheless, caution should be exercised in viewing this technology as the solution to healthcare interoperability issues, as important barriers remain to be addressed. These include the heterogeneity and complexity of health data that make exchanges across institutional boundaries cumbersome, as well as ethical and regulatory implications related to security, confidentiality and patient trust issues.[124,125]

XIII For example, HEE funds courses in genomic medicine for England-based clinicians and provides online learning resources; the AoMRC established a genomics group chaired by Professor Dame Sue Hill to devise a concerted approach among royal colleges to genomic education; and the Welsh government is planning for the delivery of further genetic training posts assessing the genomic medicine training needs of the healthcare workforce.

The current demographics of the surgical workforce

13,482
Consultant surgeons

12%
Female surgeons

1/3
of surgeons in training are women

The current population of surgical consultants is predominately male. In 2017, there were 13,482 consultant surgeons registered in the UK.[XIV] Female surgeons represent only 12% of the current consultant surgical workforce, making surgery the most heavily male-dominated medical specialty. From 2012 to 2017, the GMC registered an almost 50% increase in the number of female surgeons.[126] Women now represent almost a third of surgeons in training, although there is a high attrition rate as specialty training progresses. While this gender difference is likely to change, greater progress remains necessary to ensure all talent is encompassed within the future workforce. The Royal College of Surgeons' Women in Surgery group suggested that some of the reasons driving the gender difference include different experiences of men and women throughout medical school and foundation training, reducing women's participation in surgery. The group also suggested solutions such as phased return to full practice from maternity leave and portfolio careers to reduce attrition in career pathways.[127-128]

The surgical training programme was characterised by the lowest proportion across medical specialties of less than full-time working (4%),[XV] possibly reflecting a more difficult work–life balance than in other medical disciplines.[XVI] Surgeons in training are facing a number of challenges that need to be addressed.

Although gender diversity is lacking, the surgical workforce is more diverse in terms of nationality and race. While 60% of surgeons are UK graduates, 40% of consultant surgeons are from the EU and rest of the world (19.3% and 20.7%, respectively).[129] This is one of the highest proportions of any medical specialty.

The UK has, however, one of the lowest numbers of surgeons per head of population in Europe, and creating the correct workforce involves addressing a number of short and long-term issues. If the UK becomes a less attractive destination for worldwide talent, planning would be necessary to ensure an appropriate supply of surgeons from UK medical schools and postgraduate training schemes. If we continue to encourage and rely on talented individuals from around the world joining the UK medical workforce, it will be important to ensure that these surgeons are sufficiently supported and trained in the use of new technologies if these are not available in their home countries.

XIV Surgeons on the GMC specialty register.
XV Although current initiatives for flexible working and training are aiming to address this.
XVI Surgeons on the GMC specialty register.

Surgery has traditionally had significant numbers of its workforce working in non-consultant career posts. These surgeons have been major contributors to service provision, but have often not been considered in workforce planning, with potentially detrimental effects on career progression and job satisfaction. The GMC plans for credentialing include how Specialty and Associate Specialty (SAS) doctors might have existing skills and competences recognised and be able to make more specific contributions to the service.[130] This could also be used to progress and gain equivalence to specialist recognition. The support for such progression needs a defined structure similar to that for formal training but also must be similarly quality-assured to ensure the same standards for overall confidence and patient safety.

The Commission believes the surgical royal colleges, working with medical education bodies in all UK nations, need to review what support and training is provided to mid-career surgeons with regard to new technologies.

How will training and career pathways need to change?

To reap the benefits of innovations in medicine and technology and to guide their development, the surgical workforce of the future needs to be equipped to drive and deliver innovative surgical care. The Commission believes that there is a unique opportunity now to shape surgical education, training and career pathways that are fit for the future. The report has discussed a shift towards a multidisciplinary team approach. As a result, greater flexibility, variety and deeper collaboration across disciplines should characterise new training and career pathways. Understanding established and emerging technologies will need to be enshrined throughout education, training and continued career development.

The Commission recognises the importance of the current structure of surgical training, from foundation years, through core training, to specialty training culminating in the acquisition of a certificate of completion of training and entry onto the specialist register. This structure will continue to form the backbone of surgical training. However, credentialing mechanisms could be used to acquire further knowledge and skills not covered by existing curricula, both after obtaining the certificate of completion of training and as mid-career training, enabling surgeons to demonstrate their proficiency in the use of new technologies and techniques.

However, as information is increasingly available and accessible, the Commission believes that further reflection in the design of medical school education, surgical training and career pathways should focus particularly on the following principles.

Building on knowledge acquired in previous education and training, rather than repeating modules

Surgeons in training contributing to the Commission argued that medical students, foundation trainees and surgical trainees have been getting progressively less surgical exposure and experience, resulting in surgical skills often being acquired too late in the training or career pathway.[131] Pressures on the healthcare system often require the surgeons in training to deal with the most urgent challenges in the hospital, leaving little time for learning in the operating theatre while further straining an already difficult work–life balance.

Throughout different stages of education and training, students and trainees are often asked to undertake similar or overlapping modules. As knowledge and information is increasingly available online, the Commission believes that there is an opportunity to avoid repetitions and ensure that further stages of training build upon practising knowledge previously acquired.

Providing greater team-wide human factors training

The Commission believes that greater emphasis should be given to human factors training, with particular attention to communication skills.[XVII] As the complexity of information available and the sophistication of technology increase, the ability to communicate information and risk to patients and to interact effectively within the surgical team will gain even greater importance.

Teaching communication skills should include training all surgical professionals in the process of supported decision-making. This should include learning skills to activate patients and tailor support to individual patients to enable them to take a more active role in their health and care.

Human factors training and training in the use of new technologies for the operating room should not be limited to the surgeon. All members of the surgical team should be trained in the use and functioning of new technologies, as these may change the flow of communication among the team and in some cases even improve it, by requiring whole team rehearsal of procedures.[125]

> “Teaching communication skills should include training all surgical professionals in the process of supported decision-making.”

XVII As included in the General Professional Capabilities Framework.

Human factors training: the Royal College of Surgeons in Ireland

It has been estimated that only 25% of the important events that occur during a surgical procedure are related to manual or technical skills and that 75% relate to human factors such as decision-making, communication, teamwork and leadership.[132] Other human factors that are important in medicine include self-awareness (ie insight), conflict resolution and error management. With appropriate training, individuals can improve their personal skills and thus function more effectively as part of the multidisciplinary team in which all doctors work today.[133-134]

For example, at the Royal College of Surgeons in Ireland a programme of training in Human Factors in Patient Safety principles is a mandatory component of surgical, ophthalmology and emergency medicine training for those at junior and senior levels of training. This programme is assessed at the end of each academic year. An academic degree in the form of the MSc in Human Factors in Patient Safety is also available. In addition, non-consultant hospital doctors currently not on training programmes have access to a Personal and Professional Development programme in Human Factors in Patient Safety.

