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making science
work for health
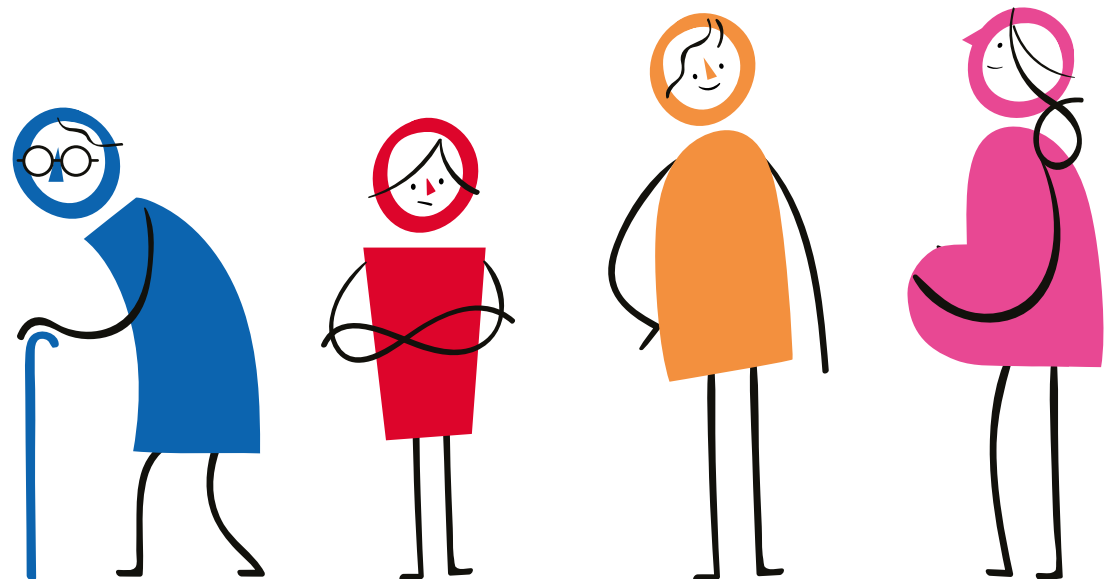
My Healthy Future

The technologies

Technologies and future health

Current and emerging biomedical and digital technologies are creating new opportunities for the prevention, diagnosis, treatment and monitoring of disease on an ever more personalised basis, both within the health system and beyond. As these technologies and their applications advance they are likely to play an integral role in shaping healthcare and the ways in which citizens manage and optimise their health.

PHG Foundation have produced a series of visual summaries highlighting existing and anticipated healthcare utility of a range of cutting edge technologies and biomedical advances. These developments have the potiential to improve and expand our abilities to assess, to understand, and to intervene in health and disease processes. Each summary includes an overview of the opportunities and challenges to their routine use for health. The technologies can be broadly categorised according to their overarching applications in health.
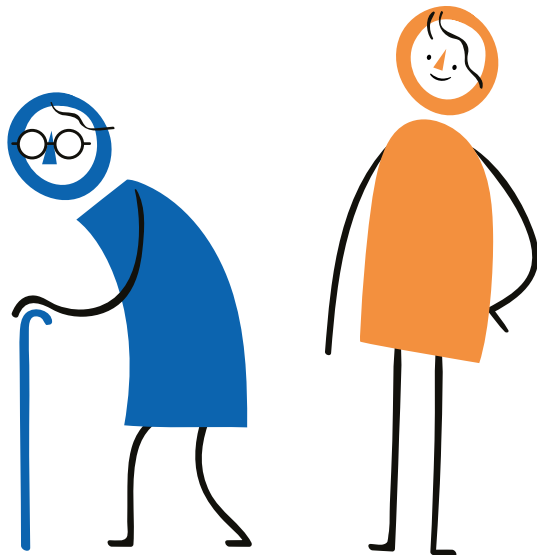
Biomedical 'omics technologies for greater molecular level characterisation of individuals

'Omics technologies enable the comprehensive or global assessment of a set of molecules in a given sample. The field has been driven by technological advances and falling costs for the high-throughput generation of data. Crucially this data is enabling the more detailed characterisation of the molecular make-up of our cells, tissues, and organs – information which is facilitating tremendous opportunities for:

- Identification of new disease biomarkers and development of new therapeutics
- Informing more precise diagnosis
- Greater stratification of populations to better target health interventions

Whilst the application and understanding of genomics in particular has advanced rapidly over the past 20 years, developments have also highlighted the immense complexity of interpreting genomic variation in the context of health and disease.
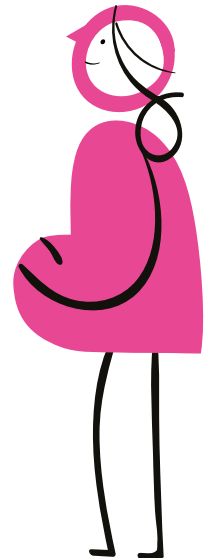
It is widely recognised that the growing armoury of other 'omics approaches are key to elucidating how the instructions laid down in our genome are expressed within our cells. Specifically, these other 'omics technologies can measure:

- Messenger (m)RNA: 'transcriptomics' to reflect the genes that are being expressed at a given point

- Proteins: 'proteomics' to understand the overall composition, abundance, structure and function of the full set of proteins coded for by our genes

- Metabolites: 'metabolomics' to quantify the products of cellular metabolic processes

- Chemical modifications that attach to DNA to regulate gene expression: 'epigenomics'

Increasingly 'omics technologies are being applied in combination to examine the inter-dependency between the various biological processes (e.g. gene expression and epigenetic regulation), and to understand how our genes interact with environmental factors. An example of the latter is 'nutrigenomics' which attempts to examine the interaction of nutrition and genes using an array of 'omics analytical tools to measure changes occurring *in vivo*.

Another factor bolstering the promise of 'omics is the growing ability to apply these approaches to a broad array of samples types - from collective populations of microorganisms (microbiome analysis) - to individual cells (single cell analysis) - to DNA circulating in blood (liquid biopsy). The analysis of fragments of tumour DNA found circulating in a patient's bloodstream is already being applied in the clinic to inform treatment decisions for some forms of lung cancer.

Biomedical technologies for more personalised therapeutic interventions

The knowledge derived from 'omics based analysis is informing advances in regenerative medicine for the repair, replacement or restoration of function to damaged or diseased human cells or tissues. Although predominantly at the pre-clinical research or clinical-trial phase, remarkable progress in this field is facilitating individually tailored therapies for patients - whether through use of their own cells, or by direct targeting of their genetic variation.

This vast field includes cell-based therapies which make use of stem cells, including those derived from the patient, which can be differentiated into other specialised cell types. Stem cell therapy can be combined with advanced genome editing techniques, to directly manipulate genetic code with the objective of correcting the genetic aberration underlying a disease. Cellular systems can also be re-engineered using synthetic biology approaches - the most promising application of which is the reengineering of cancer patient's immune cells to allow them to detect and destroy cancer cells that may otherwise subvert the immune system.

Digital and/or data driven technologies for more personalised disease and health monitoring or for therapeutic interventions

Digital technologies, in many cases originally developed for use in other sectors, are becoming pervasive in healthcare.

Mobile technologies are creating opportunities to obtain more regular health-related information on individuals (e.g. heart-rate, or movement activity) and to deliver care remotely (e.g. through telemedicine consultations or smartphone health apps).

Virtual reality technologies, originally developed within the gaming industry as headsets that display computer rendered simulations, are being considered for healthcare applications to treat mental illnesses.

Medical imaging data is providing the digital foundations for the use of 3D printing in healthcare to create bespoke patient customised personalised implants and anatomical structures for surgical planning.

The miniaturisation and portability of data-driven and digital-health devices is delivering further opportunities to monitor the health of individuals remotely and more frequently. These include implantable biosensors to provide real-time measurements of biomarkers within our bodies, and portable bioassays for the near-person and point of care diagnosis or 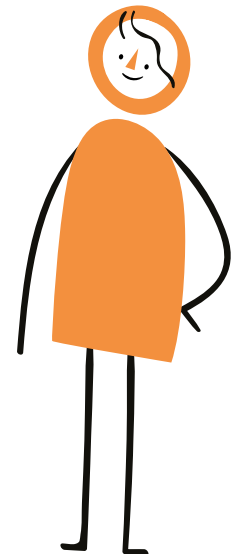monitoring of disease. The capabilities of these devices are likely to expand as bioengineering approaches such as nanomedicine and microfluidics that operate on very small scale (nanometres and millimetres respectively) evolve sufficiently to underpin new or enhanced biosensing applications.

Enabling informatics technologies for harnessing health data

Advances in information technologies are integral to the developments in data-driven medicine. The increase in the ability to generate data has far outstripped our capacity to manage, store, and analyse this data in order to maximise its value. The 'internet of medical things' (IOMT) is one approach to addressing the massive challenge of integrating different datasets generated across a range of disparate medical devices through the use of sensors, cloud computing and cloud storage.

