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Final Report: Identification of AI Technologies in Healthcare

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1. Background and Introduction

Artificial intelligence (AI) is the umbrella term to classify technology that mimic human intelligence, which can be used to automate, predict and optimise everyday human tasks. AI is often used interchangeably with machine learning and deep learning; however, they have different definitions. Machine learning requires human intervention to learn and understand data (i.e. labelled datasets); whereas, deep learning is unsupervised and can train itself using unstructured data[1]. AI interventions have enormous potential for improving the delivery of health and social care because of their ability to reduce the burden on healthcare systems by taking on tasks that can be converted into an algorithm. AI is most commonly applied to early detection and diagnosis, treatment, as well as outcome prediction and prognosis evaluation. More recently, AI tools have been developed to support core business operations to enhance productivity and efficiency, and to reduce operational risks. The translation of AI innovations into clinical services is not without challenges, but the benefits that it can offer has made it an attractive solution to increasing health demands.

The increase in AI research, a better understanding of the benefits that if offers and the large number of AI developers across the world has led to greater attention, and accelerated adoption of these technologies in multiple health care areas. As such, NHSx (via the Accelerated Access Collaborative) requested a horizon scan to ascertain the global pipeline of AI technological interventions (e.g. products) that are in development or commercialised in health and social care. This overview of AI development provides comprehensive intelligence on the developers, stage of development of products, market authorisation (e.g. CE marked or US FDA approved), country of development, clinical condition and application. Whilst interested in the application of AI broadly to health and social care (whole market), NHSx also specified 4 areas of particular interest:

- Medical Imaging/Radiology/Scanning (including oncology)
- Cardiology
- Dermatology
- Ophthalmology

The Innovation Observatory has developed this report to highlight the healthcare landscape of AI innovations and to provide important, immediately relevant data on key areas of development, to allow readers to evaluate the potential impact of these innovations and identify promising innovations for use in the NHS (or wider). To help with clarity and comprehensibility, the report has been organised and presented into four main sections:

1. Horizon scanning strategy – an overview of the search strategy devised to identify AI technologies and related evidence.
2. AI health technology horizon scan – an overview of the pipeline of AI technologies in healthcare, and the defining characteristics of the data captured.

3. Emerging patterns of AI in published literature – visualisation of key themes based on the results retrieved from the scan of bibliographical databases.
4. Summary of key themes from business intelligence including the future of AI in healthcare.

The technologies and intelligence identified in the horizon scan will be used further by NHSx to consider existing technologies for use in the NHS in future. The outputs from this work will also contribute to the annual NHSx AI Lab report, to be published in Q1 2021.

2. Objectives

1) To complete a horizon scan of AI technologies across health and social care, including a targeted scan of mature AI technologies for scanning/medical imaging, oncology, cardiology, dermatology, and ophthalmology.

2) Summarise business intelligence on AI, with the focus on finding key themes and trends, including the activities of established firms such as Google.

3. Methods

3.1 Search strategy

The horizon scan methodologies developed by the Innovation Observatory to 1) identify the pipeline of AI technologies across healthcare (general scan) and 2) identify AI technologies for the clinical areas of interest (targeted scan), involved the identification of information sources that detected 'signals' for AI health technologies. The collection of sources that were identified were systematically scanned using a combination of traditional scanning methods (manual), automated and novel text mining techniques. Search strategies were created for specific sources (e.g. clinical trial registries, bibliographical databases) and combined key terms related to AI and or clinical conditions. These searches were performed between December 2020 and January 2021 and included a date limit of January 2019 (unless otherwise stated). Based on successive screening of sources (i.e. identification of AI technologies), intelligence was extracted and imported for further data processing.

Information sources used as part of these scans included:

- ScanMedicine[2], the Innovation Observatory's clinical trial database containing information from 11 registries across the globe (e.g. UK, Europe, USA)
- Bibliographic databases, including PubMed[3], EMBASE[4] and MEDLINE[5]
- Regulatory agency sources (e.g. US FDA)[2]
- MedTech news websites (e.g. Fierce Biotech)[6]
- Conference outputs (including exhibitor lists)
- Commercial websites and reports

- Academic institution webpages

3.1.1 Inclusion criteria

All AI technological interventions with application in healthcare were included in the scan results. Clinical condition was identified from the product description (where available), though it is important to note that some products have applications beyond one health condition. All technologies were further classified (see below) and all information is collated within the AI Dataset (Excel file accompanying this report):

Classification of AI technologies:

- Clinical area and condition (if applicable/specified)
- Type of Scanning/ Medical Imaging (if applicable/specified)
- Classification of technology by a) prevention and health promotion b) diagnosis and treatment c) intelligence operational automation
- Country of Development
- Classification of development stage by Phase 1 (proof-of-concept stage); Phase 2 (prototype); Phase 3 (technology validated/demonstrated in relevant environment); Phase 4 (commercialised i.e. regulatory approved)
- Regulatory status/market authorisation (including list of approved markets)

In addition to these fields, information related to clinical trials or published evidence was also captured. Furthermore, intelligence relating to funding/investment, company size, development awards or patents that was available during the review of sources was captured under 'Additional Comments' in the AI dataset (Excel file).

3.1.2 Exclusion criteria

This scan excluded technologies that did not have application in healthcare.

3.1.3 Limitations

All technologies captured were identified from open data sources. The classification of technologies was complex and at times subjective due to limited or incomplete information available for the technology or complex aspects of the technology or application which require expert knowledge.

The regulatory information extracted from information sources (with the exception of information directly derived from the US FDA databases) was not verified. Furthermore, there is no open source regulatory database for European market authorisation (e.g. EU CE).

For technologies with clinical applications beyond one health condition, all conditions were captured within the clinical condition field. For the purposes of data analysis these products

were counted under each clinical condition. Likewise, a number of technologies were reported to be in development across multiple countries. The visualisation of development (**Figure 1**) at the country level, does count technologies associated with multiple countries under each country.