Training sessions use a combination of didactic and action-based learning teaching methods. Classes are kept to a maximum of 25 attendees to allow for simulation and practice. Emergency medicine, ophthalmology and surgical trainees attend sessions together which stimulates multidisciplinary communication. Sessions are facilitated by a clinical psychologist/senior lecturer and a consultant in surgery, ophthalmology or emergency medicine.

Encouraging opportunities to diverge from the traditional surgical training pathway

Current training and career pathways are often too rigid, allowing very limited possibilities to diverge from traditional routes. Medical students, surgeons in training and later consultants should be given the opportunity, and the appropriate recognition and support, to step on and off from their training or career pathways to do clinical research and research in the laboratory, develop innovations in industry, work with engineers, teach, develop leadership or managerial skills, or practise in other healthcare systems abroad.

Undergraduate medical education and postgraduate surgical training need to attract people from diverse backgrounds and skillsets to the profession, including mathematicians, engineers, technology experts or psychologists. Greater connections will be necessary between surgeons and engineers, technology experts, scientists and industry to design and develop innovations.

Encouraging flexibility throughout training and career pathways and ensuring mid-career re-training

Medical students and surgeons in training should develop transferable skills and knowledge to move across medical disciplines and specialties throughout their training and career if they so wish.

The General Medical Council and the Academy of Medical Royal Colleges are already moving in this direction, and commissioners welcome their efforts towards more flexible postgraduate training and easier transfers between specialties. All medical disciplines, royal colleges, professional associations, and educational and regulatory bodies need to work together to describe how this could take place. Changes to medical education and training must be implemented in unison across medical disciplines given the inherent interdependencies.

The traditional model of the career of a consultant surgeon is evolving and reflecting service requirements, extended roles and societal changes. There will always be those who wish to pursue a clinical career, but others will wish to combine their clinical practice with a variety of other options including education, research, leadership, management and entrepreneurship. This portfolio-based career with a more flexible approach requires opportunities for the development of new skills, allowing doctors to change career direction or enhance their expert skills.

In this context, new GMC proposals for credentialing are intended to facilitate career movement, access to training in new areas and recognition of skills in areas of development different to their original training.[141] This will allow the specialties to train consultants in new areas more quickly as service needs change.

Given the pace of innovation and change, future surgical professionals will continue to train throughout their career to keep at the forefront of innovation and excellence. As new developments will change the way surgical care is delivered and as types of treatments evolve, established surgeons will need to learn how to use new technologies throughout their careers. It is essential that mechanisms be in place to encourage consultants to keep up to date and that systems are available to facilitate re-training. New surgical interventions – such as regenerative medicine, tissue engineering or cell therapies – may require surgeons to learn an entirely new suite of skills.[135,136]

Exposing students, surgeons in training and consultants to emerging technologies throughout their career

The Commission believes that technologies must be embedded in the medical and surgical training curriculum and that mechanisms must be developed to ensure consultants are kept up to date and trained in their use. Investment will also be necessary to introduce technologies more widely across training centres and trusts.[137,138] The surgical royal colleges should work – in collaboration with other educational and professional organisations – to enshrine new technologies and innovation development in surgical training. Exposure to emerging technologies and variety in disciplines taught should start at undergraduate and early postgraduate level to allow surgeons in training to have a broader skillset.

Simulation and online training

Simulation training through digital platforms and technologies such as AR and VR can accelerate and enhance training, and augment experience in the operating theatre. Surgical training is likely to evolve into three key components:

- online training;
- simulation training;
- training in the operating theatre on patients.

With the further development of simulation and online platforms, more time is likely to be spent on building competences and skills before entering the operating theatre.

The use of online and simulation platforms can help democratise access to surgical training, scale up surgery globally and improve patient safety. Digital simulation platforms can build up a language to describe each step of a surgical procedure and form a repository of surgical knowledge, thus standardising surgical techniques and surgical training.[139,140] Existing digital platforms can already enable guidance or remote mentoring inside the operating theatre. Simulation training should not be limited to simulation of surgical tasks, but include human factors and whole-team simulations, as a compulsory part not only of training but of career development and revalidation.

AI will help to create more sophisticated and realistic simulation training that is patient-specific. For example, simulation or robotic platforms could tailor training to each surgeon by analysing data about their previous performance, and help them improve in areas or tasks on which they need further training.

> "AI will help to create more sophisticated and realistic simulation training that is patient-specific."

Case study 1: Fundamental Surgery

FundamentalVR©, a London-based company with offices in Boston, USA, has developed VR surgical simulations with haptic feedback. Fundamental Surgery is a software platform that combines readily available VR hardware with off-the-shelf 3D peripheral, working with any modern PC/laptop. It provides surgeons with the opportunity to learn, rehearse and practise surgical procedures within a safe and controllable space. Feedback about performance and accuracy is available immediately. This allows users to evaluate performance and improve and maintain their skill set. Currently, Fundamental Surgery simulations focus on orthopaedic procedures; however, other areas such as general surgery are currently being considered for development.

Figure 9: FundamentalVR© simulation (Image credit FundamentalVR©)

Figure 9

> "Provides surgeons with the opportunity to learn, rehearse and practise surgical procedures within a safe and controllable space."

Case study 2: Touch Surgery

Digital Surgery™ has produced Touch Surgery, a cognitive task simulation and rehearsal platform, which addresses issues such as the limited training time by digitising surgical procedures in a step-by-step fashion. The platform renders high-quality simulated content against each step and introduces user interaction points, while the product and content are free of charge to end-users. By focusing exclusively on the cognitive decision-making components of surgical procedures and utilising 3D renderings of patients, anatomy and instruments, Touch Surgery allows for iterative and deliberate learning and feedback without risk to patients. The product has been validated by more than 16 independent peer-reviewed publications as an efficacious training tool across 8 specialties – including orthopaedics, general surgery, plastic surgery and neurosurgery – and across both high-income and low and middle-income settings. The library of simulated surgical content is the largest of its kind, containing more than 200 procedures.

Figure 10: Touch Surgery app (Image credit Digital Surgery™)

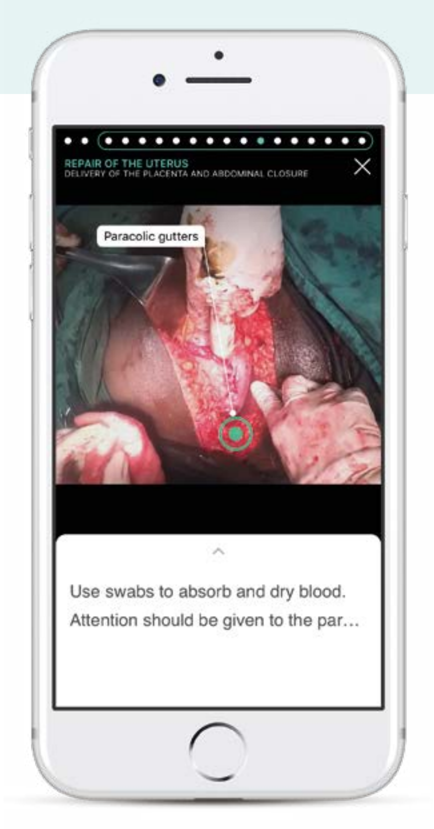


Figure 10

"The library of simulated surgical content is the largest of its kind, containing more than 200 procedures."