Artificial intelligence, including machine learning approaches are viewed as one of the most transformative technologies for healthcare owing to the capabilities to derive insight from very large and complex datasets in ways not previously possible.

Beyond overcoming the technical obstacles for collating and analysing data, blockchain - a radical approach for the sharing of data - is heralded for its potential to offer more secure, safeguarded and trusted data management solutions.

The shape of things to come?

The continuing development of technologies such as those described here (as well as others) are expected to have a major role in shaping trends for health management.

- Increasing portability and ubiquity of digital and data-driven sensing devices may result in a growth in the number of health technologies that interact directly with citizens outside of a health setting or that are available via providers outside organised health systems

- Greater molecular characterisation of individuals combined with targeted cellular therapies may enable earlier and/or more precise disease diagnosis to be closely followed by potentially curative tailored treatments

- The unprecedented volumes of health-related data now being assessed through advanced analytical approaches such as AI may reveal disease risk before symptoms manifest, and may better inform the management of long term disease to prevent complications

- Mobile and internet-enabled or connected devices may empower citizens to take greater control over their own health

These are just some possibilities, which may or may not arise, but overall it is clear that in combination these technologies are facilitating the most detailed and holistic view of health that has been possible yet.
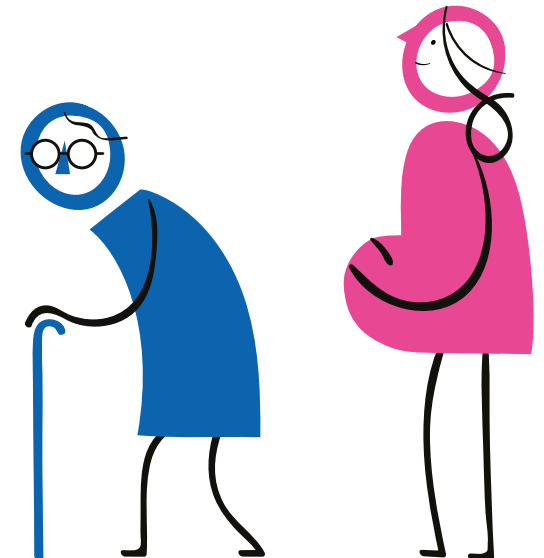
The following Healthcare Futures infographics, a series on rapidly changing emerging technologies, were produced between 2016 and 2017

Transciptomics

Transcriptomics is the study and sequencing of the transcriptome, which is the set of all messenger (m) RNA molecules in one cell or a population of cells at a given time and reflects the genes being actively expressed

The science

Techniques for measuring RNAs range from simpler methods, such as microarrays or qRT-PCR, to more advanced next generation sequencing based systems. RNA-seq is a popular research technique that can be used to sequence and analyse ('read') the whole transcriptome. It can differentiate between RNA 'species' such as microRNAs, small interfering RNAs and long non-coding RNAs.

To read RNA, the sample has to be processed, filtered and reverse transcribed into complementary (c)DNA, sequenced as short reads, and then reassembled using bioinformatics tools.

Whole transcriptome sequencing is widely used in research. However, in clinical care use of transcriptomics is restricted to specific gene expression (panel) tests based on microarrays and qRT-PCR.

Health check

- Now and in the future, the challenge lies in ensuring clinicians know how and when to use the tests, what the results mean, and when to act on them

- Efforts to assess reproducibility, accuracy and precision are hampered by the lack of standardisation of methods

- Many of the challenges facing transcriptomics mirror or overlap those of genomics and other 'omics technologies

- The integration of 'omics technologies for research, service delivery and in clinical research studies, will require joined-up approaches to data collection, analysis and management

- The volume of data generated by whole transcriptome sequencing means that extensive bioinformatics infrastructure and expertise is required to extract clinically useful information
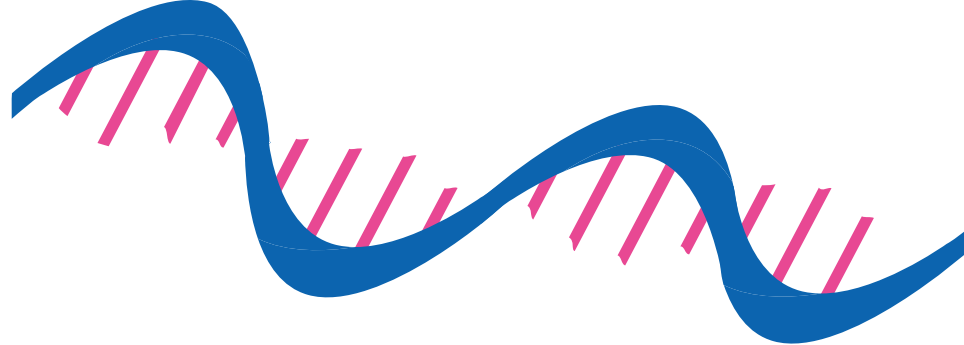
How it could help

Personalisation
As an enabling technology transcriptomics could have an important role developing personalised approaches to healthcare. e.g. the Oncotype Dx® panel test is used to predict the risk of recurrence of breast cancer. A patient with a low risk score may not need chemotherapy treatment

Infectious disease
Transcriptomics is helping researchers understand host response to infection, disease progression and treatment response. e.g. the research initiative Omics4TB is exploring the use of all 'omics technologies in understanding the regulatory networks that underlie the relationship between host and pathogen

Diagnosis
RNA assays (using qRT-PCR) are commonly used for the diagnosis and prognosis of leukaemias. One panel test under clinical trial rules out acute cellular rejection of heart transplant

As an enabling technology transcriptomics is certainly one to watch. It is an important part of the 'omics toolkit and will have a role to play in the development of more personalised approaches to healthcare, as tests such as Oncotype Dx®. However, there are challenges that mirror and overlap those of genomics – issues including data sharing; management and analysis; ethical, legal and social concerns; and integration into clinical pathways. As with other 'omics technologies, a cohesive approach will facilitate integration into medicine. At present, transcriptome sequencing is some way from routine use in clinical care.
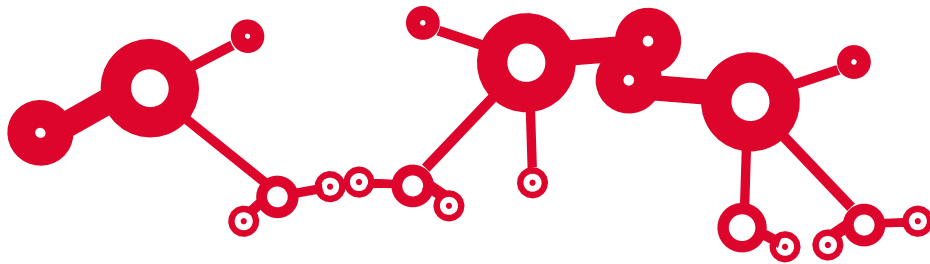
Analysis of the proteome – the full complement of proteins within a cell or organism – could form an important part of the personalised medicine toolkit. Clinical proteome analysis (CPA) focuses on understanding how the proteome differs in normal and disease states and whether this knowledge can inform disease management

The science

CPA studies and compares the proteome between healthy and diseased individuals: how abundant proteins are, how they are modified (post-translational modifications, PTMs) and how they function within wider networks. Proteins are diverse, dynamic, and more directly reflect the disease phenotype. A thorough understanding of functional changes in the proteome, such as PTMs, are needed to determine the relationship between the state of the proteome and disease.

A commonly used proteomics technology is mass spectrometry, which allows the detection and quantification of proteins within a cell, a sample of tissue, or bodily fluid such as blood or urine.

One of the goals of CPA is to discover proteins that can act as novel biomarkers to diagnose and monitor disease in individuals, which creates opportunities for more personalised disease management.