4. AI Health Technology Horizon Scan

The following results section contains a select number of visual representations of data relevant to the development landscape of AI technologies. The technological innovations presented include those in development or regulatory approved from across the world.

4.1 Overview

A total of 801 technological innovations for AI were identified from across 46 countries. Developers ranged from research institutions, small and medium-sized enterprises (SMEs), large enterprises, hospitals, social care organisations and charities. Each technology was further classified to enable the mapping of themes including clinical areas, country of development and regulatory status. Primary sources for discovering technologies included company websites, press releases, MedTech news, conference outputs, academic institutions, bibliographical databases and trial registries. Overall, the dataset has a dispersed geographical base, with 3 countries accounting for 60.7% of AI health technologies.

4.2 Global AI Innovation Landscape

The data displayed in **Figure 1** shows the high volume and increasingly widespread technological developments of AI across the world, based on the development location captured through the horizons scan. The country breakdowns provide valuable insights into the key developed countries with major AI development activities. The most active countries were the United States (246), United Kingdom (153) and China (87).

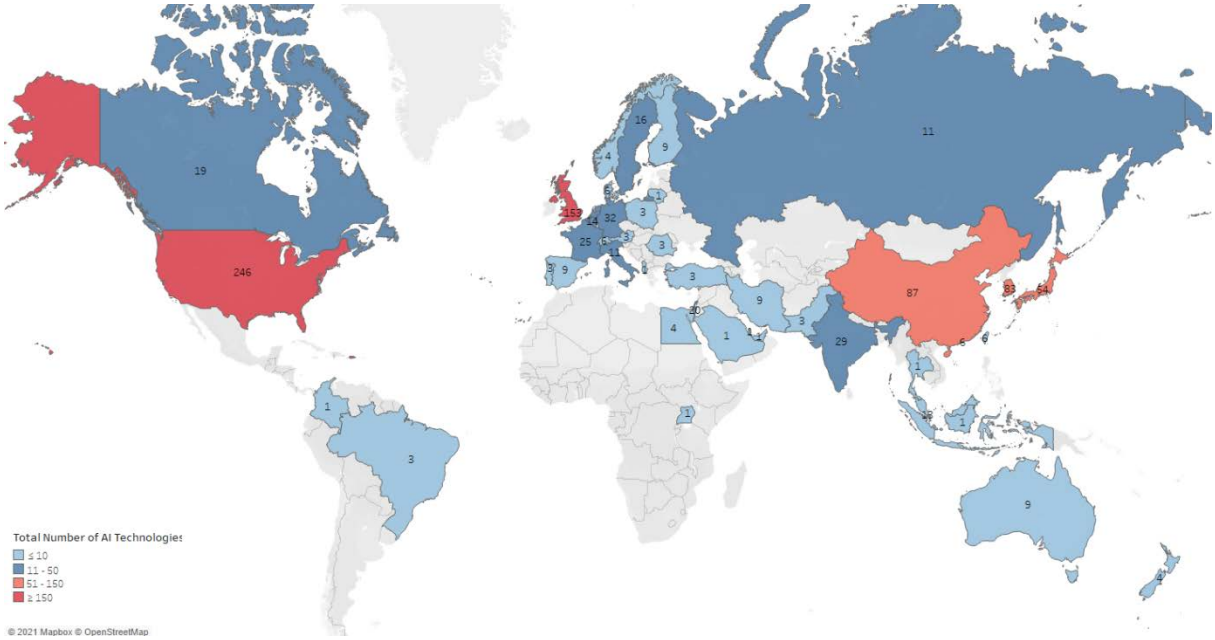

Figure 1. AI Technology Development Landscape

An overview of the global scale of AI technology development, based on 801 technologies identified through the Innovation Observatory's horizon scan, across various developmental stages. 52 (6.5%) technologies were developed in multiple countries (2+), therefore the data presented in the map is a representation of international development, rather than the total number of technologies identified and includes duplicate technology entries in order to represent the countries of development. The United States (246) and United Kingdom (153) held dominant positions, accounting for 49.8% of AI technologies in development.

4.3 Development Stage and Application of AI

AI technologies have the potential to support early detection and diagnosis, treatment, outcome prediction, prognosis evaluation, as well as aid improvements in system efficiencies in healthcare. The characteristics of the AI dataset was analysed in order to summarise the key themes in the use of AI in healthcare and the maturity of the pipeline of technological interventions. Each technology was mapped according to their use (assigned to one category only) and stage of development (assigned to one category only). Overall, 51.6% of technologies identified in the scan were classified as Phase 3, which indicated the technology had previously or was currently being validated/demonstrated in a relevant environment (**Figure 2**). Almost a quarter of technologies (23.8%) were prototypes (Phase 2) and 3.2% of technologies identified were considered proof-of-concepts. The remaining 171 technologies (21.3%) identified had obtained regulatory approval i.e. market authorisation (Phase 4).

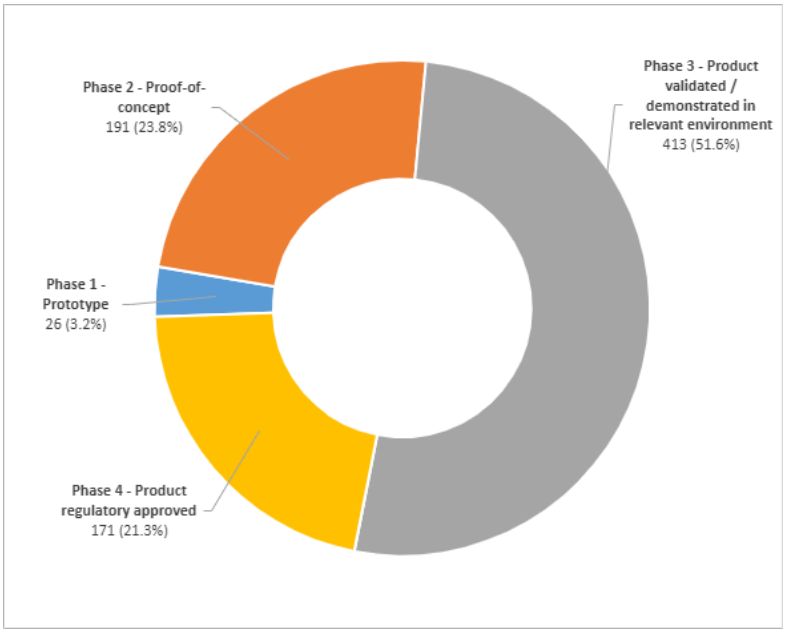

Figure 2. Development stage of AI technology
AI technologies were classified based on their stage of development: Phase 1 (proof-of-concept stage); Phase 2 (prototype); Phase 3 (technology validated/demonstrated in relevant environment); Phase 4 (commercialised/regulatory approved)