Case study 3: Pearson Education Mixed Reality learning tool

Pearson Education developed a mixed reality (MR) learning tool called HoloPatient. It aims to introduce more opportunities for medical trainees to develop clinical language, observation and assessment skills in a safe and controlled environment. Using readily available MR hardware, the user can interact with the hologram as they would with a real patient in real-world scenarios. Unlike VR, MR allows the projection of 3D immersive holograms by overlaying data and images onto the physical world. Developed for nursing and allied health, this tool brings the standardised patient to almost any environment. The interactions between the HoloPatient and the user are assessed in real time and the outcomes are based on the data collected and made available immediately.

Figure 11: Pearson MR tool (Image credit Pearson)

Figure 11

> "The user can interact with the hologram as they would with a real patient in real-world scenarios."

Improving the teaching of biomedical sciences and including traditionally ‘non-medical’ disciplines, such as engineering and computing

The Commission believes that the study of genomics, stem cell biology, data analysis and uses of AI would add great value to medical education and surgical training, with a small modification to the curricula. The offer of a wider range of disciplines, including engineering and computing, would give students and surgeons in training the opportunity to tailor their curriculum and start developing knowledge and expertise in specific areas of interest, should they wish to undertake further specialised training later in their career or engage in the development of innovation.

Retaining open surgery skills

As developments in technology enable less invasive interventions and more sophisticated support to the operating team, caution should be exercised in over reliance on increasingly autonomous surgical instrumentation. Despite such developments, the need for open surgery is unlikely to disappear, particularly in emergency situations. It is necessary for surgeons to retain the skills to be able to perform open surgery and operate without the support of machines in case of malfunctions. Emergency and open surgery training should be provided across all relevant specialties in parallel with training in other minimally invasive techniques.

Personalised learning through data sharing

Surgical training is supported by a number of different digital learning products, systems and platforms, which produce a staggering amount of valuable data. While an increase in learning data is promising and offers a huge potential for adaptive and more impactful learning experiences, the value of big data is largely underutilised in postgraduate medical training. The key issue is that data cannot be shared freely between systems, which leads to duplications, inefficiencies and less flexibility.

To bring together data from a wide range of disparate systems and to increase the quality of training opportunities, the US Department of Defense's Advanced Distributed Learning Initiative designed the Total Learning Architecture framework.[141] This framework created a common language to set standards for the interoperability of learning technologies, offline and online. The output of the framework is called experience API (xAPI).[142] Through xAPI, a person's learning experience can be captured and a meaningful output produced. It supports an organisation to identify learning needs and gaps against required capabilities, and thus builds new evidence-based interventions and validates development material more effectively. These learning experience platforms have been put into practice widely in many blue-chip companies.

In the UK, the NHS and Health Education England (HEE) piloted a scheme in 2013 to understand what kind of training would have the greatest impact to improve the care and safety of people with dementia. By capturing learning activities and tracking learning experiences from various online resources and learning opportunities via xAPI, the NHS and HEE gained insights on how well learners performed. They also learnt which training interventions had the greatest impact and how those could be adopted to suit the needs of the individual learner, as well as the team. As a result of the pilot, the nurses who took part in the study 'were more self-aware of their knowledge following the training'.[143]

The use of xAPI is likely to become an integral part of learning solutions across medical educational institutions. HEE are in the process of implementing a Learning Record Store to capture xAPI statements from a wide range of systems and digital tools, such as e-Learning for Healthcare. They also recently commissioned an AI-powered digital capabilities tool that learns the user preferences and needs, and sends xAPI statements to learning records services for further developments and tailoring of learning tools.[144]

Understanding and evaluating innovation

As new technologies and techniques are developed every day, surgeons will have an increasingly important role in their rigorous evaluation. Surgeons should be trained in the assessment of evidence and work more closely with statisticians, economists and epidemiologists to evaluate the outcomes and cost-effectiveness of proposed innovations. The surgeon of the future will be required to know how to introduce new technologies, evaluate them and report outcomes for their patients. Efforts should be made to enhance the ability of surgeons to lead and take part in clinical research. Medical schools and colleges will need to create the training platforms for this transformation. Similarly, surgeons will have an important role to improve existing national audits of standard surgical practice and be capable of developing new audits specific to innovations.[145]

Supporting surgeons

The Commission believes that more support is needed throughout surgical training and the entire career pathway. Contributors suggested different mechanisms for support including: pastoral support and mentoring within the surgical community; together with all members of the surgical and ward team, participation in regular sessions – such as Schwartz rounds – to discuss difficult emotional and social issues; the incorporation of stress and challenge coping mechanisms into training; and further development of an online surgical community to support individuals.[146-147]

Support and professional coaching can help surgeons to find their area of interest, deliver innovation and thrive throughout their career.[148] It is often in the professional culture of surgeons to innovate and to improve outcomes, patient experience, procedures or themselves. This feature should be nurtured and made an established part of the surgeon's role.[149] The success of programmes such as the NHS England Clinical Entrepreneur Training Programme should be built upon to give surgeons who want to develop innovations professional coaching, recognition and an umbrella under which to develop their ideas.

Professional associations, including royal colleges, should support such programmes and act as a link between surgeons through networking events and workshops between industry and surgeons interested in innovation, or hold events such as 'hackathons' to stimulate innovation development.

Formally recognising and rewarding surgeons in training for the development and delivery of innovations will nurture new development. Trainers and mentors need full recognition in the academic environment and in the workplace.

Royal surgical colleges should take the opportunity to work now with national stakeholders, educators, medical schools and other medical royal colleges to identify and implement changes in the current curriculum. Due to the long implementation time, changes agreed now would enable the workforce of the next 20 years to be prepared to deliver the surgical care of the future.

In summary: preparing the surgical workforce of the future

The surgeon's role in a new system

- The role of the surgeon will be increasingly multifaceted and will change depending on the nature of the intervention delivered. Surgeons will need to become 'multi-linguists', speaking the language of medicine, surgery, radiotherapy and bioengineering, and working with experts from other fields of knowledge.
- Surgeons will also need to possess leadership, managerial or entrepreneurial skills.
- Many procedures will still require surgeons to maintain their traditional role, while using a new suite of technologies or therapeutic tools to enhance care.
- Where non-surgical interventions become increasingly preferable, the role of the surgeon is likely to become increasingly blurred with that of other physicians and health professionals.
- The need for the 'human touch' of the surgeon and her/his technical skills will not disappear.
- Surgeons will have greater involvement and responsibility in the evaluation of the effectiveness of new technologies and interventions. Surgeons will play a particularly key role in genomics, collecting and managing tissue samples, and often being the first medical professional to discuss genomic analysis with a patient.
- The role of the wider surgical team will be expanded, as its members will deliver further elements of surgical care.
- The surgical team in the digital age will use tools such as surgical robotic platforms, enhanced pre and intraoperative imaging, AR or MR, AI, data analytics, and 3D planning and printing. Digital technologies will enable patients and surgical teams to access experts from across the globe.
- New technologies will further increase transparency about surgical outcomes.