Health check

- In the UK, the Clinical Proteomics Centre for Stratified Medicine is studying the differences in the proteome between healthy people and those with diseases such as rheumatoid arthritis, psoriasis, lupus and cancer, to gain insights into disease development and treatment

- There are problems around standardisation of experimental procedures which can make comparing results between laboratories a challenge. The Human Proteome Organisation (HUPO) is developing standard operating procedures relating to sample preparation, analysis and reproducibility of experiments and for data collection, analysis, storage and sharing

- The greatest challenge of CPA is the complex nature of the proteome, its scale and constantly changing constituents. As such, proteomics is still in the research phase

- There is wide variation in the concentration of key proteins in the body. Many proteins thought to be relevant to disease may be present only at lower concentrations, presenting a technical challenge to detection. Emerging technologies, such as SWATH-MS, are advancing the science

How it could help

Advancing disease research

Combining advances in genomic analysis with proteomic investigation can help us understand how a disease is uniquely affecting an individual patient and how best to treat them

Medical applications

Specific, sensitive, easy to use biomarkers could allow early identification of disease or disease precursors. Identified biomarkers could be used to measure patient response to treatment in real-time or reduce the use of more invasive interventions required for later stage disease

Germline editing

Proteins found within cells can display a characteristic biosignature. In some disease states, such as cancer, these proteins can also be released into easily obtainable bodily fluids such as blood and be measured, avoiding the need for more invasive biopsies

Drug development

Understanding the disease proteome could help identify targets for drug discovery and provide accurate, real-time data on how a specific compound performs

Clinical proteome analysis is an interesting technology with great potential to improve future healthcare. But given the immense challenges involved in studying the proteome, without improvements in practices and standards it is unlikely that the field will discover biomarkers that are ready for clinical application any time soon. In the short term, it is likely that individual biomarkers or panels of biomarkers discovered using conventional approaches such as antibody assays will be developed and contribute to the delivery of personalised healthcare.

ctDNA liquid tumour biopsy

Less invasive than a traditional tissue biopsy, one type of liquid biopsy involves the extraction and analysis of circulating tumour DNA (ctDNA) from a blood sample to inform cancer management

The science

As tumour cells die they release fragments of DNA (ctDNA) into the bloodstream. ctDNA is analysed from a blood sample using genomic techniques including PCR, exome sequencing and whole genome sequencing. ctDNA analysis is used to provide information about genetic variation in the whole tumour, rather than just one tumour section as in the case of solid tumour biopsies, which are the current 'gold standard' technique.

Liquid biopsies are less invasive than tissue biopsies, and so can be used throughout treatment, as well as in patients for whom a tissue biopsy is difficult or impossible. Each technique involves a trade-off between sensitivity, specificity, cost and time taken.

Health check

- Health economic analysis of implementing this technology is needed. A liquid biopsy aids personalised treatment, but does personalisation of care save money?

- More research is needed on the biology of ctDNA

- One challenge will be to integrate liquid biopsies into services where solid tumour genetic testing is not consistently provided

- Effective integration into routine care will rely on availability of expertise and knowledge of how to respond to test results

- Standardisation of techniques is needed

- Technology is closest to clinical use with lung, breast and colorectal cancers

- Liquid biopsy testing is being developed by a small number of UK labs. The test is to measure *EGFR* status in non-small cell lung cancer, to see whether a patient can receive tyrosine kinase inhibitor drugs

How it could help

Personalised medicine

A liquid biopsy can help determine whether patients are eligible for certain therapies. Testing during treatment can monitor early emergence of mutations that will make tumours resistant to drugs, so alternatives can be tried

Monitoring treatment response and relapse

Liquid biopsies can be used to monitor changes in ctDNA levels, to assess treatment effectiveness, or to detect changes that could indicate disease relapse

Screening

A liquid biopsy could potentially be used for screening purposes, but overdiagnosis is a risk. It is questionable whether early detection always results in better outcomes for patients

Liquid biopsies will have an impact on the personalisation of cancer treatment by indicating therapies for patients on the genetic profile of their tumour. Smaller studies show that these technologies work and the first ctDNA tests for lung cancer are becoming available, with more likely to follow in the next 1-2 years. Protocols on when to use ctDNA technologies and how to respond appropriately to tests will be essential. Questions to be answered are whether personalising treatment using these technologies will improve and personalise care and in what situations they can save money.
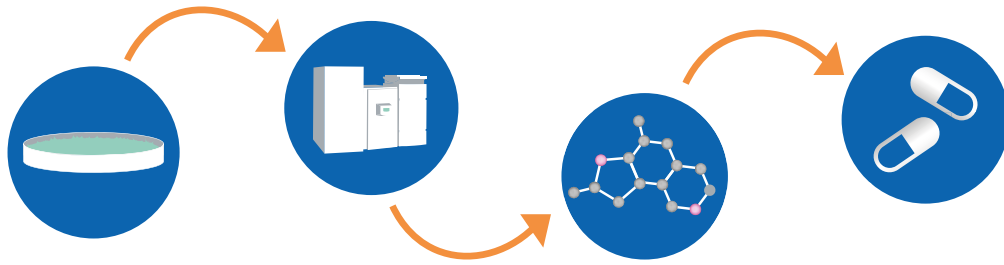
Metabolomics is the study of the products of metabolism, which are formed from intracellular biochemical reactions and are collectively referred to as the metabolome

Metabolomics

The science

Most 'omics technologies assess parameters intrinsic to the individual. Metabolites reflect both internal and external parameters, offering insight into the interplay between genetic and environmental factors within an individual.

Metabolites can be detected in routinely collected clinical samples, such as bodily fluids and tissue biopsies. Markers of specific diseases are found nearby, e.g. markers of kidney disease can be found in urine; markers of cardiovascular disease in blood. Mass spectrometry (MS) is the most commonly used laboratory technique in metabolomics, and enables thousands of metabolites at very low concentrations to be detected within a single sample.

Defining metabolic pathways may aid our understanding of the mechanisms of disease and improve treatment strategies by informing the selection and/or generation of targeted drugs.

Health check

- A major limitation of metabolomics is the slow progress in identifying biomarker candidates and in clinically validating them

- MS is a well established technique in the public sector, which means that once clinically validated metabolites are identified, metabolomics could quickly become an important clinical investigation

- Among the applications for metabolomics, diagnostics and theranostics have the greatest potential for providing evidence-based and cost-effective improvements to patient care

- Owing to its infancy as a clinical technology, no reference to metabolomics has been made in government policy or parliamentary records

- Enabling higher throughput will require significant investment in laboratory equipment and trained personnel

How it could help

Personalisation
Metabolomics has the potential to provide highly personalised phenotypic information, with applications in disease prevention, diagnosis, theranostics and disease monitoring

Detection
Metabolic screening is routinely performed to detect inborn errors of metabolism in newborns in the UK. A commercially available metabolic test is available in the US for the detection of precancerous colon polyps

Theranostics
Metabolic associations with drug efficacy and risk of adverse effects/toxicity could help target therapies and improve patient safety in clinical decision-making processes

Disease prevention
Metabolic traits could yet prove useful as biomarkers of disease, particularly in conditions where few are available (e.g. prostate cancer), and in complex, multifactorial and chronic diseases

Metabolomics has exciting potential to provide insight into the pathophysiology of many diseases and to enhance our understanding of how genetic predisposition and environmental triggers drive disease development. There are challenges to overcome before metabolomics can be used in clinical practice with confidence. Identifying metabolites of potential clinical interest will require standardisation of experimental techniques between research groups, followed by lengthy clinical validation processes. Once achieved metabolomics could be integrated in clinical practice with relative ease, and may yet prove to be a cost-effective technology that is advantageous to patient care.

Epigenetics

There is increasing evidence that the environment we live in and our lifestyle result in changes to our DNA. Epigenomics is the study of the biological mechanisms behind those changes and which ones impact on our health and how

OFF ON

The science

The genome is the complete DNA sequence present in almost all a person's cells. The epigenome is the set of chemical modifications to the structure and packaging of genomic DNA with certain proteins in a cell. The epigenome can vary between cells and over time while the underlying genome stays the same. Research has linked epigenomic changes to certain cancers, as well as obesity, diabetes, heart disease and mental illness.

Epigenomic changes occur when external agents (food, oxygen, toxins) affect a cell's environment, leading to modifications in a set of DNA in that cell. Some of these changes influence the behaviour of a cell by changing gene expression (switching genes on and off).

Epigenomic inheritance occurs between generations of cells within a body. This is called somatic inheritance. Some scientists believe epigenomic inheritance also occurs between generations, being passed from parent to child (germline inheritance). Only some of these modifications will influence genetic traits and diseases.

How it could help

Diagnosis

Epigenomic biomarkers are specific epigenomic changes that have been linked to a disease. Although they are not necessarily causative, they may indicate that a person has or is at increased risk of developing that disease. Testing for these biomarkers could potentially aid diagnosis and risk

Personalised medicine

Epigenomic changes are reversible, creating opportunities for more personalised therapies; for example, drugs that block a form of DNA modification are used to treat bone marrow cancers

Health check

- It is hard to analyse the epigenomic status of cells in medical research. Some tissues are very difficult to sample, such as brain tissue; some (e.g. blood) contain multiple types of cell with different epigenomic profiles; and they must be sampled at the right time to identify disease-linked epigenomic changes

- Epigenomic changes are not 'all or nothing' - they may be partial modifications, necessitating analysis of DNA from many cells of the same type to identify the change under investigation

- Determining causality is problematic: did a lifestyle factor such as smoking induce a certain epigenomic profile, or did that epigenomic profile influence a person's decision to smoke?