Figure 3 provides an overview of the main market authorisations for AI technologies identified in the scan. A total of 171 technologies received regulatory approval and of these 70.7% had received the CE (Conformité Européene) mark of approval in Europe and 65.2% had received the United States Food and Drug Administration (US FDA) approval. Overall, 94.2% of technologies which reported regulatory approval had obtained either CE mark or US FDA

approval. 45.6% of approved technologies obtained approval in two or more jurisdictions, with the majority of technologies reporting approval in both the US and EU (86%).

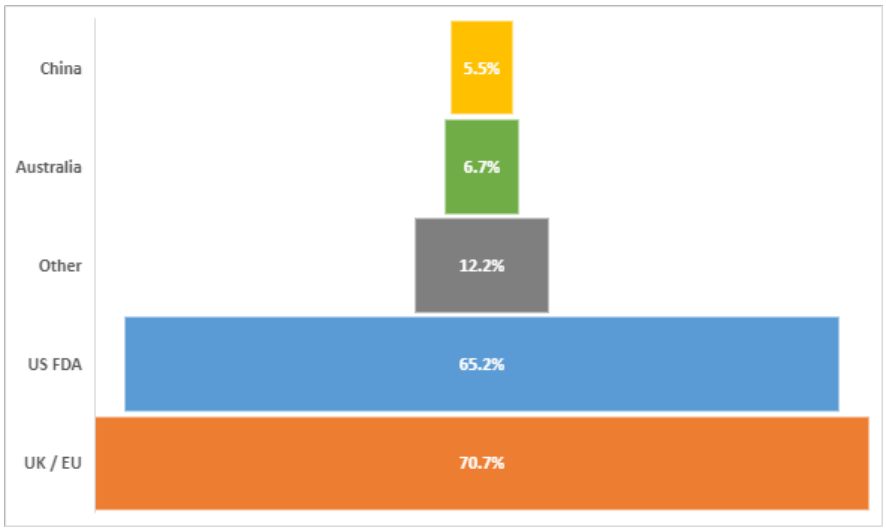

Figure 3. Regulatory approval landscape

As illustrated in **Figure 4**, the vast majority of technologies (68.8%) were developed to support diagnosis and treatment (including prognosis evaluation). 137 technologies (17.1%) were developed to aid in the prediction or prevention of a disease or health promotion. The remaining 113 technologies (14.1%) were developed to aid internal operations (intelligence operational automation).

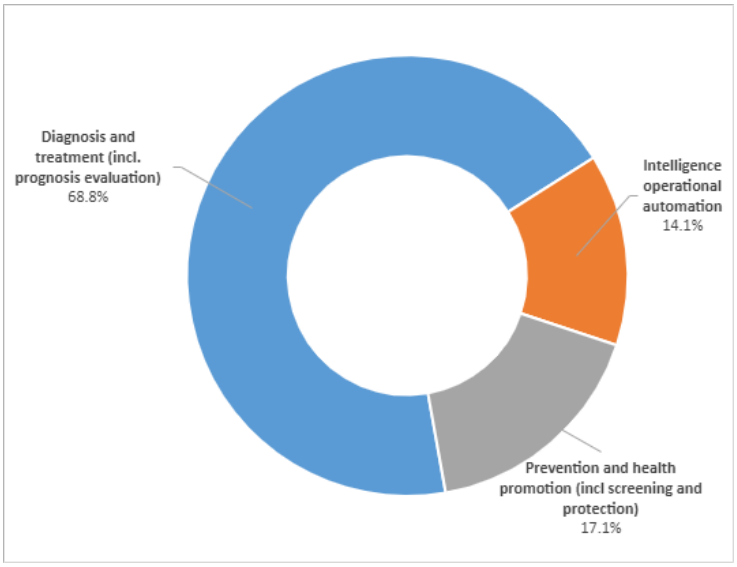

Figure 4. The role of AI healthcare technology in healthcare: Diagnosis and treatment; Prevention and health promotion and Intelligence operational automation.

A closer look at the data revealed that the majority of AI technologies developed to support diagnosis and treatment (**Figure 5a)** were in Phase 3 (45%), followed by phase 4 (26%). There was a significant emphasis on the use of AI for diagnostic and treatment on a range of clinical areas including oncology, cardiology, neurology, dermatology and infectious disease. Technologies developed to aid prevention and health promotion (**Figure 5b**) mainly focussed on cardiology, ophthalmology, oncology and infectious disease. The medical condition for a small proportion of AI solutions could not be identified from the product description available and or source of information, however these may warrant further review if of interest.

Figure 5. Diagnostic and treatment (a) and Prevention and health promotion (b): key themes in AI development and clinical areas of focus.

4.4 Clinical Areas

All technologies identified during the horizon scan were categorised according to the clinical area(s) for which they were repotred to be developed for. As shown in **Figure 6** below, AI is in development across diverse areas in healthcare. AI healthcare technologies were most commonly in development for use in oncology (22.3%), cardiology (14.1%), and neurology (9.2%). Radiology (medical imaging) is one of the main fields in which the implementation of AI is growing in. 51.6% of AI innovations identfied in the scan were integrated with a form of medical imaging, imaging analysis and or scanning to enable diagnosis, prediction of disease risk, triage and to determine the appropriate treatment.