Surgical training throughout the career

- Education and career pathways need to be more flexible, varied and multidisciplinary.
- Further effort in the design of medical school education, surgical training and career pathways should:
  - Build on applying the knowledge acquired in previous education and training, rather than repeating modules, such as basic sciences. This could allow further focus on acquiring surgical skills.
  - Provide greater team-wide human factor training, especially how to communicate within teams and to patients.
  - Encourage opportunities to diverge from the traditional surgical training pathway.
  - Encourage flexibility throughout training and career pathways and ensure mid-career re-training.
  - Expose students, surgeons in training and consultants to emerging technologies throughout their career.
  - Improve the teaching of molecular biology, including traditionally 'non-medical' disciplines such as engineering and computing.
  - Retain open surgery skills.
- Further support for surgeons throughout their career is needed through mentoring and professional coaching programmes.

WIDER IMPLICATIONS

This report has outlined the advances in technology, medicine and science that will have a profound impact on patient care and on the work of surgical professionals. The delivery of surgical care over the next 20 years will require changes in the way we plan and organise it, the way we regulate surgical professionals and how we fund, develop and deliver innovations.

From digital technologies and big data to genomics and regenerative medicine, these innovations offer the opportunity to transform surgical healthcare by enabling a shift towards prevention, prediction, early detection and personalised treatment. This section discusses some of the wider implications of these technologies including the process for their introduction, financial implications, the organisational delivery of care, the way we support innovations, ethical implications and concerns around health inequalities.

Organisational implications

Locally and centrally delivered surgery

As the provision of care depends on the burden of disease, the needs and wishes of patients should ultimately guide the organisational delivery of care. One of the biggest debates in surgery is the extent to which complex or specialised interventions should be centralised to improve outcomes, and the sustainability of what might otherwise be a small surgical team. The argument has to be balanced with patients wanting to be able to access care close to home, without the cost and time of travelling to more distant hospitals. This can be particularly important for older people who may be too frail to travel long distances or wish to be close to relatives and friends during their hospital stay, as well as for people on low incomes and those with caring responsibilities. Older people are also more likely to live outside metropolitan areas and this trend is set to increase.[150]

Bringing care closer to the patient is not just a way of meeting their expectations, but can also reduce geographical variation in provision and improve the accessibility of care. High-volume procedures such as joint replacements, cataract surgery and cholecystectomy will need to continue to take place at a local level.

With the current drive for integrated health and social care, it is important that new and existing surgical units are well integrated with community care and the wider welfare state, especially in the context of more patients living longer with chronic disease. Examples of closer working between services – such as the 'DevoManc' model in Greater Manchester or the first integrated care systems in England – are leading the way to better integrated health and social care services.

In those specialties where this is feasible, consideration should be given to the separation of elective and emergency surgery, the benefits of which include not only protecting elective waiting lists from being cancelled when pressures on emergency departments are high, but also protecting surgical exposure and teaching for those in training. The *Getting it Right First Time* project in England has already recommended this approach for orthopaedic surgery, and it seems likely that a similar model will be applied to other specialties.[151]

What will drive centrally delivered surgery?

Highly specialised treatments, such as bioengineered therapies, will need to be delivered in a few locations, reflecting cost and the need to concentrate multidisciplinary teams with appropriate expertise. There is evidence that patients are happy to travel for highly complex surgery if they anticipate benefits in terms of outcomes for their care.[152]

Centrally delivered care needs to be carefully planned. The purchase and location of some innovations, such as earlier generations of surgical robots, have historically been poorly organised across the UK. The UK healthcare service and clinical commissioners, working with the surgical royal colleges, need a clearer and better coordinated system in place for purchasing devices and planning the provision of new interventions to ensure widespread access to innovations across the country, reduced variability in the devices available and cost-effectiveness of the devices purchased. On the basis of the evidence on effectiveness and cost-effectiveness, NHS England should initially lead a strategy to help the NHS plan and purchase new surgical robotics systems.

What will drive more locally delivered surgery?

Technology could enable greater remote support allowing the development of networked surgical delivery teams, so that some treatments are delivered closer to patients. For instance:

- Digital applications, mobile phones and AR could help deliver remote care. Platforms with enhanced imaging and AR tools can enable remote mentoring and support, with specialists remotely directing the work of local teams.
- Digital clinics are already widespread and are only likely to become more widely adopted. Their use could help to connect patients with specialists and experts located miles away and deliver care closer to home at the pre-habilitation and follow-up stage.
- The next generation of surgical robots is expected to be cheaper, more intuitive and easier to transport between theatres and sites. Their lower cost will enable more hospitals to purchase them for more common surgical interventions. Distant specialist support could also increase access to expert surgical care in remote locations.
- Developments in robot-assisted surgery and a more reliable internet connection in hospitals could enable telesurgery, with a surgeon sitting at a console in one centre controlling robotic arms in a different location with the support and supervision of a local team. Although there are challenges that still need to be overcome – such as the provision of a safe, reliable and encrypted connection and medicolegal issues concerning the line of responsibility – telesurgery could be an instrument to reduce health inequalities and provide surgical care in remote locations.
- As the ageing population is expected to live increasingly outside of metropolitan areas, demand for care in those areas will also grow.
- Earlier diagnosis leading to earlier and therefore less extensive interventions may also enable more surgical procedures to be delivered in local day or short-stay centres. Some types of surgery could potentially be delivered by highly skilled non-surgeons under the supervision of surgeons, further increasing local access to care.

NHS digital infrastructure

It is clear that hospitals will need to be well-equipped to cope with the digital demands of future healthcare. A recent Freedom of Information request made by the Royal College of Surgeons[153] found that more than 8,000 stand-alone fax machines were present in NHS hospitals in England. Many doctors have difficulty using mobile devices around hospitals due to insufficient wireless capability or mobile coverage. The challenge to upscale the existing digital infrastructure in the NHS must not be underestimated and may be a major barrier to implementing change.

A coordinated IT strategy demands a concerted focus by the health service and government, with leadership at every level, to improve the availability of digital services within hospitals and the wider health service. The Commission welcomes the recent choice of digital innovation by the Secretary of State for Health and Social Care as an immediate priority. This should not be limited to England, but should encompass all UK nations.

Contributors to the Commission argued for the need for a digital infrastructure that allows the safe sharing of data and encourages innovation. Interoperability across systems and the simple ability to share data and imaging of a patient more easily across health organisations is an urgent requirement. Systems that are more user-friendly and use technology to save the time of trained medical professionals are needed to ensure that data are entered and coded correctly.

Staff working within the healthcare system will need to be open to change and receive training in the use of new systems and innovations. Commissioners believe that the achievement of interoperability across NHS systems and the realisation of the conditions to enable and encourage innovation should be viewed as a health priority.

Figure 12

Streams – DeepMind Health

Streams is a secure digital app developed by DeepMind Health in collaboration with doctors and nurses. It aims to address what clinicians call 'failure to rescue', which is when the right nurse or doctor does not get to the right patient in time. To do this, Streams brings together important patient medical information from different hospital IT systems in one place. Clinicians can use the app to spot serious medical issues, check patients' vital signs and make notes while on the move. Streams is currently in use at the Royal Free Hospital in London, where it is helping the timely diagnosis and treatment of acute kidney injury.