- Only one of the four trials examining links between disease and epigenetic changes showed changes in epigenomic markers after treatment, and the treatment itself was not successful for any of the patients. Only eight tests or drugs have been approved

Epigenomics is a thriving area of active research. However, the science is enormously complex and the research is in relative infancy. With the exception of cancer, clinical applications remain of unproven value, and the development of tests and treatments is hampered by complexity and our limited current understanding. The research is good, but epigenomics is not ready for use in health services.
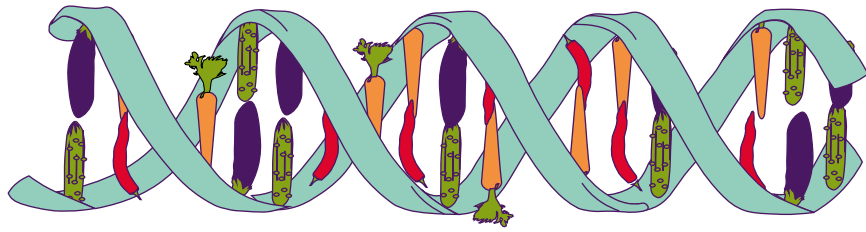
People differ in their nutritional requirements and response to food intake. Nutrigenomics attempts to understand to what extent these differences can be explained by genetic variation between individuals

Nutrigenomics

The science

The relationship between food and genetics is two-way - genes affect our drive to eat and response to nutrients, whilst nutrients can lead to epigenetic changes. 'Omics technologies help us understand the roles food components play at the cellular and molecular level, with a view to providing personalised dietary advice.

Some genetic mutations have a significant effect on dietary behaviour and nutritional response, leading to severe obesity. However, the complexity of these interactions makes finding other genes or gene combinations with more moderate impact challenging. Nutrigenomics looks at all levels of the process, which includes genes and gene expression and biomarkers e.g. hormones or metabolites, then linking these with measurement of food intake and phenotypic, clinical and behavioural data.

Nutrigenomics is being applied to conditions such as diabetes, obesity, heart disease and mental health.

Health check

- Direct to consumer testing in this area has resulted in legal challenges surrounding marketing claims. Proposed reform of EU regulation could restrict access to DTC tests

- There are clear financial advantages for the NHS if the technology proves able to reduce the burden on its resources in key areas, particularly for obesity related ill-health

- Nutrigenomics is a highly resource intensive approach. Amassing sufficient evidence of its benefits to justify replacing low tech approaches will be a challenge

- Building the evidence base is critically dependent on the development of technology to measure and analyse the necessary parameters, and on collaborative working and data sharing

- Food is much more than an environmental determinant of health. Attempts to intervene in this part of people's lives must take account of the social, cultural and emotional dimensions of diet

How it could help

Personalising health

The technology could also be leveraged to improve effectiveness of behavioural and therapeutic options through more tailored, personalised health advice to 'at risk' individuals

Personalised medicine

Predictive tools based on nutrigenomics could contribute to personalised prevention by identifying people at risk of developing disorders such as diabetes or metabolic syndrome

Health management

Nutrigenomic tools could be used to ensure those that need higher levels of nutrients can be supplied with them to prevent or slow disease progression
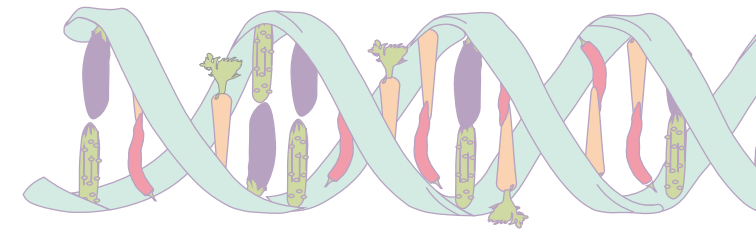
Nutrigenomics research shows much promise, but currently few applications are used in routine clinical care. The complexity of nutrigenomics and the cost of associated tests mean new applications must be chosen carefully. For certain complex conditions, for example obesity, with a range of often interacting determinants, nutrigenomics may be best used as one of a number of tools. Ultimately, the knowledge base is still under construction and nutrigenomics has a way to go before it is ready to make a substantial contribution in healthcare.

Microbiome

Living in and on the human body is an enormous community of micro-organisms such as viruses, bacteria and fungi called microbiota. Collectively they form the microbiome

The science

Technologies such as high-throughput DNA sequencing are enabling analysis of the human microbiome and expanding our knowledge about how microbiota affect our health. Microbiota are being linked to bowel and intestinal disorders, obesity, diabetes, mood disorders, heart disease, arthritis, dental and gum health and cancer.

The structure of the microbiome varies from person to person and is influenced by genetics, diet, environment and behaviour. It also varies over time. Its flexible nature suggests it can be deliberately manipulated to promote health and combat disease. Some basic manipulation is already possible

According to a January 2016 study the ratio of human to bacterial cells is about 1:1. Previously it had been thought that bacterial cells outnumbered human cells by 10:1

Health check

- Despite the sequencing of over 3000 microbiomes, there remains no standard classification for what consitutes microbiota, no clarity as to responsibility for regulating technologies and no standard 'healthy microbiome'

- There are no applications currently ready for routine use in the clinic

- Technologies for manipulating the microbiome are still in their infancy

- Whole person approach requires integration between medical disciplines

- Huge variability and pliancy make it difficult to establish causal links to specific disease

- There is huge interest from pharma and biotech on the development of related therapies

- The only signficant government-led initiatives, e.g. the Human Microbiome Consortium, are focused on research

- The only clinical application microbiota-based therapy is faecal microbiota transplantation, used only in severe cases of c.difficile (an infection of the digestive system)

How it could help

Personalised medicine
Gut microbiomes may influence individual responses to a specific disease

Patient empowerment
People can adapt their lifestyle to bring about changes in their own microbiome

Treating the whole
Aims to go beyond tailoring and precision by taking a whole person approach

Significant hype permeates discussions on the microbiome and its implications for healthcare. Research is in its infancy and supporting evidence is currently scarce. The hope is that more precise manipulation of the microbiome may become possible by manufacturing microbial communities or engineering specific microbes. Fine-tuning dietary supplements by identifying the metabolites that microbiota produce is also a goal.
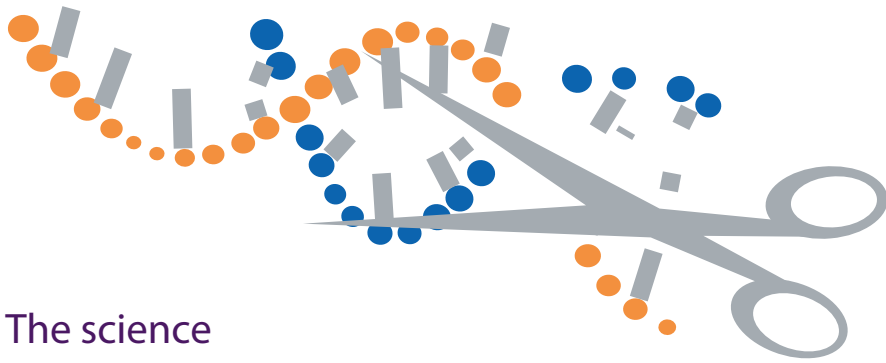
Genome or gene editing is a means of changing genetic sequences within living cells. It utilises technologies that cut DNA at precise locations to inactivate or replace sections. The technologies have been around for decades, but the recent development of CRISPR/Cas9 has put genome editing in the spotlight

Gene editing

The science

Genome editing techniques - zinc finger nucleases, TALENS and meganucleases - all make use of genetically engineered versions of naturally occuring restriction enzymes, that cut DNA at specific locations. Creating these enzymes can take up to six months.

CRISPR/Cas9 (clustered regularly interspaced short palindromic repeats) is a powerful bacterial defence system that has been reprogrammed by scientists to edit genomes. It is a much more flexible system to design and control because the part that locates DNA sequence (RNA) is separate from the part that cuts. CRISPR/Cas9 system is much cheaper and quicker to use than previous methods.

Health check

- Need more work on efficacy, specificity and safety, especially in understanding off-target effects (when the DNA is cut in the wrong place)

- A lot to be done on basic biology of gene editing, including understanding the knock on effects on organisms and the environment

- Focus on the ethical and safety issues around germline editing, while important, could divert attention away from more immediate clinical applications

- Challenge lies in managing increased workload involved in research oversight resulting from widespread use of a more accessible technology

- Regulation of genome editing should be carefully considered to avoid delays in implementation of useful therapies

- UK Human Fertilisation and Embryology Authority (HFEA) has approved a licence to use gene editing of embryos in research, subject to ethical approval

- In mainstream use in research labs for *in vivo* and *in vitro* use. Could be in therapies in 2-5 years

How it could help

Advancing disease research
Revolutionising research, through use in the development of new cell and animal models. Some mouse models can now be created in months using gene editing, compared to 1-2 years previously

Medical applications
Genome editing of somatic/non-sex cells could treat a range of genetic diseases, last year a one year-old girl with advanced acute lymphoblastic leukemia was successfully treated using gene edited donor T cells

Germline editing
Genome editing could potentially be used for germline manipulation, producing heritable genetic changes. This is subject to intense ethical debate and self-regulation by the scientific community

Genome editing has enormous potential to advance medical research and benefit human health. Much of the ethical and safety debate on genome editing is centered on germline editing, but this distracts attention from medical applications. It is important ensure that specific moratoria do not restrict research and that a wide range of voices collaborate in discussions surrounding its ethical and safety issues.