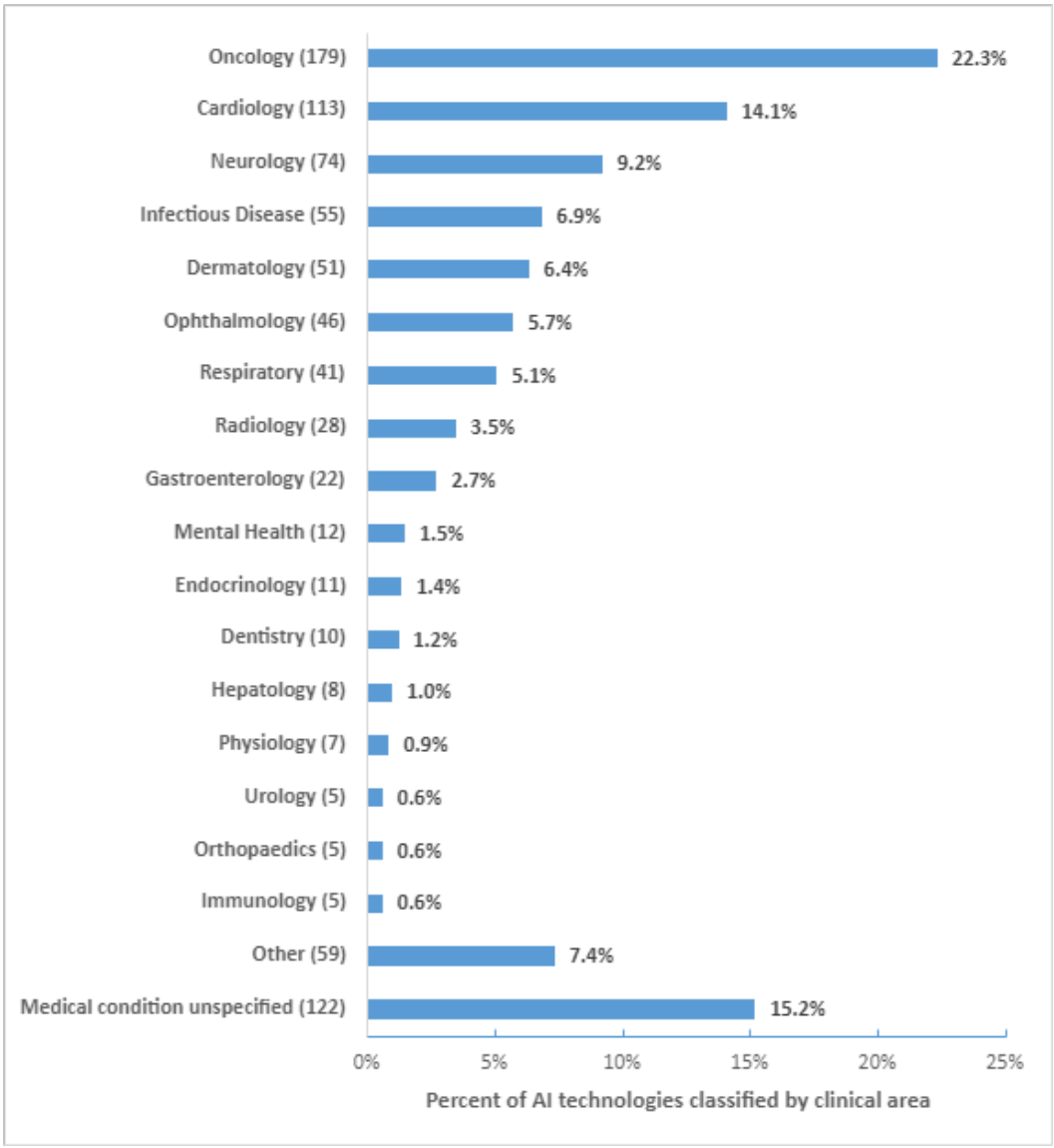

Figure 6. Overview of AI development across a diverse range of clinical indications.

4.4.1 Clinical Area Focus: Oncology

The majority of AI technologies in development for oncology were aimed at diagnosing and treating cancer (85.5%) and overall, 19% of technologies had received regulatory approval. AI-based solutions were mainly clustered around breast cancer, melanoma, lung cancer and prostate cancer. The main imaging applications included CT, mammography and MRI and in addition, we observed a high number of technologies which utilised image analysis (rather than imaging specifically).

