INSIGHT

MOONDANCE CANCER INITIATIVE

Digital & AI technologies for cancer care

An expert snapshot

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About us

Moondance Cancer Initiative is a not-for-profit company established to find solutions so that more people in Wales survive cancer. We want to help achieve significant and sustained improvements in cancer survival outcomes over the next ten years. What we do:

- We identify and trial new pathways, practices, and technologies, so that more people in Wales survive cancer
- We work in partnership with the Welsh health community and beyond – connecting great people across different disciplines, sectors, and regions
- Our work is evidence-informed, rigorous, and adventurous: we see value in moving quickly, trying and learning
- We bring funding, research intelligence, and an ethos of collaboration to the table

We're a not-for-profit company (company number 12305964), privileged to be funded by the Moondance Foundation.

About the author

Digital technology in cancer is a fast-moving field, with huge potential impact on how we deliver cancer care. Here at Moondance, we decided to commission this informed expert snapshot, to help us identify what really holds promise for cancer services and patients in Wales.

Dr Jonathan Gregory worked in the (English) NHS for 20 years, with the last ten as a consultant cancer surgeon. He held numerous regional and national roles, including lead clinician for two supra-regional cancer MDTs, Clinical Service Lead, Cancer Network Expert Advisory Group member, and a member of two National Cancer Research Institute Clinical Study Groups.

Jonathan now bridges the gap between digital innovation and clinical medicine. He works with the computational oncology team at Imperial College London and provides digital healthcare consultancy services to a variety of public, private and third sector organisations. He is a member of the NHS Clinical Entrepreneur programme, the Faculty of Clinical Informatics and has been an assessor for the NIHR (National Institute for Health Research) artificial intelligence grant awards and the AHSN Network National Innovation Accelerator Fellowships.

How can digital and AI improve cancer care?

In this chapter, I provide my personal snapshot of some key digital and AI products I believe have potential to improve cancer care in Wales.

Where I include products, it is because they are prominent in the current marketplace, they illustrate a category of product available, and/or I can see they may offer potential value *in principle* to cancer outcomes in Wales. My aim is to offer a flavour of this exciting field of development.

I have not undertaken detailed due diligence, and inclusion here does not represent endorsement. It can be challenging to fully separate reality from hype, even for those working in this field. It is also very difficult to identify where AI is already in use in healthcare – however it is my opinion that narrow AI will be more widely deployed in some routine NHS healthcare within the next 2-3 years, and I provide examples in this section.

Where possible, I offer an indication as to when a product, or a product with similar functionality, may be available for real world implementation at scale:

- Under 3 years – **soon**
- More than 3 years – **later**

These estimates are based on the significant assumption that all real-world testing is successful. I also provide examples of areas being explored in the current research literature where these illustrate what AI may be able to do in the future.

The recipients of NHSX AI awards have been peer reviewed and judged to merit public funds for further development and evaluation. Although no guarantee that these particular products will come to market, the NHSX portfolio offers an insight into the types of products coming to market in the next few years. As such, I draw on many of these recipients as examples of products that may be able to impact cancer outcomes in Wales.

Assessing the value of digital and AI solutions

Any digital healthcare tool can and should be assessed for the **benefits afforded to its direct users** – the patient or clinical team using it. Digital healthcare and AI can however bring different benefits to patients and clinical teams than medical devices or new pharmaceuticals. The traditional paradigm for demonstrating benefit in medicine – involving randomised control trials as 'proof' of benefit or absence of harm – is therefore not always well suited to evaluating digital healthcare tools. Digital tools can bring benefits across a range of parameters which are hard to capture in a randomised control trial. For example, it is unlikely in my opinion, that a digital app will improve survival or quality of life, in isolation, excluding the impact of clinical teams. However, the digital tool may (in addition to supporting the clinical team to improve survival or quality of life) deliver improvements in communication, patient satisfaction or empowerment, as well as supporting clinical decision making.

Digital healthcare tools may **increase efficiency and effectiveness**, freeing up staff and equipment for more value-adding activity. Clinicians spend many hours of their working week engaged in repetitive low value tasks. By digitising these processes, we free healthcare staff to spend more time doing what they can do better than any technology: listening to patients, using human compassion to support patients, and working at the limits of their training to tackle complex problems. These potential gains make adopting digital healthcare tools a necessity, especially at a time when NHS services are stretched.