Synthetic biology

Synthetic biology draws on expertise from multiple disciplines including computer science, engineering and chemistry. Broadly, it is the design and construction of novel biological functions or systems which do not already exist in nature

The science

Synthetic biology works by putting together biological parts, sequences of DNA that code for basic biological functions (e.g. a protein coding region) in new ways that do not exist in nature. Biological parts can be derived from existing organisms through genetic engineering or synthesised from scratch. They are assembled together to create devices which can perform a useful high level function, such as switching genes on or off or integrating multiple genetic signals.

Multiple high level functions can be combined together in a host organism - like components soldered onto a circuit - to create a single system that performs a complex task, such as a biosensor able to detect pathogenic bacteria.

Health check

- In 2013, the UK Science Minister identified synthetic biology as one of the eight great technologies to propel UK future growth and boosted funding into the field

- Relies on the use of well characterised biological parts that function predictably; efforts to establish common libraries of biological parts have been hampered by lack of data standardisation and quality control

- Two established health applications: artemisinin production (an anti-malarial drug) and the branched DNA assay (diagnostic tool that measures viral load for HIV and HCV)

- A major problem is its sheer complexity and our lack of knowledge about the molecular processes that underpin life

- The global market for synthetic biology is expected to increase from $1.9 billion in 2013 to $5.6 billion by 2018

- There are concerns about the safety of biosynthetic devices when hosted within human cells , for example unintended effects or mutations

How it could help

? Cancer immunotherapy

One promising application of synthetic biology is re-engineering immune cells to allow them to target and destroy cancer cells that would normally subvert the immune system and avoid destruction

? Diagnostics

Synthetic devices can be dried onto paper discs and coded to detect viral RNA. Such tests have been developed for both Ebola and Zika and are easy to use in remote locations

? Theranostics

Synthetic devices are being developed that can detect biomarkers relevant to specific diseases and then produce an appropriate therapeutic treatment

? Drug synthesis

Many of today's drugs are derived from natural products, manufacture of which is often time consuming, expensive and subject to unpredictable yields. Using synthetic biology, drugs derived from natural products could be produced more reliably, on an industrial scale and at a lower price

Still an emerging technology, synthetic biology has considerable potential to contribute to personalised healthcare - but it is a long way from reaching its full potential. The areas in which it could achieve the most, such as in therapeutic circuits and the modification of immune system cells to fight cancer, are still very much in the experimental and clinical trial phases. That said, the nature of synthetic biology means that many of its applications will be as a key part of other technologies of interest, such as in portable diagnostic bioassays or implantable biosensors.
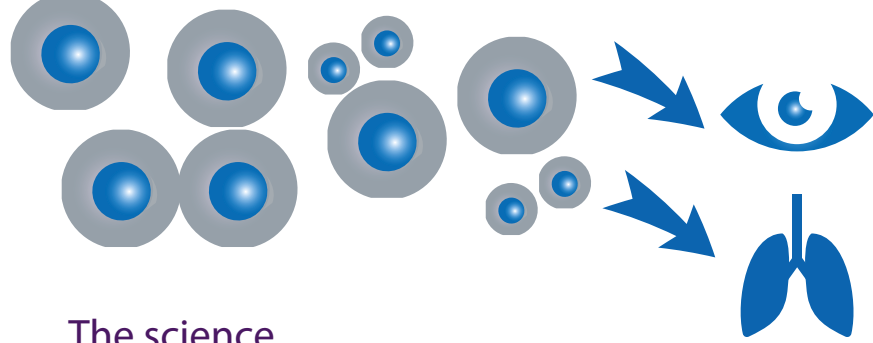
Regenerative medicine, in which stem cells play a key part is being hailed by the UK Government as one of the 'eight great technologies'. The use of stem cells in research and treatment is generating considerable ethical debate. Here we focus on the less controversial use of stem cell therapies derived from human adult tissues

The science

Stem cells are undifferentiated cells from which different tissue types can develop. There are four distinct sources of stem cells: embryonic, cord blood, adult (somatic) and adult induced pluripotent stem cells. Their key characteristics are self-renewal i.e. they can reproduce almost indefinitely, and potency i.e. they can be directed to produce specialised tissues and organs of the body.

Stem cell therapies take numerous forms but essentially involve harvesting, culturing, and in some cases manipulation (as in genetic modification), followed by transfer to the patient. Therapies may use donor cells (allogeneic therapies) or the patient's own cells (autologous therapies) to replace or repair bone, blood, organs, muscle or neurons.

How it could help

New approaches

For example the creation of blood components or engineering the patient's own immune cells to attack cancer tumours

Total personalisation

Personalisation of existing treatments, e.g. organ and tissue replacement using stem cells would reduce risks of rejection, and remove the need for immunosuppressant regimes

Access to treatments

Stem cell therapy could increase access to treatments by reducing reliance on scarce donor organs

Health check

- A complex regulatory environment, involving multiple bodies, must be navigated before any new stem cell treatment can be used in the NHS

- Stem cells are 'living drugs' with the potential for tumour formation and ectopic tissue growth so there is a need for long term monitoring

- Producing therapies is technically complex and requires highly specialist skills to isolate cells and manage pluripotency

- There will need to be investment in logistics and infrastucture, e.g. cell therapy suites, and training to develop a cadre of clinical trial nurses

- Technology is closest to clinical use with lung, breast and colorectal cancers

- Clinically approved treatments are currently limited to 'like for like' tissue applications e.g. using corneal stem cells in treatments for eye disorders

- In 2015 the Cell Therapy catapult recorded 51 clinical trials in progress of which 23% were in oncology, 17% in neurology and 12% in gastroenterology

Stem cell therapies have long term potential in personalised healthcare. Although a limited number of stem cell therapies are available in the NHS (and unregulated treatments are being accessed in private clinics) it will be several years before we can expect to see a wider array of these therapies approved for routine use in the NHS. Clinical trials are still at a relatively early stage and, assuming scientific validity and safety is established, there will be significant regulatory and health economic conditions to satisfy.

Portable diagnostic bioassays

Portable diagnostic bioassays (PDBs) are devices or tools that can be used to diagnose or monitor patients' status at the point of care, eliminating the need to transport samples to a laboratory

The science

The technologies underpinning portable bioassays devices (PDBs) are varied, ranging from simple, dip-stick or paper based systems, to electronic, 'lab-on-chip' style devices. Ultimately these devices all operate on the basis of searching for a specific molecule in a given sample, e.g. detecting the hormone HCG in urine as a marker for pregnancy.

PDBs differ from traditional laboratory diagnostic devices in their size (often hand-held), portability, and self contained test mechanisms. This makes them amenable to remote self-monitoring and point of care testing.

Innovations in mobile phones, wearables, DNA sequencing, microfluidics and microelectronics are driving the next generation of PDBs.

Health check

- The market worth is projected to grow to $2.75 billion by the end of 2018

- There is considerable commercial investment and development, suggesting how profoundly the field could change the process of care

- Timely access to diagnostics tests is key to delivering on the current political ambition of a seven day NHS

- Many PDBs are already in use within the NHS. Some more recently than others, like the Labkit ® system, designed to be a 'lab in a bag' for use by paramedics

- Upcoming changes in the legislation surrounding self testing could impede innovation and uptake

- Care pathways will need to be restructured and reorganised if the benefits of portable diagnostics are to be reaped
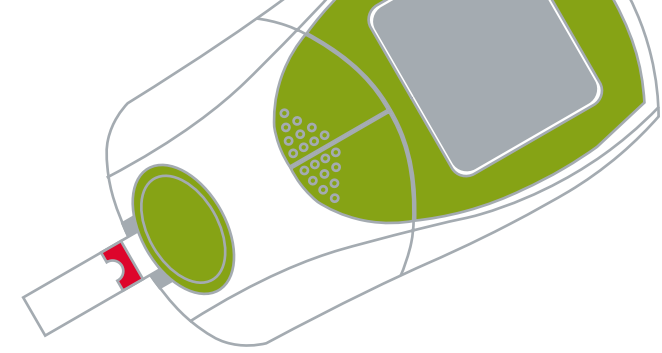
How it could help

Better access to diagnostics

PDBs can expand access to diagnostics because of their portable nature and by removing the need for laboratory facilities

Time to treatment

By reducing the turn around time from taking a sample to finding a result, PDBs can speed up treatment decisions in time sensitive situations

Monitoring

Portable personal devices allow improved provision of care and treatment for patients with ongoing conditions e.g. by enabling self-monitoring

Cutting costs

In principle, the time saved by earlier disease detection and rapid results, can save money through more effective use of resources

Whilst PDBs have been used within the NHS for some time, in the last few years they have not dominated diagnostic testing or evolved considerably in their capabilities. Developments in emerging technologies may change this. As the capability of the technology expands, its potential to improve the personalisation and quality of treatment is massive. In particular, PDB technologies could have a dramatic effect on the management of health services in countries with a shortage of laboratories, and overstretched health services.