Figure 12: DeepMind Streams platform (Image credit DeepMind Health ©Sophie Mutevelian)

Implications for primary and community care

The impact of changes will not only be felt by surgical patients in hospital, but also in primary, community and social care. In particular, digital technologies need to support patients and be interoperable across different care settings so that data and information can be easily shared by patients and staff across organisations.

For the benefits of innovations to reach all patients, it will be important for general practitioners to keep on top of technological change to support patients in their treatment decisions and advise them on developments, such as genomic testing or new cell-based therapies. The increasing importance of peri-operative care to improve patient outcomes will also increase the need for primary and community care to work more closely with hospital-based surgical teams.

As people live longer with multiple chronic conditions, they will need greater access to a wider variety of healthcare services. Multiple uncoordinated appointments can have a detrimental effect on a patient's ability to stay in work.[154,155] Better coordination across the patient journey should extend to all patient interactions with the healthcare system, and the need for single points of contact or care coordinators will increase.

The Commission encourages the Academy of Medical Royal Colleges and its members to discuss in detail the implications of the changes outlined in this report for different care settings.

Financial implications

Will this digital future cost more?

Undertaking a cost analysis of single innovations and making recommendations on overall levels of healthcare funding are beyond the scope of this Commission's work. However, the Commission has considered some of the financial implications of the innovations and changes discussed.

Many of the complex specialised interventions described are likely to have high initial costs due to the rarity of skills and equipment involved and low economies of scale. Undoubtedly, cost will be a barrier to development and adoption of some innovations. The healthcare system is increasingly under pressure for funding, with often competing spending priorities. The current drive for efficiency driven savings is unlikely to disappear, but it risks the NHS missing out on improvements in patient care. Innovations need to demonstrate cost-effectiveness as well as clinical effectiveness if they are to be adopted across the healthcare system.

Some innovations could reduce healthcare costs, particularly where they reduce the complexity or need for surgery. The use of simulation and imaging for training and surgical planning will decrease the need for costly alternative training tools (such as the use of cadavers) and reduce surgical errors, complications and operating times, with efficiencies for hospitals in the form of shorter stays and less litigation. Developments in minimally invasive surgery are likely to make minimally invasive devices more widely available, and, if savings are demonstrated, in turn achieve greater economies of scale. As their use becomes more intuitive, with shorter learning curves, non-surgical professionals might soon be able to undertake more aspects of surgical care or simple procedures, with savings of the surgeon's time and increased labour productivity.

Where should investment be prioritised?

Any financial modelling by clinical commissioners or providers needs to include the analysis of long-term financial effects. At a time when change and innovation move at impressive speed, funding choices cannot rely on short-term analyses. This is not only to ensure that innovations that bring benefits to patients are implemented and available to patients, but that other vital services do not suffer any consequent reduction in their funding.

Important changes to the patient pathway will need system-wide investment in the extension of genomic medicine and the creation of digital infrastructure that enables the collection and analysis of big data to nurture innovation.

Both changes have already required investment and will continue to do so. However, they will revolutionise patient pathways with major societal benefits. The use of both data and genomics might deliver some savings in the medium to long-term, as they will enable better prevention, and early and targeted intervention.

The pathway to innovation

How are surgical innovations currently evaluated?

The history of the NHS is characterised by the development and adoption of innovations that have revolutionised patient care. From the first baby born as a result of in vitro fertilisation to the development of the first computed tomography scan and the world's first liver, heart and lung transplant, the NHS has been an enabler of innovation.[156]

At present, new surgical techniques and devices are sometimes adopted with little clinical trial or long-term follow-up data, making it difficult to objectively assess benefits for patients. Unlike the process required for the adoption and commercialisation of medicines, surgical procedures and devices do not currently need level one evidence – involving high-quality randomised control trials (RCTs). This is partly because RCTs are more difficult to achieve in surgery.

Concerns over the lack of evidence-based mechanisms for the evaluation of surgical procedures and a coordinated adoption strategy for innovation have been raised by numerous contributors.[157-158] The evaluation and adoption of innovations in surgical practice are often left to local innovators and hospitals, resulting in varied approaches and a lack of shared UK-wide data. This may lead to unintended consequences, such as the premature adoption of innovations unready for clinical use on the basis of insufficient evidence or over optimistic views of clinical and cost-effectiveness.

The Commission believes these current arrangements leave the health service poorly placed to evaluate the efficacy and safety of future innovations. They may also hinder wider implementation of effective innovations.

Some attempts have been made to better evaluate surgical innovations, including:

- The National Institute for Health and Care Excellence (NICE) has introduced mechanisms such as the Interventional Procedures Programme to assess the safety and efficacy of interventional procedures and produce guidelines.
- The Medicines and Healthcare Regulatory Agency (MHRA) – the recognised notified body for the UK – ensures that medical devices meet the requirements set out in EU legislation to obtain a CE mark before they can be put on the European market.
- The IDEAL collaboration – an international network of surgeons, research methodologists, regulators and industry experts – has set out phases for surgical device innovations under the principle of 'no surgical innovation without evaluation'.[171]
- The development of statistical techniques such as network meta-analysis which aim to improve the comparison of novel techniques that have not necessarily been compared in head-to-head RCTs.[159]
- Patents and publication counts have been used to measure innovation.[160]
- The development of network based surgical innovation-specific metrics. It has been argued that with the advent of big data only advanced analytical processes – such as machine learning, deep learning, AI, supervised learning and network approaches – can be used to measure innovations effectively.[161]

- Long-term national clinical audits have the capacity to evaluate the effectiveness and cost-effectiveness of innovations and technologies. The use of the National Joint Registry to look at hip prostheses is one recent example.[162]

Although all of these examples present numerous merits, there remains a need for a recognised and established evidence-based mechanism to evaluate innovations in surgery – both devices and procedures – and assess their long-term effects.

A proposed approach

The Commission proposes a new approach to evaluating and introducing novel technologies. The present system where individual hospitals oversee and collect data on innovations, without sharing information, is neither safe nor effective. It prevents national evaluation and the collection of evidence to support wider uptake of devices that benefit patients.

The Commission believes that all innovations should be registered and their outcomes monitored into the long-term, through individual patient tracking to assess safety and efficacy. The surgical royal colleges could have a role in working with other national regulatory bodies such as NICE to support or oversee UK-wide registries that collect data about innovations, their introduction and outcomes.