However, these benefits are rarely captured by traditional RCT–focussed evaluation approaches, which are geared to detect clinically meaningful differences in outcomes for individual patients. It has to be remembered that at a population level, delivering the same outcome more efficiently, reliably and cheaply is as meritorious as achieving small increases in overall survival. Many of the products discussed have the potential to save thousands of hours of clinician time, releasing clinicians to do more of what they are good at. I draw out these benefits in the discussion of examples of digital and AI tools that follows.

When considering the examples below, please consider the potential benefits at a range of scales, for example the patient, clinical team, department, hospital, primary care, population levels. When this is done, the wider system benefits can often be revealed as large, even though benefit for any individual patient or healthcare professional may be small.

Communication and information

One of the clearest ways that digital technology will improve healthcare is by facilitating the free flow of information and communication. Patient preferences can be captured, and remote monitoring or outcomes data can be submitted to care providers.

I believe AI will soon have an important role to play in curating content and providing summaries of vast amounts of information, digestible for busy patients and clinicians.

Digital communications and information tools

Social media is being utilised with the aim of improving cancer outcomes. Where it is perhaps most effective is in terms of peer support, where patients can find 'patients like me' to share help and advice.

There is some limited evidence that social media intervention may improve cancer screening and early diagnosis rates, although the evidence base for this is weak. Most of the studies try to evaluate the impact of national cancer awareness campaigns, where isolating the effect of the social media component is difficult.[1]

However, there is some evidence of focused impacts on health-seeking and information-seeking behaviour linked to specific events. The social media response to a celebrity being diagnosed with cancer demonstrates that social media can be a key channel for awareness raising. One paper explored the impact of the announcement by Ben Stiller of his diagnosis of prostate cancer on subsequent Twitter conversations: for 2 days afterwards there was a statistical difference in the number of conversations relating specifically to prostate cancer.[2] When we consider that this involved 1.2 million messages, the reach of such stories is very large. Therefore, it would feel appropriate for those in cancer care, especially in the early diagnosis arena, to be prepared to exploit these 'waves' of interest in specific cancers to raise awareness and provide reliable sources of information.

The creation of online communities for peer-to-peer support is another way for digital technology to help patients and carers with their cancer journey. An example of this is a breast cancer online community run by the Mayo Clinic which enables patients to improve their understanding of treatment plans and to find peer support. Being able to facilitate patients joining appropriate online communities to exchange validated information, maybe one component of enabling patients to self-manage more of their cancer journey.[3]

Digital technology also offers a way to support both larger numbers of people, and more isolated people, than can be managed by conventional services. For example, a study has looked at the benefit of providing a digital tool to parents of children who are being treated for cancer. A digital app was designed to support users to increase their resilience. The intervention was compared to a placebo tool. At 6 months post-intervention, the test group had higher levels of resilience and lower depression scores than the control group.[4] Given the low recurring costs and unlimited numbers of people who can benefit simultaneously, building a library of high quality self-management tools could be a key way to supplement in-person support, to help mitigate some of the harms caused by cancer and its treatment to patients, their families and carers.

AI communications and information tools

AI technologies offer multiple opportunities to support patients and families to gain a better understanding of their condition and treatment. The use **of natural language processing**, a form of artificial intelligence which interprets language, has been used in research to provide annotated recordings of clinical consultations for patients and their carers. Colour coding and tags were generated to help patients and carers find specific pieces of information within the recordings, such as medication or treatment. Hyperlinks were also inserted to direct the patients to further information related to specific parts of the consultation.[5] Tools such as this will hopefully be able to empower patients to understand and manage their cancer care, especially those with complex treatment plans.

Another very interesting use of AI is in preparation of patients for treatment. For example, the 'digi-do' trial is a randomized controlled study due to open in 2022 looking at the use of virtual reality technology to help prepare patients for radiotherapy.[6] There are other uses of augmented or virtual reality which could be helpful in cancer care such as preparation for major surgery or in rehabilitation. Costs of development of these tools may be offset by relatively low ongoing costs post deployment.

Tele-health and tele-medicine

The Covid-19 pandemic has accelerated the development and adoption of telehealth. Numerous platforms are available for primary and secondary care. Some are very simple – really only providing a secure channel of communication – others are linked to scheduling software to run clinics, or to patient records and imaging.