The field of microfluidics is concerned with controlling the movement of fluids in very small spaces, within devices that aim to miniaturise macro (i.e. normal scale) laboratory processes. At such scales, fluids behave in a way that can be utilised for many clinical or biological applications, such as implantable biosensors, point of care testing devices or portable diagnostic bioassays

The science

Miniaturised laboratory experiments take place in devices that combine a microfluidic chip(s) and accessory equipment to enable the device to work. Microfluidic chips measure a few mm to cm in size.

Some are made of hard material, e.g. glass, and have networks of channels, reservoirs and mixing chambers, cut or printed onto a substrate material. Fluids behave differently on the micro-scale and accessory equipment is needed to control fluid flow and mixing within the chip. Paper or cloth can also be used to construct microfluidic devices utilising capillary action, passive flow or wicking, which can be controlled by the creation of hydrophobic barriers, printed or woven into the material.

Accessory equipment is needed to control the inputs and outputs of the device and to measure results. The size and scope of this equipment affects the size of the final device and the situations in which it can be used effectively.

How it could help

Point of care

Microfluidic technology is already in use, both in laboratories and real world settings. Applications include: chemical synthesis and drug discovery; health monitoring; genetic analysis; cell analysis; implantable devices and point of care (POC) testing. POC devices are already being used in hospitals to test patients and enable swift clinical decisions

Accessibility

Devices at this scale have many advantages including: small sample sizes; multiple experiments can be conducted at once; reaction conditions can be precisely controlled; devices are easy to transport, cheaper to produce and store

Health check

- Although microfluidic technologies are in widespread use, only some laboratory processes have been miniaturised. There is a consensus that the 'killer application', the transformative technological development that will allow universal miniaturisation, has not yet been found

- More research is needed into the costs versus benefits of using microfluidic devices, e.g. in point of care testing

Devices containing microfluidic technologies are widely used in clinical and laboratory settings and have great potential in enabling other advances - facilitating research, development and clinical diagnosis. These devices could have significant impact in addressing global concerns, such as infectious disease outbreaks, and also in low-resource health systems, where the advantages of portable and infrastructure-independent devices can be realised. However, the transformative technology that can replace all laboratory processes with miniaturised microfluidic devices does not currently exist – the universal mini-lab is for the future.

Implantable biosensors

Biosensors are devices that provide information about an individual organism using minimal human input. Where implantable biosensors monitor validated biomarkers they can be used to manage chronic conditions, aid personalised treatment and are showing potential in the early detection of disease

The science

A biosensor comprises a biological sensing element coupled to a transducer that converts the signal produced by the sensing interaction into one that is easily measured and quantified. A third element displays the results in a user-friendly way. The tiny biosensors can be implanted under the skin or elsewhere within the body. They then measure biomarkers - biological components such as enzymes, DNA or cells which are indicators of normal or disease processes, or the effects of drugs in the body.

Recent advances in nanomaterials and wireless technologies are overcoming early obstacles such as miniaturisation and strong signalling.

Health check

- Mechanisms needed for efficient and secure collection, storage, analysis, interpretation and sharing of the huge volumes of data that will be generated by biosensors

- Regulation will be important e.g. clinical validity of data from biosensors, as will agreement on appropriate clinical responses to given information

- Existing approaches may be more effective, cost-effective or acceptable to patients than implantable devices

- Use in chronic disease management still relies on patient acting on the information provided by biosensors – but failure to respond to natural signals from body (such as pain) is common

- Biosensors that can measure levels of five different substances simultaneously are in a proof-of-concept clinical trial for schizophrenia

- Implantable continuous glucose monitor by Senseonics received CE approval in the UK in May 2016

How it could help

Chronic disease management

Reduce non-compliance with regular glucose readings for diabetes patients by offering automatic, painless testing; could potentially be paired with continuous drug delivery methods

Personalised healthcare

In medicine, chips are in development to measure changes in biomarkers that influence a tumour's response to radiotherapy or chemotherapy. In personalised prevention, biosensor in early-stage development to measure genetic mutation biomarkers in blood that indicate disease

Health management

Could be used in clinical trials to track the effects of drug candidates on the body precisely and in real time, speeding up evaluation

Post-operative care

Potential use in tracking biological responses in real time before, during and following procedures such as hip implant operations

Implantable biosensors delivering automatic and precise real-time measurements of biomarkers could ultimately become a central element of personalised healthcare, offering continuous monitoring of our bodies to detect early disease and assess response to treatments. However, for this to happen there is still much to be done: overcoming technological barriers (e.g. extending device life), addressing potential public concerns, validating biomarkers and dealing with big data issues.
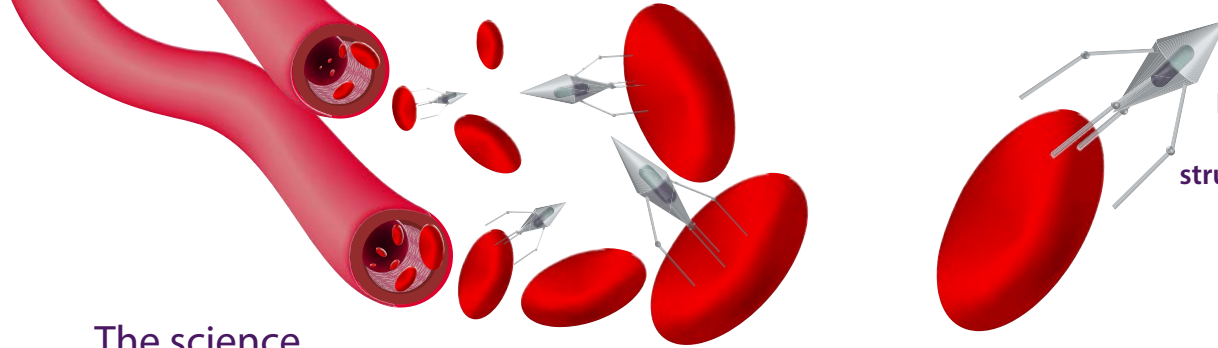
Nanotechnology is the science, technology and engineering of very small devices or molecular structures. In medicine it has exciting potential for drugs, implants and diagnostic tools

Nanotechnology

The science

Nanotechnology operates on an exceedingly small scale: between one and one hundred nanometres - only visible with an extremely high powered microscope. Materials constructed at this small scale have many beneficial characteristics, such as electrical super conductivity, anti-bacterial properties or binding ability which have many potential uses in medicine. The exceptionally small size of nanomaterials means they can penetrate living cells, while their durability means they can stay in the body without degrading.

'Programmable' nanomaterials, such as dendrimers or liposomes, can be constructed to contain pharmaceuticals, allowing the targeted delivery of compounds to specific sites. Nanomaterials are being developed as biocompatible replacements for parts of the body, such as bone substitutes, dental restoratives or soft tissue implants.

Health check

- Regulations tends to be on a product by product basis. This unpredictability is creating uncertainty and hampering investment

- Knowledge gaps and uncertainties persist, making it difficult to assess the health, environmental and ecological impacts of nanotechnology

- There are many inherent production barriers including: reproducibility, quality control, unwanted byproducts, scalability, high costs and production rate

- The complexity of the current regulatory environment makes the cost of achieving regulatory approval for certain nanotherapeutics, specifially for rare diseases, prohibitively high

- The nanomedicine industry is predicted to be worth $196 billion by 2020

- The worth of nanomedicine in the drug development sector is predicted to rise from $12.6 billion in 2014 to $32.2 billion by 2019

How it could help

Pharmaceuticals

Utilisation of nanotechnology carriers to deliver pharmaceuticals is already a clinical reality. Truly 'smart drugs', multifunctional nanocarriers containing targeted, diagnostic and therapeutic agents personalised to the patient, could be the next step

Personalised medicine

Nanoscale materials could be used in diagnostic systems to create exceptionally accurate sensors capable of detecting and mapping hundreds or even thousands of diseases at the same time with a high degree of accuracy

Health management

Implantable nanodevices and tailored, controlled release drugs allow for accurate and extended disease management, whilst nanomaterial based replacements increase medical stability and reduce rejection rates

Nanomedicine has the potential to genuinely revolutionise personalised healthcare across the board - from prediction and diagnosis through to treatment and monitoring. However, whilst the implementation of nanotechnology to date has improved the effectiveness of medicine, truly personalised technologies are still relatively far from commercialisation, let alone common use. For even the most promising technologies in the testing phase or clinical use, production costs are exceptionally high and health and safety concerns persist within a complex and uncertain regulatory system. As a result, the mainstream implementation of nanomedicine is still some way off.