The Commission's proposal consists of three components:

1. **Central registration:** New procedures and devices should be centrally registered. This would allow their introduction in a controlled fashion and at a scale that is appropriate for evaluation. For example, a low-risk intervention (such as a new skin preparation for surgery) could be released through 20 hospitals for prospective evaluation, but a new biodegradable mesh could be released only at 3 designated units for detailed early evaluation. This would lead to a far more co-ordinated approach following a nationally agreed pathway.
2. **Individual patient tracking:** For devices used in the operating theatre, there are systems already in place that can monitor a specific item using a barcode. Such systems are also used to track patients through theatre. Device codes linked to each patient could, therefore, be introduced into routine practice without establishing new processes.
3. **Longitudinal monitoring:** It is crucial for implantable devices to undergo long-term monitoring. Central registration with independent oversight and review would reassure patients that the data are for their benefit and would not be misused. Such oversight could be provided by the surgical royal colleges. It would allow long-term safety to be established, and, if adverse effects were identified, patients could be tracked and contacted for review.

Achieving this would require a national collaboration, with a searchable database and regular outcome publication. Complete submission of data would be an integral part of the pathway for innovation.

Alongside improved evaluation of devices, there is a need for the Department of Health, the NHS in England, Wales and Scotland, and the Health and Social Care in Northern Ireland to fund the expansion of the currently limited number of procedures for which national clinical audits exist. At present, they cover clinical outcomes for procedures such as joint replacement, vascular surgery, cataract surgery and emergency laparotomy. The Healthcare Quality Improvement Partnership should assess the viability of ultimately establishing a national registry of all procedures.

These changes would bring surgical innovations more closely in line with the way new drugs are introduced. This system should cover both the NHS and independent providers of surgical services.

Enabling innovation

The pace of innovation is increasing and there is a growing volume of impressive medical research in the UK. To continue to deliver innovative surgical treatments and improvements in surgical care, it is essential to ensure the creation of fertile ground for its development and adoption. Some of the issues already mentioned act as obstacles to the innovation process:

- pockets of resistance within some parts of the surgical profession;
- a difficult process to gather evidence;
- lack of a clear process to evaluate and audit innovation;
- lack of funding;
- excessive daily pressures on clinicians that leave no time for innovation development.

Based on the contributions received, commissioners believe that:

- Surgical training pathways should encourage surgeons in training to develop innovation and learn about the evaluation of evidence. This includes closer work with professionals from other disciplines, such as engineering and computing, as well as with academia and industry.
- The process to apply for funding and set up surgical trials should be made less cumbersome to incentivise their diffusion.
- Surgeons, whether in training or later in their career, should be able to access support to innovate in the form of programmes and schemes that give them a platform to develop innovations, grants, appropriate recognition and professional coaching.
- Efforts should be made to introduce a culture in hospitals that is more open to innovation and change, for example by establishing mechanisms that ensure local responsibility for innovation development and implementation and improving digital capabilities.

Further collaboration with industry and support of UK small and medium enterprises (SMEs) will better enable the development of innovations. Industry has a key role to play in funding the development of innovations. British SMEs and start-ups need access to better opportunities for their innovation to be evaluated and, if deemed worthwhile, adopted within the NHS.

An example of innovation: the Urolift™ device

Looking at examples of innovations that have indeed delivered their potential and have been successfully and widely adopted, three characteristics seem to be key:

1. The resulting improvement in clinical outcomes and/or patient experience
2. Their cost-effectiveness compared with other treatments or tools to deliver the same results
3. An effort to value and involve the healthcare workforce in their adoption, and to engage with and focus on patients and the public.

For over 50 years, the traditional ‘gold standard’ approach for the treatment of the enlarged prostate that causes troublesome urinary symptoms that are unresponsive to medical treatment has been transurethral prostatectomy (TURP). However, TURP requires a general anaesthetic, usually an inpatient stay and it can be associated with a range of complications including sexual dysfunction and incontinence. For many years there have been attempts to identify alternative, less invasive treatments for this condition, most of which have not become established as genuine alternatives.

Over the past five years, an alternative and truly minimally invasive technique has undergone clinical trials which uses an implantable device, Urolift™. While not as clinically effective in objective terms as a TURP, it is minimally invasive, it can be performed as a day case and it has far fewer side effects, with preservation of sexual function. Further, in the best hands and in selected cases, it appears to be cost-effective. On this basis it has been approved by NICE for the treatment of the symptomatic enlarged prostate and has been widely embraced by the urological community. As such it has been a successful innovation that enhances the patient experience.

However, its introduction has raised a number of questions, most notably around whether it is truly cost-effective in the short-term for the average patient, and secondly whether the treatment is durable or whether patients will ultimately need a TURP either some months or years down the line. The long-term risks of the implanted Urolift™ devices are at present unknown and will need to be followed up. However, for patients who are prepared to accept lesser clinical efficacy than TURP but are keen to retain sexual function the Urolift™ is now an option.

Written by Mr Ian Eardley, Consultant Urologist and RCS Council Member

Surgical care in the independent sector

Innovations are sometimes developed and delivered by private providers who are prepared to invest funds and time due to financial or commercial incentives. At the same time the potential reluctance or inability of the NHS to invest in, or provide, innovations may also fuel demand for private healthcare or treatment abroad. This may be particularly the case where a patient has exhausted conventional treatment options and wishes to try something experimental that has not yet been approved for use in the NHS.

The recent scandal in the West Midlands – where a surgeon performed ‘cleavage-sparing mastectomies’ without clinical evidence or regulation – was a horrific reminder about the dangers of unverified innovations and the need for experimental techniques to be properly audited and scrutinised. This case also raised other issues around standards in private hospitals and risks associated with independent behaviour among surgeons.

The Royal College of Surgeons has called for private hospitals to contribute to existing national clinical audits to help monitor outcomes.

The Commission underlines the importance of both the NHS and the private sector aiming for the same high standards and rigorous assessment of innovations. There is no excuse for the private sector failing to contribute to future audits of new devices or treatments. Insurers will also play an important role in assessing which innovations their customers should use and many of the recommendations in this document apply equally to the NHS and the independent sector. It is also important for patients to be prepared to question claims about efficacy of innovations and not rely on the opinion of a single individual for assurance, although this cannot be expected to substitute for safe systems and professional responsibility.

Ethical implications

Healthcare staff could soon find themselves able to deliver therapies and interventions that not so long ago seemed the realm of science fiction. With the fast pace of change, new ethical and regulatory challenges emerge. The Commission considers some examples below along with some of the issues raised. The Commission acknowledges the more detailed work of the Nuffield Council on Bioethics on some of these issues.

Understanding risk of disease: Genetic testing is likely to uncover information about the patient and risks for themselves and their entire family, the consequences of which are unclear. The ethical implications of uncovering such information require support for the patient and the extension of duty of care to their family.

Gene editing: This offers the opportunity to treat genetic diseases that can currently only be managed as chronic conditions. The possibility of manipulating DNA to stop current or future disability or illness from occurring, even in the pre-natal stage, could certainly offer an answer to such diseases. There are ethical questions about editing the genetic makeup of someone who has yet to develop the ability to consent to treatment, particularly when the long-term consequences of editing genes may be unknown. Gene editing could also be extended to enhancing physical or mental characteristics, from augmenting cognitive abilities to interventions which adhere to the most recent definition of beauty. In extreme scenarios this could increase inequalities or even create social classes based on genetics.