The use of telehealth to support team working across sites has also evolved. The ability to remotely attend meetings, including cancer MDT meetings has aided clinical efficiency. In addition, the ability to share imaging is improving. Historically, transferring imaging between hospitals was a source of delay. Improvements in linking centers digitally means that obtaining clinical advice on cases or transferring care between providers is less cumbersome.

The NHS Wales Video Consultation Service is a platform called Attend Anywhere. This has now enabled over 250,000 video consultations for patients in Wales. Both patients and clinicians report positive experiences, though patient satisfaction exceeds that of clinicians.

- In the phase 2a evaluation, uptake was felt to be broadly representative of the Welsh general population except for Black, Asian, mixed, multiple group or ethnic groups who were under-represented. These demographic groups can have lower engagement rates in digital services, and should be tackled as a potential exacerbating factor to healthcare inequality.[7]
- The issue of space or privacy for virtual appointments was not an issue for the vast majority of respondents. Other telemedicine evaluations have found that patients in multi-occupancy homes find it hard to have privacy and access to computer and internet facilities simultaneously.*
- Respondents reported very few problems with computer devices, internet, visual or audio problems, with less than 5% of users responding that they had problems. Clinicians reported far greater technical issues with between 8.5% and 15.7% saying they had technical issues a lot of the time.
- Interestingly, patients also had a lower preference for face-to-face appointments than clinicians. The study made an estimate of journey time saving and based upon over 12,000 respondents, it estimates that 150,000 hours of travel time was saved for patients using video consultation.

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*In the evaluation of the NHS Scotland video consultation service the public reported more barriers to use than was reported in Wales.[33] These included lack of access to an appropriate device (23%), poor internet connectivity (30%), restrictions on mobile data packages (17%) and lack of private space at home (20%). As described above we need to understand if the difference compared to the Welsh survey relates to sampling bias, question construction or something else as the platforms are similar so are unlikely to be solely responsible for such marked differences.

Screening

Cancer screening enables the diagnosis of asymptomatic cancers at earlier stages, when hopefully they are curable and associated with less burdensome and expensive treatment. Digital interventions may support screening in several ways: improving uptake, improving the delivery of screening services, or automating screening services to allow scaling, compensation for staff shortages and improved timelines.

Further, digital and AI tools may be able to help identify those at risk of cancer either due to co-morbidities or lifestyle behaviours, so that screening can be based upon individual risk rather than population risk.

Digital and AI research and product development for screening is very active but in its infancy. There are numerous examples of research papers and products being developed that promise potential benefit. However, at this early stage, it is not yet always easy to pinpoint specific products.

Digital tools to assist screening and detection

Smartphone-based technology has been used in several studies with the aim of improving cancer screening and detection.[8] Much of this work has been in low resource communities where geographic distance or resources are a limitation to cancer screening. However, several of the methodologies identified could be of benefit in relatively well-resourced communities.

Studies have looked at increasing uptake in cancer screening. For example, The North Midlands Breast Screening Service have successfully increased uptake in their breast screening service by driving communication with their community through **Facebook**.[9]

Text messaging to improve cancer screening has also been explored. NHS England sought to improve cervical screening uptake in London, which had the worst uptake rate in England. Earlier work had identified that messaging that 'appears' to come from a patient's GP or to be endorsed by their GP is more effective. In this project women who were due cervical screening were sent a text message reminder 2.5 weeks after being sent the standard invitation letter. At 18 weeks' follow up, uptake in screening was 4.8% higher in those women who received the text message, which equates to 13,400 more screening attendances. Interestingly the text reminder had a larger impact on women aged 50-64 than 25-49. A phone number was available for 88% of patients and was successfully delivered to 75% of these women (wrong number on record being biggest reason for failure).[10]

A systematic review has identified an overall positive impact on increased screening rates from text messaging interventions although the scale of benefit varies. Clear benefit was seen in breast and cervical cancer, and possibly marginal benefit in colorectal cancer. The absolute increase in screening with text intervention varied from 0.6% to 15%. This was across a range of countries, and therefore the differences in culture and healthcare systems means the effect size in Wales is uncertain.[11]