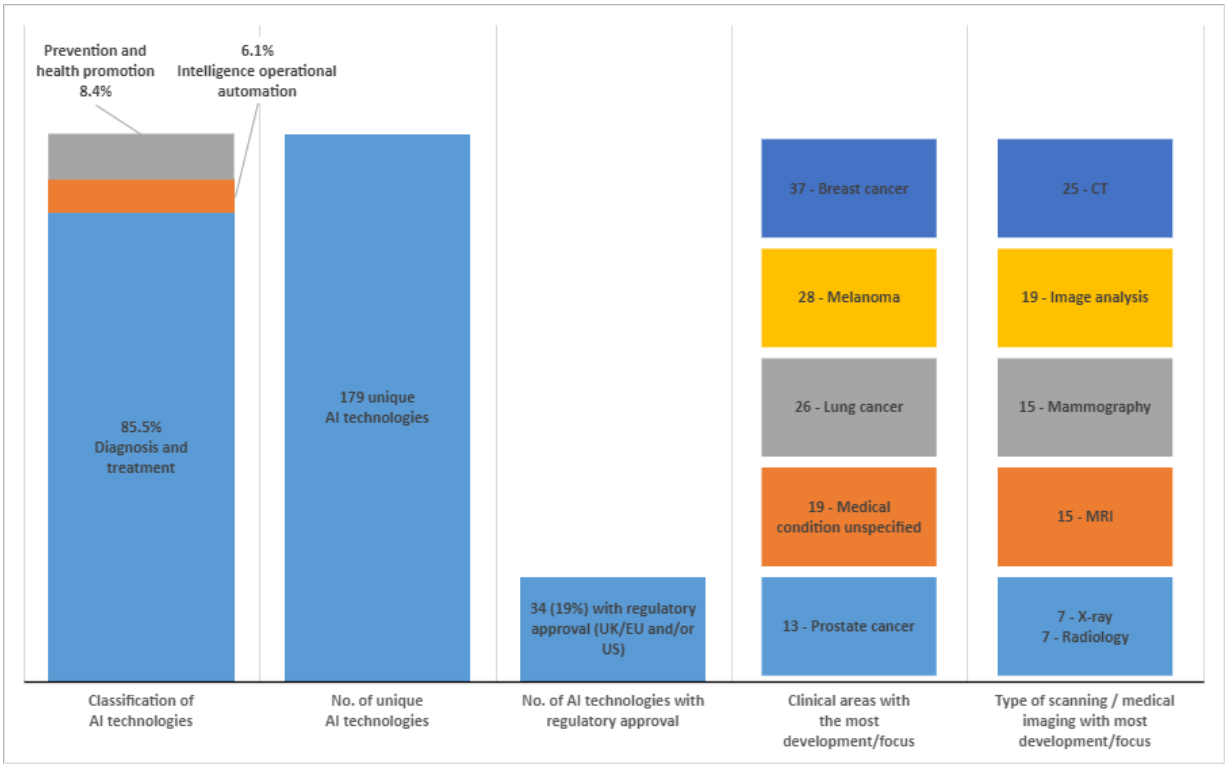

Figure 7. Key themes in AI development activity for Oncology: application, regulatory approval, clinical areas and type of imaging.

4.4.2 Clinical Area Focus: Dermatology

The majority of AI technologies in development for dermatology were aimed at the diagnosis and treatment of dermatological diseases (94.1%). In total 51 products were identified, that concentrated on a diverse range of skin conditions (e.g. actinic keratosis, psoriasis, acne, atopic dermatitis and seborrheic keratosis). The specific condition of 22 AI interventions identified was unspecified (or unknown). Clinical imaging (general/unspecified) and Dermoscopy were the main imaging applications identified for dermatology.

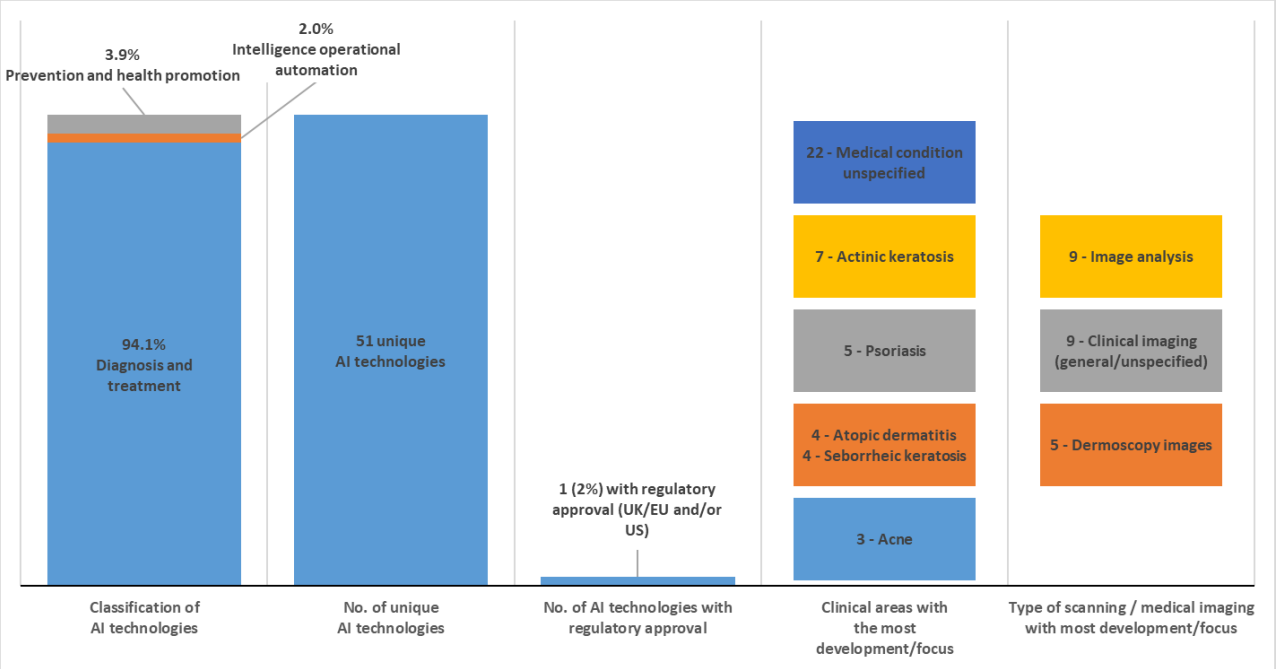

Figure 8. Key themes in AI development activity for Dermatology: application, regulatory approval, clinical areas and type of imaging.

4.4.3 Clinical Area Focus: Ophthalmology

Overall, 50% of AI technologies in development for ophthalmology were aimed at diagnosis and treatment, whilst prevention and health promotion accounted for 45.7%. 17% of technologies have regulatory approval (UK/EU and or US FDA) and the most common areas of clinical application included diabetes/diabetic retinopathy, age-related macular degeneration and glaucoma. The main imaging applications included Fundus photography/imaging (17) and Retinal imaging (4).