The use of animal or human parts: For some patients there will be ethical considerations for treatments derived from animals or humans, such as the use of xenotransplants or embryonic stem cells. Discussion and engagement with the public need to take place to agree what limits should be placed on these innovations to ensure they bring acceptable societal benefits.

Body augmentation: Advances in regenerative medicine could, in 10–20 years, enable the creation of tissues and simple organs. This will have significant consequences for patients waiting for an organ transplant and for those who have suffered burns or trauma. The same techniques could, however, enable us to regenerate tissues and organs that have lost some of their properties due to natural ageing. Developments in 3D printing and prosthetics could be used to augment and improve body parts and limbs. As the population ages, patients will want to maintain physical and cognitive capabilities later in life. If treatments with the potential to delay the signs of ageing are possible, patients may expect access to them. Cost may inhibit NHS application, but if there is societal demand this may be met by the independent sector. This generates two ethical questions. Firstly, is it acceptable to delay ageing in this way and, if so, for how long? Secondly, providing this type of treatment risks the creation of health inequalities as wealthier citizens will be able to purchase interventions to delay ageing or to augment their physical and mental abilities. How can this inequality be avoided?

Commissioners believe that such implications should be considered, widely debated in the public sphere and addressed before these innovations are introduced. While non-government bioethics organisations should continue to analyse these issues and provide guidance for debate, the government should also consider how it continues to receive formal views on ethical considerations. To date, medical and scientific advancements have been analysed on an ad hoc basis in the UK, either by specially appointed committees (such as the Warnock Committee of 1982–84) or some non-departmental public bodies (such as NICE), while other countries have adopted more formal cross-government structures (such as the Presidential Commission for the Study of Bioethical Issues in the US).

Healthcare inequalities

Innovations pose new dilemmas for managing health inequalities. Specialised interventions such as stem cell therapies or bioengineered solutions are unlikely to be affordable or accessible at each local hospital in the country, posing possible geographic inequalities in access. Financial barriers may mean some costly innovations are only available in private hospitals or abroad, creating further inequity of access.

New, or newly recognised, inequalities may also arise from genomics. Patients with some genotypes may become more conscious of their predisposition to poor health or certain illnesses. If some treatments are only effective for some types of patients, those not eligible may feel they are neglected by the health service. There is also a risk that some groups of patients, sceptical about sharing their data or the ethics of innovations like xenotransplantation, might miss out on some of the benefits of new treatments.

As patients are encouraged and enabled to take a more proactive role in their health and care, support from health practitioners should be tailored to each patient to avoid the creation of health inequalities resulting from different levels of health literacy or initial ability to manage one's own health. In particular, both physical and mental health should be considered to direct the surgeon's support to the patient and the process of supported decision-making.
For example, patients with learning disabilities and other mental health conditions are more likely to present later and possibly with more advanced disease.

Conversely, the Commission expects that some developments may help to reduce inequalities. Cheaper robotics, remote support and telesurgery raise the prospect that more hospitals will have easier access to better technology and expertise. The continued development of online resources, for both patients and surgeons, will democratise knowledge. However, this should be set against the need to ensure that patients with different levels of health literacy and cognitive ability are supported and enabled to understand the complexity, risks and benefits of new treatments.

Ensuring equitable access must remain a key goal of health service planners and commissioners. Surgical teams should be committed to seeking ways of achieving equity of access. The risk of specialised or high-cost surgical interventions only being available to the few underlines the importance of planning the availability of such treatments at a nationally coordinated level. This will involve better horizon-scanning mechanisms and a more proactive, rather than reactive, role for NICE in reviewing and recommending new treatments.

Implications for low and middle-income countries

This Commission has focused on the impact of new technology for surgical patients in the UK. Clearly some of these technologies will also have an impact on low and middle-income countries. Digital technologies, such as telesurgery and AR, have a particular power to bring greater expertise to other parts of the world. Particular consideration should be given to how these technologies can scale up local expertise rather than providing one-off benefits, such as surgeons in more developed countries providing ad hoc advice to local teams during specific operations. For instance, digital learning tools including the use of VR and AR can improve access to training and the sharing of knowledge and best practice. The use of technologies that are cheaper and easier to transport, such as those that can be used with smartphones, will, however, have the biggest immediate impact.

Those interested in the future of surgery in low and middle-income countries are encouraged to read *Global Surgery 2030* – the report of The Lancet Commission on Global Surgery.[163] This presents detailed findings on the state of surgical care in low and middle-income countries, and makes recommendations to achieve universal access to safe, affordable surgical and anaesthesia care. The Lancet Commission, together with surgical royal colleges, may wish to further consider how the technologies identified in our report can support this vision.

Figure 13

Using smartphones and AR to aid the surgical treatment of cleft lip and palate in low and middle-income countries

Cleft palate affects almost every function of the face except vision. It is among the most common birth anomalies affecting children worldwide and it can take over 10 specialists to work as a team to deliver optimal care. Due to the current supply and demand mismatch between patient need and surgical availability, patients often delay their care, travel huge distances or, in the worst case, never get treated and live with the associated social and physical ramifications.

The Global Smile Foundation (GSF) works to provide comprehensive cleft care for patients born with cleft lip and palate in underserved communities worldwide. Partnering with Proximie©, a digital platform that works with operating theatre hardware already in use and on site, GSF could provide improved access to surgical training and sharing of best practice. The aim is ultimately to upskill surgeons all over the world so they can act independently in nations such as Ecuador, Peru and El Salvador and successfully manage their patients, treating more children sooner.

By connecting to a tablet, phone or laptop in all locations – even at low bandwidths – care teams can use the digital platform to collaborate effectively, from preoperative consultations to intraoperative mentoring and collaboration, and record the entire procedure for advanced review.

Figure 13: Using Proximie© to provide support in cleft lip and palate surgery in low and middle-income countries (Image credit Proximie© and GSF)

Possible system-wide threats

Antimicrobial resistance (AMR)

Although resistance mechanisms to antibiotics are not new, the challenge of antimicrobial resistance (AMR) has become greater in recent decades. The main cause of this acceleration is the excessive and clinically inappropriate use of antibiotic drugs in the treatment of humans and animals or for agricultural and environmental purposes.[164] Common surgical procedures – such as hip replacements or organ transplantation – could become too dangerous without the use of effective antibiotics.[165] The 2014 review on AMR in the UK calculated that a continued rise in resistance would lead to 10 million people dying every year and a reduction of 2–3% in GDP worldwide by 2050.[166-167]

The success of national measures to fight resistance shows the possible impact that actions to tackle AMR can have. For example, the UK's implementation of surveillance systems for MRSA in hospitals has led to a significant reduction in the presence of the drug-resistant bacteria.[183] Furthermore, following the introduction of a UK government target to reduce inappropriate prescription of antibiotics, there has been a 5% decrease in their use among patients since 2012, and a 9% reduction in sales of antibiotics for use in animals between 2014 and 2015.[183,185]

New epidemics

Following advances in pharmacological treatments, antibiotics and vaccines in the late 20th century, the burden of infectious diseases has been greatly reduced, especially in high-income countries. The focus of health interventions and research has shifted to non-communicable diseases. Yet, according to data from the World Health Organization, since 1970 more than 1,500 new pathogens have been discovered, including the Ebola virus and the human immunodeficiency virus (HIV).[168]