Several studies have tried different modes of communication to increase uptake of bowel cancer screening. This work, including in operational research conducted by Bowel Screening Wales, appears to confirm that meaningful improvements can be made with simple interventions. At its most simple a phone call appears to improve uptake. In one study in England, a single SMS reminder was sent if a FOBT kit had not been returned 8 weeks from initial invitation. The outcome was not statistically significant, a 0.6% increase in screening uptake with the text message. However, once difficulties with incorrect phone numbers were set aside, the SMS reminder drove screening uptake up by 5.6% amongst first time screeners compared to standard care. The low cost of SMS interventions and the opportunity to automate reminders both suggest it should be considered for use at scale.[12]

Smartphone apps have also been developed with the intention of impacting screening attendance or delivery. A team in Hungary developed a lung cancer risk assessment smartphone app. The free app, available in the UK App store and translated into over 10 languages, asks simple questions relating to age, smoking status, family history and asbestos exposure, and produces a risk of developing lung cancer using a traffic light system.[13] For patients identified at high risk the app uses GPS co-ordinates to direct the user to the nearest lung cancer screening centre.

No data is available to show whether this app improved the stage of lung cancer at diagnosis, or that individuals attended for lung cancer screening. However, in this trial the app was downloaded nearly 14,000 times and completed 90,000 times over a period of 20 months, suggesting repeat engagement. Therefore, it created a data source of smoking status and lung cancer risk against geospatial data which could help planning of lung cancer screening and treatment provision. If smoking cessation services were linked, further benefit might also be achieved: the moment of receiving feedback on cancer risk offers a 'teachable moment' when people are more open to behavioural changes.

Some apps targeted at services in resource-poor environments aim to support the performance of the screening test itself. Several might be able to be adapted to assist cancer pathways in Wales.

One example is a point of care smartphone based oral cancer screening tool.[14] It uses a smartphone to capture photos and identify areas of cancerous or potentially precancerous tissue within the oral cavity. These images can be relayed to an expert for interpretation or passed through an AI model which is able to classify the images into suspicious or not suspicious. This has been designed for use in a population with a much higher incidence of oral cancer than Wales; however, it identifies an approach that may be used to link dentists to secondary care oral cancer services. With development such a system could possibly reduce the numbers of patients needing to be seen in secondary care or allow those at greatest risk of having a malignant lesion to have an expedited pathway.

There have been several studies looking at the use of smartphones related to cervical cancer screening in both low and high resource settings.[15,16] Of note was a study which utilised a smartphone to capture and transmit images for remote assessment. Women who were HPV positive and undergoing cervical screening also had visual inspection after application of acetic acid/lugol's iodine. A smartphone was used by a healthcare professional to capture a photograph of the cervix, and these photographs were then remotely viewed by experts. The study showed that the experts felt that the images were of diagnostic quality in over 75% of cases. This offers an opportunity to consider the provision of colposcopy services in low resource settings, but it possibly also allows us to start considering whether there are digital applications which could be used around cervical cancer screening in the UK to augment cervical smears to reduce the requirement for colposcopy or to triage colposcopy cases into high risk / low risk so the patients at greatest risk of having cancer are prioritized through the diagnostic pathway.

AI tools to assist screening and detection

There is understandable interest in **helping General Practitioners** identify patients who are most likely to have an underlying cancer. Tools that can assist in this prioritisation offer the promise of detecting more patients who need urgent investigation whilst minimizing harms associated with over referral and over investigation.

Dermatology is one of the fields which appears to be advancing most rapidly in the use of AI to guide the diagnosis of benign and malignant conditions. However, at the current time it's difficult to assess which approaches are going to be most clinically useful. There is marked heterogeneity in the AI approaches used; datasets do not have adequate representation across different skin types, and whilst the average number of images used to develop key AI models was approximately 7800, the lowest number was 40 and the highest was over 125000.[18] The evaluation metrics used in different studies also vary, again making comparison challenging. Accuracy was reported most often, but even this important metric was not stated in all papers.

AI tools are also being used to help **assess the quality of screening procedures**. For example, a deep learning system to quantify the quality of bowel preparation for patients undergoing colonoscopy has been developed.[19] Poor bowel preparation is associated with a lower adenoma detection rate. The decision boundary between acceptable and unacceptable bowel preparation can be challenging and there is variation in practice even when trying to use objective measures such as the Boston Bowel Preparation scale. Using a deep learning algorithm, researchers developed an AI model to provide a Boston Bowel Preparation scale automatically. The scale had very strong correlation with the ability to detect adenoma and has been tested in an external dataset, therefore providing some assurance regarding generalisability of the model to other settings. In practice the AI could allow clinical teams specify a bowel preparation level and the AI can indicate when that level is breached. Interventions such as this augment clinical expertise, and may help to minimise missed adenomas, but in a way which does not affect the clinician's workflow.