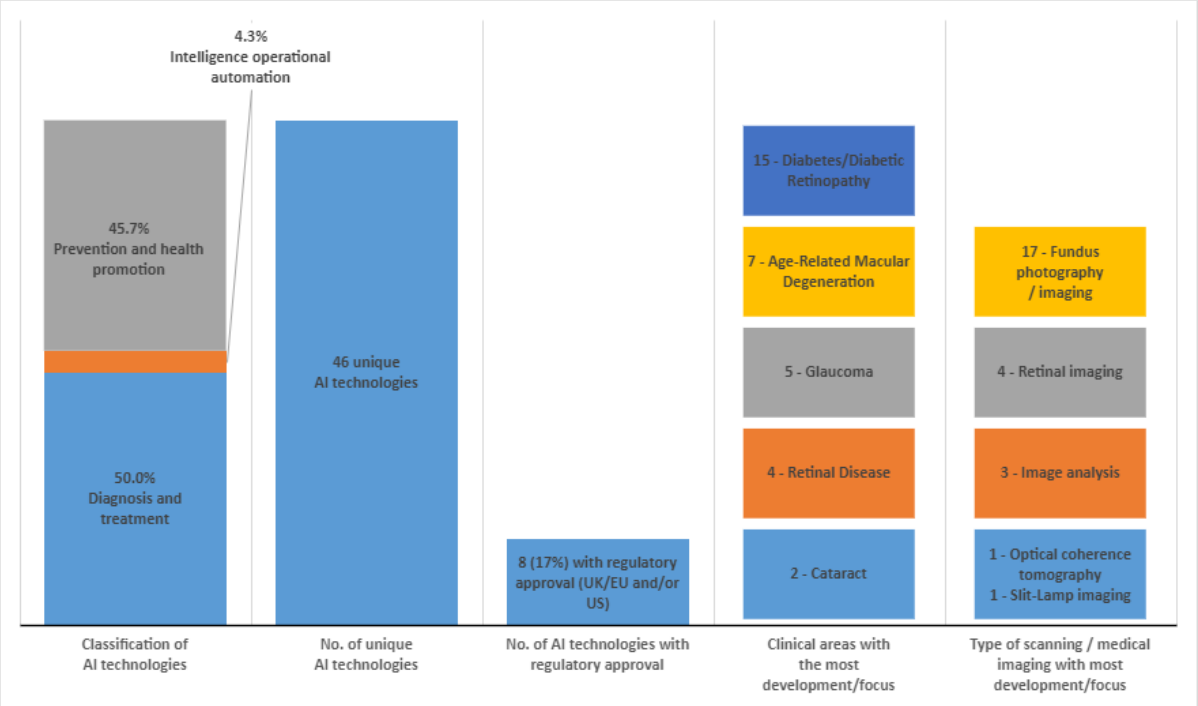

Figure 9. Key themes in AI development activity for Ophthalmology: application, regulatory approval, clinical areas and type of imaging.

4.4.4 Clinical Area Focus: Cardiology

AI technologies in development for cardiology were mainly focused on supporting diagnosis and treatment (58.4%), whilst prevention and health promotion accounted for 32.7%. Regulatory approval (UK/EU and or US FDA) was obtained for 16% of technologies and the most common areas of clinical application included heart failure, heart disease and coronary artery disease. CT, echocardiography, ultrasound, MRI and X-ray were the main imaging applications identified for cardiology.

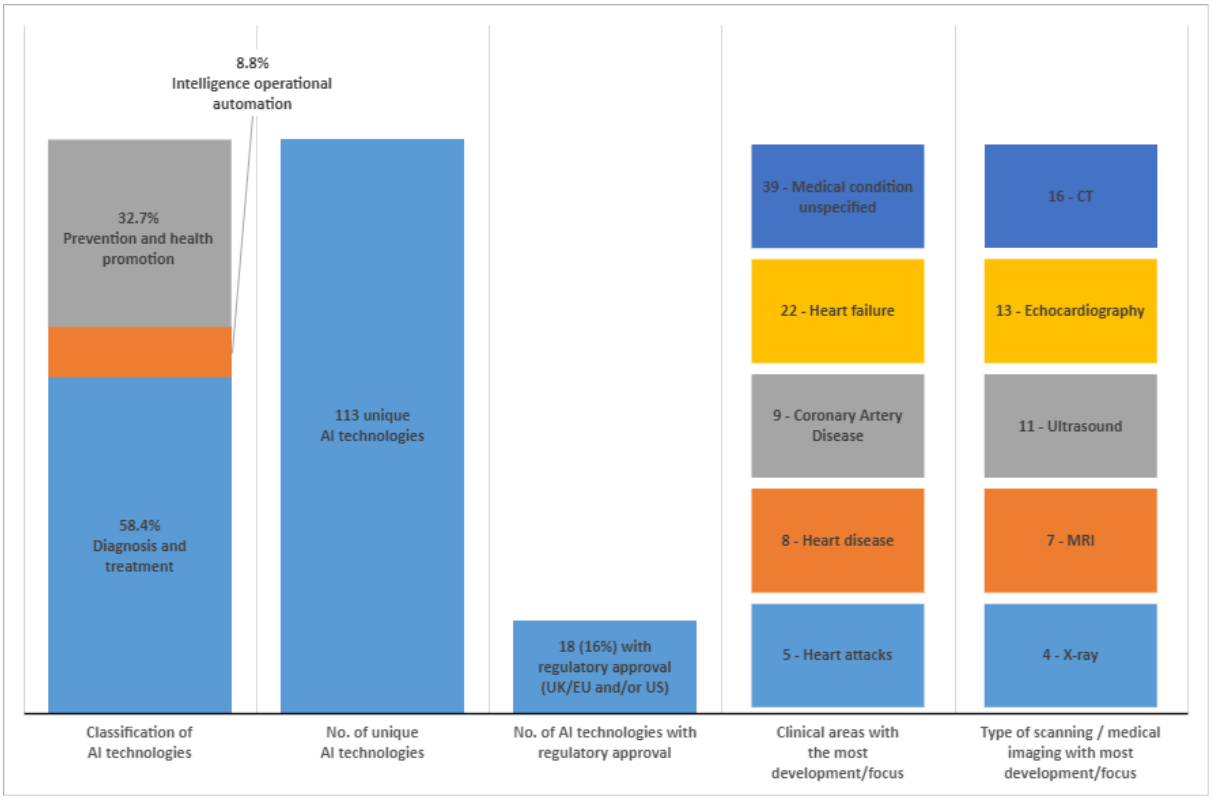

Figure 10. Key themes in AI development activity for Cardiology: application, regulatory approval, clinical areas and type of imaging.