3D printing

Also called 'additive manufacturing', 3D printing builds layer upon layer of a material to create a new product in three dimensions, offering a more precise and customisable alternative to traditional manufacturing - with potential for medical applications

The science

A wide range of materials can be 3D printed, including metals, powders and living cells. In 2016, the first examples of 3D printing using multiple materials emerged. Techniques for 3D printing vary but the concept is the same - the object to be printed is scanned (e.g. by x-ray, MRI or CT scan) to create a 2D image.The 2D image is converted into a 3D print file containing instructions for the 3D printer, which then prints the object.

Health related applications include highly customised scaffolds (porous, biodegradable structural implants that guide and stimulate tissue regeneration), medical implants and prostheses, surgical models, hearing aids and drugs.

Health check

- 3D printing market for medical and dental applications is expected to expand by 365% to US $867 million (£523 million) by 2025

- No strategy for NHS-wide implementation

- Lack of data on economic benefits

- Lack of data on long term benefits for patients or quality and durability of products

- How should safety of highly customisable and therefore variable - products be regulated

- Not all materials are suitable for printing

- 3D printed activity is taking place in clinical research, commercial and healthcare settings. Maxillofacial surgeons are using 3D printed products to plan surgery and for implants
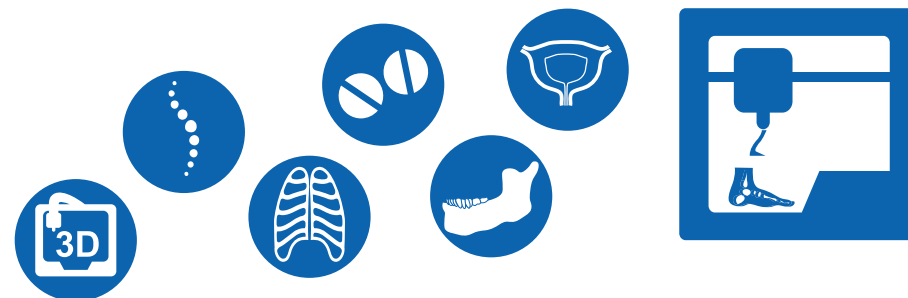
How it could help

Highly customisable

Bespoke 3D printed models of patient organs can help surgeons more precisely plan operations; scaffolds, implants and prosthetics can be accurately tailored to fit the individual's body

Better outcomes

Biodegradable scaffolds implanted into patients could guide and stimulate tissue regeneration, potentially reducing the need for further surgery

Accessible

In principle objects can be printed on demand, anywhere. Design ideas may be crowdsourced

Faster

The few hours it takes to 3D print a customised product is faster than using traditional manufacturing methods

Looking beyond the hype surrounding 3D printing, there are credible examples of where the technology is having or is expected to improve clinical outcomes. This technology enables better personalisation of healthcare and has the potential to prevent or at least reduce secondary complications following treatment. There is still work to be done on assessing the anticipated impact of the technology and how it could benefit patients. The lack of an NHS strategy for implementation or investigation into the policy implications of the use of this technology in healthcare could slow uptake in the UK.
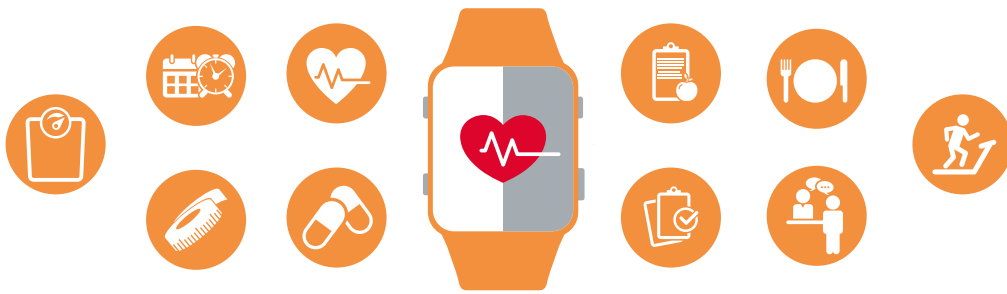
mHealth is 'the delivery of healthcare services via mobile communication devices' *, a huge field ranging from telemedicine and mobile phones to patient monitoring devices such as wireless sensors and wearables

The science

Sensors on or even inside the patient detect physiological signs, data about which is transmitted to a receiver (e.g. a smartphone or PC) then sent wirelessly to the wearer or to a health provider to be actioned. Real-time data can be used to alert the wearer or healthcare staff prompting them to take action e.g. take a medicine or increase activity. This data can be stored in patients' electronic health records for use in follow-up appointments.

How it could help

Personalised prevention
Tracking physical activity to help with excercise programmes. Crash helmet sensors can help alert emergency services following an accident

Independent living
Motion sensors can detect doors opening, toilets flushing or provide medication and appointment reminders

Better outcomes
Monitor vital signs such as heart rate, glucose level or give access to medical and health expertise, including consultations

Health check

- Integration into routine care will require investment in staff, IT and purchasing devices

- Need for interoperability so apps could be incorporated into health records

- Lack of evidence on accuracy and utility for the diversity of apps coming onto the market

- Risk of increasing health inequalities

- The UK National Information Board is developing a set of endorsed NHS and social care apps for healthcare professionals to use or recommend to patients

- Fits government agendas of personal responsibility for health and potential support for personalised prevention

- 0% time saved in data access and analysis

- Estimates suggest the Propeller health system that monitors asthma could reduce US spending on asthma by 50%

mHealth has the potential to transform health services, with benefits for patients, professionals - and finances. However there are barriers that must first be tackled, including the current lack of system-wide integration into health services; the ways in which personal data will be used; and the risk of increasing health inequalities between those with and without resources to fully engage with mHealth.

*National Institutes of Health (NIH)

Virtual reality

Virtual reality (VR), creating computer generated but realistic environments that are displayed to users, could have numerous healthcare applications for both patients and professionals

The science

VR is not a recent concept or technology, but only in the last five years has the technology matured fully. It works by creating a computer rendered simulation of a 3D environment displayed through a headset. The user interacts with it in a realistic manner using head or position tracking systems and a controller or hand and gesture recognition.

High end consumer systems can cost over £500, and can display cutting edge simulations at high quality and speed. A computer able to handle the demanding processing requirements amounts to around £600 at the very least. Lower cost options, using smartphones cost as little as £15 plus the smartphone but are less capable of displaying high fidelity, low-latency images. They have limited interaction capabilities, making them better suited to simpler applications.

Health check

- Development has been rapid, mainly driven by the games industry, which has shouldered the production and R&D costs. Innovate UK, the Digital Catapult and the European Regional Development Fund have all awarded funds for VR development, but focus on VR in general and not healthcare

- There is no clear guidance on validation or accreditation of VR in healthcare, which risks exposing consumers to potentially dangerous content. There are also protection and privacy concerns around the potential use of personal data

- Evidence for its utility and efficacy is limited, with no studies of longterm use or economic analyses of costs and benefits of using VR in healthcare

- Estimated worth of the virtual reality industry is predicted to rise to about $25 billion by 2021

- Creating VR simulations requires extensive technical expertise; most medical VR applications have been collaborations between tech and healthcare

How it could help

Phobias & stress

A particularly promising use for VR is in treating mental illness, specifically for phobias or PTSD. The classical treatment for a phobia is to expose the patient to what they fear in a controlled manner. With VR, this process can be easily achieved. An NHS trial of a VR technology called the 'blue room' is in use for children with autism, and is now accepting referrals for further study

Planning surgery

A combination of medical imaging, 3D computer modelling and virtual reality could be used to help plan surgeries; a number of trials in surgical specialities have had some positive results. In the future, VR could form the basis of an interface for robotic surgery

Medical training

Immersive high fidelity VR simulations could be used as training aids, but it will be essential to ensure that the simulation is of a high enough quality to demonstrate optimal techniques, and not put patients at risk

Medical applications of VR are very much in their infancy. As consumer hardware improves and becomes more readily available, we can expect to see its development for clinical application. However, demonstrations of its feasibility in healthcare settings are of questionable quality and focus mainly on short term outcomes. Further evidence of effectiveness will help with the integration of VR into healthcare. On its own VR is unlikely to transform healthcare, but in conjunction with other technologies, e.g. robotics and machine learning it could have an impact, especially in areas such as mental illness and training.
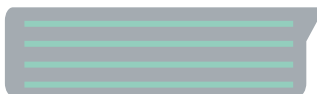
Bots are computer code applications that perform automated tasks. In medicine bots are being developed for use by patients and clinicians

The science

Computer bots have been around for years, but recent improvements within the field of artificial intelligence have massively expanded their capabilities. Two related technologies - machine learning and natural language processing (NLP) - are key to the improved capabilities of next generation bots. Using NLP, bots can interpret the intent behind what we say despite the idiosyncrasies of our speech.