AI will be able to support improvements in **screening investigations**. Sometimes this is by changing the way studies are performed, but in other times it is by allowing the human workforce to focus on areas where they can add value. A recent paper described a deep learning method to review MRI breast examinations performed on women whose breasts were too dense for routine mammography.[20] In a total of 4581 MRI examinations from different women, 9162 breasts were imaged. The deep learning model was 100% sensitive for the identification of malignant lesions. Any MRI examination that was not normal was triaged to radiological review. On this basis the deep learning model was able to dismiss nearly 40% of MRI scans, whilst not missing any abnormalities or cancers. Reducing the volume of reporting by 40% releases significant opportunity cost for consultant radiologist staff.

PinPoint Data Science (urgent cancer referral triage)

https://www.pinpointdatascience.com/

On market soon.

Working with the NHS, PinPoint Data Science has developed a machine learning algorithm which interrogates a patient's routine blood test results.[17] The algorithm provides the GP with a %risk that the blood test 'pattern' may be linked to cancer which they can use to inform their decision-making on referral. The algorithm can identify the group of patients with a low risk of cancer (<5% risk) and the GP may then consider that they can be managed in other ways rather than as a fast track suspected cancer referral. The product can also identify the group of patients with a very high risk of having cancer and the GP may use this to decide to refer on an urgent suspected cancer pathway. The product is CE marked for nine cancers, including most visceral cancers.

Kheiron Medical Technologies (MIA mammography)

https://www.kheironmed.com/products/mia-reader/

On market soon. Funded by NHSX for Initial Health System Adoption.

One AI product close to use in routine medical care is the Mia Mammography Intelligent Assessment tool developed by Kheiron Medical Technologies.

Traditional breast cancer screening involves mammograms being reviewed by two consultant radiologists. Given shortages in consultant radiologists in the UK, there is a strong desire to find ways to support this screening pathway.

Mia has been designed to be a second reader of mammograms. A consultant radiologist will review every mammogram, and Mia AI will act as the second reviewer. If there is agreement between the consultant radiologist and Mia, then the diagnosis reached by the consultant radiologist is used as the output. If there is disagreement between the consultant radiologist and Mia, then the mammogram is reviewed by a second human radiologist and the diagnosis formed between the two radiologists is taken as the output.

This is a good example of how AI tools will be deployed in the next few years: to augment human performance, help to compensate for staff shortages and speed up workflows – with human doctors retaining control and decision-making.

Kheiron Medical completed a successful evaluation in the East Midlands Radiology Consortium and has now been awarded a phase 4 funding from the AI in Health & Care Awards from NHSX. Mia is due to be deployed across 15 hospital sites this year, including one in Wales, to check for safety and effectiveness and if successful then it may be adopted more widely into routine care.

Lunit (mammography)

https://www.lunit.io/en

On market soon.

Lunit has also developed a breast mammography AI tool. It is currently approved for commercial sales in Europe and Korea, having been awarded a CE mark. It has been trained on 240,000 images. One trial demonstrated that while the tool performed well, as did consultant radiologists, when the artificial intelligence was combined with a radiologist, the overall sensitivity approached 90% and the specificity was over 90%.[21] An evaluation of the tool in settings across South Korea, the USA and the UK also suggested performance was significantly higher than that of a single radiologist. The performance of a radiologist with the AI as a second reader was even better. Of note was that the Lunit tool was more sensitive at detecting small T1 cancers and node-negative cancers than radiologists. Patients with these cancers have the most to gain from screening mammography.

Optellum Ltd (lung cancer detection)

https://optellum.com/*On market soon. Real world testing being funded by NHSX.*

Developed by Optellum Ltd, Dolce is an AI lung cancer prediction model, which supports decision-making with regards to incidental abnormalities detected on chest CT scans. Incidental abnormalities on chest CT scans that are not clearly malignant or benign are classified as indeterminate pulmonary nodules. These can be present in approximately 30% of CT scans and whilst some are relatively easy to classify as benign others require surveillance for up to 2 years or biopsy to exclude malignancy.[22] This causes problems for all patients found to have pulmonary nodules: those with small cancers will have a delay in diagnosis until the doctors feel able to confirm that the nodule is a cancer, which may be several months; and the group whose nodule was always benign are subjected to unnecessary worry, interventions and follow-up scans. If unnecessary procedures can be safely avoided, this releases scanner and clinician capacity to care for those patients who do have cancer.