4.5 Technologies to Watch

The fast development and growing adoption of existing and emerging technologies in healthcare, undoubtedly increases the complexity and challenges of identifying the most potentially promising technologies. From our pipeline of data, we identified technologies that have attracted investment and or have been shortlisted for development awards and competitions, based on available information at the time of extraction (December 2020 - January 2021) from the information source. In total 41 technologies were included in this

shortlist, included under the tab 'Technologies to watch' in the accompanying Excel file. Technologies include AI tools to detect cancer (e.g. Artificial Intelligence Expert, AI-MICADIS and Nucleai, Machine Learning, Deep Learning, and Machine Vision technology) and to predict future heart attacks (University of Oxford, Fat radiomic profile (FRP)).

4.6 Summary

- Diagnostic and treatment is the most common use of AI (68.8% of identified technologies) and were mainly concentrated in oncology (27.8%)
- The majority of AI products are in the mature phase of development (phase 3) and over 20% of technologies identified have obtained regulatory approval (phase 4)
- The most active countries of development at this time are the US and UK
- Overall, AI innovations are clustered around oncology, cardiology, neurology and medical Imaging.

5. Emerging Patterns of AI in Published Literature

5.1 Search and screening results

A sensitive search strategy was devised in Medline OVID[5] to identify literature on the application of artificial intelligence in health technologies. The search used a combination of key word and free text search terms with controlled vocabulary terms when available. The search was combined with topic searches for scanning and medical imagining, oncology, cardiology, dermatology and ophthalmology. A standard algorithm to eliminate animal studies was applied. The search included all Medline indexed studies as well as those in process, ahead of print and non-indexed published from 2018 and in English language. The Medline search results were further supplemented with an EMBASE[4] search for conference abstracts.

Given the number of retrieved results (+9,100) and the timeframe available for processing the data, results were prioritised on the bases of signal strength where "strong signals" were defined as those emerging from randomised controlled trials and systematic reviews and "weak signals" those emerging from other studies types, including observational data.

For the identification of randomised controlled trials a validated Cochrane RCT filter (sensitivity and precision maximizing version 2008)[7] search filter was applied to the Medline search strategy above. For the identification of systematic reviews, a validated search filter used by the Centre for Reviews and Dissemination (CRD)[8] was used.

The results retrieved (2271) were transformed into a visual map in order to identify and explore relevant topic clusters (i.e. key themes) occurring in this body of evidence.

5.1.1 Visualisation of topics clustered for AI

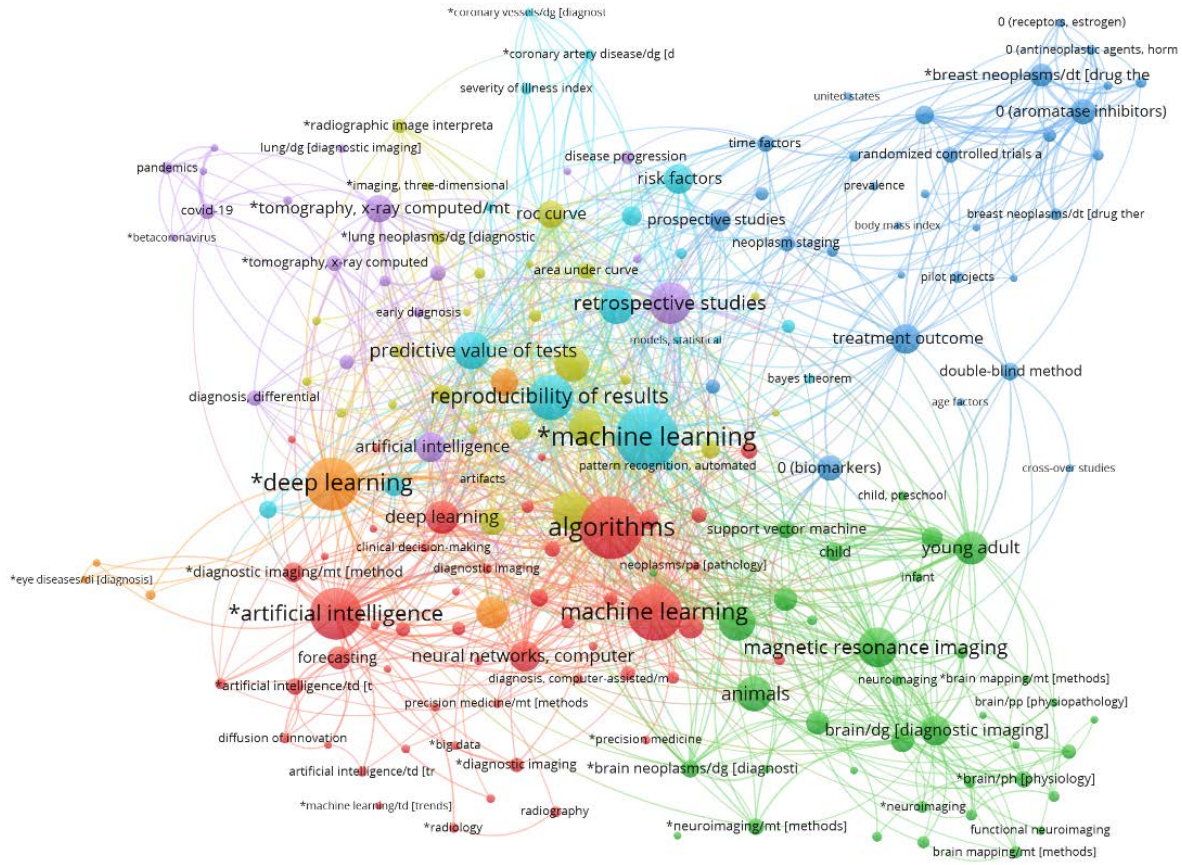

Figure 11. Evidence Map of AI
The map presents a visual overview of the key occurrences and themes from the published evidence, based on our topic search for AI, medical imagining, oncology, cardiology, dermatology and ophthalmology.