Although pharmacological treatment regimens have made diseases such as HIV a chronic condition that is in most cases completely manageable, epidemics of new pathogens – such as a new strain of influenza or new versions of old ones, such as a new type of Ebola virus – remain real possibilities. The recent Zika virus in Brazil, the Ebola epidemic in West Africa and an outbreak of plague in Madagascar are only a few examples from the past five years. Furthermore, increased globalisation and population mobility are factors likely to increase the spread of infectious diseases, such as the re-emergence of tuberculosis in countries where vaccination has no longer been seen as necessary.[186]

Global health security – including technologies to detect outbreaks and mechanisms to manage epidemics and pandemics – should lead to better protection against such risks, with greater awareness and cooperation among countries and organisations. The outbreak of a new pandemic might, however, have a disruptive impact on both the ability to deliver basic surgical care and the development of new surgical treatments as new communicable diseases become the focus of medical research.[186]

Technological failures and cyber crime

New technologies are developed every day with the power to change the way we deliver healthcare and improve patient experience and clinical outcomes. We increasingly rely on imaging and new technologies for diagnosis and treatment, on algorithms to analyse complex and vast amounts of data, and on basic computing and internet connection to organise appointments, waiting lists, rotas and clinical records.

As a result, failures in a specific technology could have a significant impact on patient care, especially as clinicians become more reliant on the use of devices and less familiar with undertaking procedures without their help. Healthcare is vulnerable to cyber crime. Although recent cyber attacks on healthcare trusts were often exploiting outdated IT systems, greater reliability on digital systems may increase the risk that such a threat would pose.

RECOMMENDATIONS

Patient journey

Recommendation	Who for?
• The implementation of the NHS 10-year plan in England should address how the NHS will prepare for the changes in technology and patient care outlined in this report.	• NHS England • Devolved nations should reflect the findings of the Commission's report in their own future health service plans
• To take full advantage of the potential beneficial impact of data and innovations on the patient, priority in the allocation of resources should be given to achieving interoperability and safe data sharing across different data systems, such as through immediate access to patients' records across healthcare organisations.	• Department of Health and Social Care • NHS Digital • NHS England • Welsh government • NHS Scotland • Department of Health, Northern Ireland
• The surgical royal colleges of the UK and Ireland should review how they could best support surgeons to understand the benefits and risks of new treatments as they emerge.	• Royal College of Surgeons of England • Royal College of Surgeons of Edinburgh • Royal College of Physicians and Surgeons of Glasgow • Royal College of Surgeons in Ireland
• The government should commission a review of how NHS digital resources can be used to support patients to understand the benefits and risks of new treatments and surgical procedures, and to provide appropriate pre and postoperative advice, including other mechanisms (eg face-to-face consultations or texts) to inform patients that such resources are available and how to access them. In particular, NHS Digital should carry out a review of how NHS websites and digital and other communication from patient charities can achieve such a goal.	• Department of Health and Social Care • NHS Digital

Workforce and training

Recommendation	Who for?
• The Royal College of Surgeons together with the Scottish and Irish surgical colleges should conduct a thorough review of the implications of this report for surgery, including potential changes to the surgical workforce, examinations, training and research. Priority should be given to those areas with longer implementation time, such as changes to the surgical curriculum.	• Royal College of Surgeons of England • Royal College of Surgeons of Edinburgh • Royal College of Physicians and Surgeons of Glasgow • Royal College of Surgeons in Ireland
• Following the government's announcement to regulate physician associates and physician assistants (anaesthesia), the Commission urges them to extend regulation to cover surgical care practitioners.	• Department of Health and Social Care • Health Education England, Health Education and Improvement Wales, NHS Education for Scotland, Department of Health, Northern Ireland
• Molecular biology (with specific attention to genomics and stem cells), data literacy and human factor training (especially communication skills and supported decision-making mechanisms) should be embedded into undergraduate and postgraduate curricula by all medical schools. Surgical royal colleges should review the surgical curriculum and continuing professional development to ensure these areas are reflected.	• Deans of medical schools • Royal colleges • Health Education England, Health Education and Improvement Wales, NHS Education for Scotland and the Department of Health, Northern Ireland
• Medical students, surgeons in training and consultants should be encouraged to step on and step off traditional training and career pathways to spend time in industry, academia, teaching or abroad to bring back innovation to the healthcare system. The surgical colleges should review this as part of the actions they take forward following this report.	• Royal colleges • Health Education England, Health Education and Improvement Wales, NHS Education for Scotland, Department of Health, Northern Ireland • NHS trusts

• Health Education England and national education bodies in devolved nations should, following on from their work on flexible training, reflect on how best to ensure flexibility in training and career pathways as part of forthcoming workforce plans.	• Health Education England, Health Education and Improvement Wales, NHS Education for Scotland, Department of Health, Northern Ireland
• The Royal College of Surgeons, in conjunction with the other surgical colleges, should establish and embed in training and continuing career development sufficient exposure to and training in the use of new technologies for both surgeons in training and consultants. This will ensure they can deliver the most innovative care and best patient outcomes. Training in the use of new technologies should include doctors joining the UK healthcare system from abroad.	• Surgical royal colleges
• The Royal College of Surgeons and Royal College of Anaesthetists should review the possible role of peri-operative care physicians and their responsibilities compared with the wider surgical team.	• Royal College of Surgeons of England and Royal College of Anaesthetists

Wider implications

Recommendation	Who for?
• A UK-wide registry should be established to track new devices. Implantable devices should have long-term monitoring in a register akin to the breast implant registry. These developments should involve expertise from the royal colleges.	• Department of Health and Social Care • National Institute for Health and Care Excellence • Royal colleges
• There should be a review of the viability of creating a national database that encompasses a much wider range of procedures than currently covered by national clinical audits.	• Healthcare Quality Improvement Partnership
• The location of surgical robots and centralised services need to be much better planned in the future to ensure access across the country and cost-effectiveness. NHS England should initially lead a robotics strategy to help the NHS plan and purchase new surgical robotics systems – this approach could be extended to other innovations.	• NHS England and clinical commissioners

• Over the next five years, the NHS would be better placed to benefit from new innovations by prioritising central government investment in:
  • the full integration of genomic medicine
  • the collection and analysis of data and improving the digital infrastructure of the health system.
	• Department of Health and Social Care
	• HM Treasury

• The NHS in England, Scotland and Wales and the HSC in Northern Ireland, in conjunction with local trusts, should encourage investment in the creation of multidisciplinary specialised hubs for the delivery of complex interventions. In the immediate-term, they can enable the use of 3D printing and planning technologies. In future years, other specialised interventions, such as regenerative medicine, can benefit from centralised multidisciplinary expertise.	• NHS in England, Wales and Scotland, and HSC in Northern Ireland • Hospital trusts and health boards in Wales
• The Academy of Medical Royal Colleges should review this report and assess its implications for patients in non-surgical medical specialties.	• Academy of Medical Royal Colleges

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