Medical bots can be integrated into existing messaging apps, to communicate with patients by text, asking questions about symptoms and giving algorithmically derived advice.

Health check

- It is unclear how forthcoming regulations on diagnostic devices and data protection will impact on the development of AI medical bots

- AI and its uses have been subject to ongoing Parliamentary debate and Government consideration

- A lot of useful health related data needed for developing AI algorithms currently resides within the health system. This data is often difficult to extract and use because of technical, regulatory and public trust related factors

- Questions remain as to how health services will integrate AI bot derived information such as triaging advice into medical pathways

- One study analysing 23 different symptom checkers concluded that they tended to be risk averse and encourage unnecessary consultations

- It is unclear how companies may use data submitted to bots by users for their own purposes, such as marketing or developing algorithims

- It is difficult to evaluate the economic impact of medical bots given the relative paucity of evidence including the accuracy and effectiveness of symptom checking and triaging recommendations

How it could help

Support self management

Symptom checking bots could help reduce unnecessary GP consultations by supporting individuals to self-manage minor ailments, but also advise when they should promptly seek medical advice

Patient triaging

Bots are being developed to assist health systems in triaging patients. An AI powered chatbot is being trialled across parts of London as an alternative to the NHS 111 non- emergency service

Patient engagement

With the vast growth in mobile and messaging apps, conversational health 'chat'-bots may encourage individuals to engage more in their health and easily access answers to their health-related questions

Patient management

Whilst existing bots work with a users' entered symptoms, future bots could integrate data generated by smart devices and monitors to generate automated alerts and reminders and to help patients, such as those with diabetes to better manage their own care

Whilst medical bots are already in use, their current applications remain limited, and questions of utility, accuracy and effectiveness abound. However, as the technology improves and the applications of AI bots widen they could have considerable impact, especially in personalising healthcare by improving detection, triage procedures and patient adherence to treatment plans. The pace of progress is likely to be influenced by factors that impact on data availability to develop AI bots, including public trust for sharing data, the rate of uptake, regulation and addressing technical obstacles.

Machine learning

Machine learning is a form of artifical intelligence which can be used in healthcare to identify new biomarkers, refine our understanding of disease and help personalised care and prevention

The science

Machine learning is a statistical approach used for analysing big data sets. It uses algorithims that actively learn from data and improve performance with experience, without being explicitly instructed by man-made rules.

Data generated both within and outside the health system can be valuable for optimising and developing machine learning algorithims for health.

How it could help

Developments underway

Developments underway include: medical image analysis in radiology; early detection (e.g. in cancer) and personalised prediction; drug discovery and remote monitoring and virtual assistants

Machine learning in use

Risk management support tools - e.g. for hospital readmission, prescribing error detection. Predixion, a risk management support tool which flags patients at risk of hospital readmission, has been used by Carolinas Healthcare System in the USA. It reduced readmisssions of patients with COPD from 21% to 14% over two years

Health check

There are multiple obstacles to collating the required data sets including:

- Paper health records are still rife - data is needed in a digital format

- Lack of standards for describing data - makes data integration from different sources challenging

- Public trust - reservations to data sharing, especially with private companies

- Collaborations are needed between health organisations and the computing and technology industry for the full impact of machine learning to materialise

- Assessing machine learning tools in health could be hard as the logic used to reach a conclusion isn't always clear

Given the number and breadth of applications under development the use of machine learning in healthcare looks promising. However realising its huge potential will require addressing the technical, structural, social and regulatory challenges to gathering and integrating relevant and representative datasets. Overcoming these challenges will be essential for developing machine learning algorithms that yield valid insights and function correctly for all individuals.
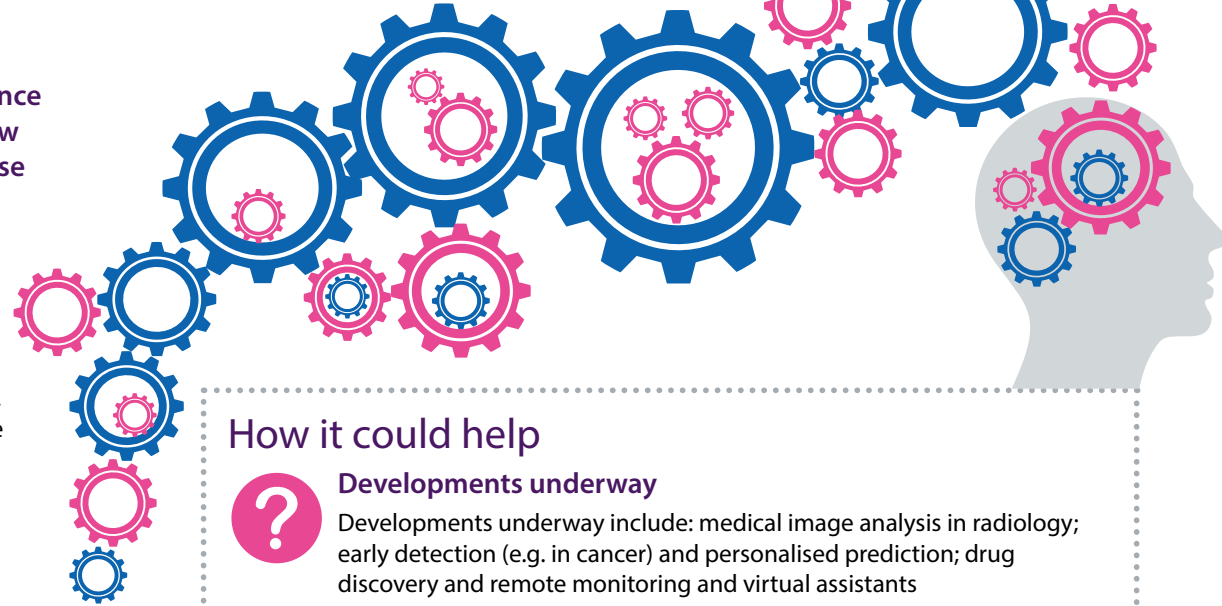
Internet of medical things

The science

IOMT encompasses a wide range of devices, technologies and services including mobile phones, static sensors, cloud data, AI and telecommunications.

Sensor equipment, whether wearable, implantable or within a home, can digitally transmit its readings to a mobile phone, computer or the cloud. Different combinations of components result in different levels of application, ranging from a simple tracking chip, using radio technology to more complex applications, able to monitor, analyse and prompt a response.

A large number of companies are involved in designing and connecting devices and there are also open source platforms through which individual citizens have contributed to development.

Health check

- Numerous UK government policy initiatives have sponsored IOT and IOMT development, £30 million in 2017, and £40 million in 2014

- There are a large number of commercial companies active within the field both independently and as part of academic partnerships including: Google, Microsoft, CISCO and Intel

- Whilst there is currently a clear boundary between commercially and medically orientated devices, this line is likely to blur in the future

- Although purportedly low cost, supportive health economic analysis is currently lacking

- For many healthcare providers, the digital infrastructure to effectively utilise IOMT is not in place

How it could help

Assisted living

Activity monitoring devices allow vulnerable groups to live independently and care to be administered when needed. An NHS test bed project, technology integrated health management, is aiming to identify what technologies could improve in-home dementia care

Chronic disease

A combination of devices can be used for patients with long-term conditions such as diabetes or cystic fibrosis. By combining wearables, smart-medicines or ingestible sensors, patients can better self manage their condition and enable remote monitoring by health professionals

Cancer treatment

Activity tracking devices can be used to gather lifestyle data for patients with cancer. Collecting data such as appetite or activity level before, after and during treatment to assess how well the patient is reacting to therapy

The number of connected 'smart ' devices in the world is expected to reach 200 billion by 2020, roughly 30% of which will be part of a dedicated IOMT. This rapid pace of expansion threatens to leave health services behind as they struggle to provide the digital infrastructure necessary to manage and effectively use all the data that an average of eight medical devices per person could supply. Concerns about data safety, security and privacy will need to be resolved. And whilst IOMT may enable a move into a citizen led healthcare system, this will require greater involvement and responsibility from individuals in managing their care, and greater trust from them when it comes to sharing their data. Without these the benefits of the IOMT may never be realised.

The PHG Foundation is a non-profit think tank with a special focus on how genomics and other emerging health technologies can provide more effective, personalised healthcare and deliver improvements in health for patients and citizens

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