The visual map highlights that the published evidence, at its core, focuses on describing and evaluating the various underlying AI approaches, which are driving the functionality of AI health technologies (e.g. 'machine learning', 'algorithms', 'deep learning', 'neural networks' etc.). There was a large body of published evidence clustered around 'magnetic resonance imaging' to support clinical conditions concerning the brain. X-ray and radiographic imaging also emerged as key topics, particularly in relation to diagnostic procedures. Key clinical conditions emerging from the published evidence included brain, lung, and breast cancers. There were smaller clusters of published evidence concerning cardiology, skin disease, various eye diseases, and infectious diseases (including COVID-19). The published evidence suggests that the majority of evaluative studies are currently retrospective in nature, however, a smaller cluster did emerge suggesting a growing number of randomised controlled trials in this space.

6. Summary of Business Intelligence

6.1 AI Trends and Insights in Healthcare

The use of AI in healthcare has risen exponentially since the last decade. The increase in available health data (e.g. from medical devices, medical imaging, electronic health records), along with new tools for big data modelling and analysis, offers the opportunity for tremendous growth of AI technologies within the healthcare setting. It is estimated that around 80% of health-related data is not contained in a database or data structure. The unstructured data cannot be constantly updated and accessed by human capabilities, which is the major driver for the rise in the use of AI in healthcare[9].

The current trending areas for the use of AI in healthcare are administrative workflows, radiology (image analysis), robotic surgery, virtual assistants, and supporting clinical decision-making[10]. AI is also used in several other applications within healthcare, such as

- Precision medicine
- Drug discovery and development
- Augmented reality and virtual reality
- Intelligent personal health records

Due to technologies constantly evolving and AI and machine learning methodologies and application constantly evolving, new trends are continuously being introduced. Alongside technology evolving, the amount of data is increasing at an exponential rate and this should allow AI to be more precise. Upcoming trends regarding AI in healthcare consist of[11-14]:

- Diagnosing diseases and other medical conditions
- Personalised treatments
- Healthcare biometrics
- Computer vision-based object detection
- Oncology
- Triage
- Mental health

Other upcoming trends regarding AI in healthcare revolve around addressing the challenges that the current applications face. For example, AI models can be given data to train the algorithm to ensure the predictions remain accurate. Another challenge that is expected to be address is the implications surrounding medical ethics (e.g. patient confidentiality, accountability and hacking)[14].

6.2 AI and Companies in Healthcare

As AI is constantly evolving, many companies are exploiting this field to produce new and innovative technologies; however, the large number of developers in this space make it challenging to keep up to date with development activities. The current and future AI

development activities in healthcare for 3 large firms of interest to NHSx are summarised below:

6.2.1 Google

Google has increased their presence within the field of digital healthcare. As of 2020, they have 57 digital health start-ups where the investments include utilising AI to advance scientific research. Google aims to use AI to assist healthcare professionals through the review and analysis of large volumes of data[15]. A current solution that Google offers is Streams (Google DeepMind). Streams provides real time data regarding acute kidney injury to clinicians, which a study has stated could potentially save the NHS an average of £2,000 per patient[16]. Through Google focusing on using AI in healthcare, the company is enabling the process by innovating the use of health data and utilising AI to handle the unstructured data. The advancement of machine learning is emphasised by Google compared to other main technology companies (e.g. Amazon). Some of the main focuses of Google include the diagnosis, screening and management of patients with atrial fibrillation, and detection and management of diabetes[15]. Currently, Google is working on developing AI with the purpose of assisting clinicians in detecting breast and lung cancer, as well as predicting sight-threatening eye conditions[17].

6.2.2 IBM Watson Health

IBM aims to use its AI to help reduce variability in the treatment and diagnosis of cancer and help improve cancer outcomes worldwide, through more personalised, evidence-based cancer care[18]. IBM believe AI can help improve the way clinicians treat cancer by utilising AI's ability to comprehend complex and large health datasets[18]. In 2016, IBM Watson established a partnership with Quest Diagnostics and created Watson for Genomics, which combines Quest's state-of-the-art tumour analysis with the cognitive computing of IBM's Watson. This tool is able to analyse patient-specific tumour mutations, allowing the identification of the most optimal therapeutic option[19].

6.2.3 Amazon

Over the past years, Amazon has grown its healthcare presence, in particular the use of AI within the field. In 2018, Amazon launched a new patented version of Alexa (virtual assistant) that can detect signs of illness and offer to sell the user medicine[20]. Amazon is currently collaborating with the University of Southern California to create a machine learning and artificial intelligence research centre. This joint research program is expected to develop new approaches to machine learning privacy and security, to answer the growing concern surrounding the use of technology in healthcare[21].

7. Conclusion

Advances in AI has the potential to generate significant benefits in healthcare. Our horizon scan provides valuable and relevant insights into the global scale of AI development activities covering a diverse range of clinical indications. The most common indications in AI development were oncology (e.g. breast cancer, melanoma and lung cancer), cardiology, and neurology, which was unsurprising given that cancer, heart disease, and stroke are amongst the leading causes of death worldwide[22]. The UK has a strong record in AI research and development, strengthening our position to be among the world leaders in the development of promising artificial intelligence. Our geographical data showed a high level of AI development activities in the UK, which will be a key driving force to support the UK's AI capability to address current and future healthcare challenges.

The majority of AI technologies identified in our scan were developed for use in diagnosis and treatment (68.8%). Health promotion and prevention and intelligent operational automations were least developed and highlights gaps in the market, which may emerge as future priorities.

One of the key challenges facing developers is navigating the regulatory framework for AI/digital technologies. In order for AI to realise its potential in healthcare, further work is required to improve the regulatory framework, standards of clinical accuracy and address ethical issues in the application of AI to healthcare.

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