Research to date shows that Dolce appears to reduce variation in practice between radiologists and improve the accuracy of determining malignant and benign nodules, reducing the time to diagnosis for incidentally-discovered lung cancer. It was assessed in a formal clinical research setting where it appears to allow a significant number of what humans would call indeterminate pulmonary nodules to be diagnosed as benign, but without missing any that are an underlying cancer.[23] Further evaluation is underway.

Behold.AI Technologies Ltd (Chest x-ray reporting)

https://behold.ai/

On market soon. Funded by NHSX for initial health system adoption.

Many thousands of chest x-rays are performed every day in the NHS. Many of these do not have any abnormalities on them, but radiologists still have to assess them carefully to make sure that they are not missing any subtle problems. Behold.AI have developed an AI algorithm to review chest x-rays, and determine if there are any abnormalities. If there are no abnormalities a report is produced automatically within seconds. When the AI identifies an abnormality or cannot be sure if there is an abnormality the case is fast tracked to a radiologist to review on the same day. Same day reporting becoming possible due to the release of capacity that was previously consumed reporting 'normal' x-rays. Products such as this are associated with significant opportunities to improve workflow and allows clinical teams to focus on high value activity such as making diagnoses on those x-rays which are abnormal.

Faculty AI– NHSx Breast Cancer Screening Round Length Planning Tool

On market soon.

The scale of breast screening means that scheduling patients is a complex task; meeting high volumes of patient needs and optimising the use of clinical resources, with limited ability to bring patients forwards or push them back to smooth any demand-capacity mismatch. This process is called breast screening round length planning and has been a manual process for many years. It is an ideal area for AI as it has defined parameters, is repetitive, is a source of a lot of low value but high-volume admin work, and is a source of unmerited variation across the country.

As part of a collaboration with the East Midlands Radiology Consortium Faculty has developed an AI tool to take over this process. In work sponsored by Innovate UK they developed a breast screening round-length planning tool using synthetic patient data (based upon historical cases). The tool has been demonstrated to operational staff in breast screening services, Public Health England and NHSx and is being prepared for roll out for further evaluation.

Advanced Expert Systems Ltd (stratification of colonoscopy following positive screening test)

On market later. Feasibility testing funded by NHSX.

Advanced Expert Systems Ltd is seeking to improve the diagnostic accuracy of **faecal immunochemical (FIT) testing** for bowel cancer. They are developing an AI model which will combine the results from FIT testing with other patient data with the aim of stratifying patients into low and high-risk groups. This can then support prioritisation of colonoscopy for those at most risk, minimising delay in diagnosis.

Diagnostics

The role for digital and AI in diagnostics is twofold. First, they can help in the automation and speeding up of processes. This can take time out of diagnostic pathways and facilitate sharing of diagnostic data to bring expert opinion to patients in a seamless manner. Second, AI can support diagnostics – for example selecting areas of slides that need a pathologist to review them, through to more complex work such as AI determining new pathological markers in histology slides, or determining molecular signatures of tumours without the need for extensive specialised tests. While this will be more transformative, AI-enabled diagnostics may however also be more controversial and difficult to deliver.

Prostate cancer and breast cancer applications are being developed, and results published in high numbers (likely a function of the availability of data sets and the large potential market).

Digital tools to assist in cancer diagnoses

Digital platforms are able to support transfer of huge quantities of data rapidly and to integrate multiple diagnostic tests in order to speed diagnostic time. This can allow centralisation of services and expertise. It can be difficult to demonstrate benefit for such changes primarily in terms of patient outcomes. However, the efficiencies gained can help compensate when there are staffing shortages, and facilitate split-site and remote working.

One such example would be the Munich Leukaemia Laboratory (https://www.mll.com/en.html). They provide a comprehensive digital diagnostic service based upon next generation sequencing. The results are reviewed against a human-specified clinical decision tree. The system is able make a diagnosis in 6/10 cases based upon genes, morphology etc with good levels of accuracy. The system states what the basis for the diagnosis was and this can be checked by a human. In 4/10 cases the system does not reach a confidence threshold to make a diagnosis and so these cases are passed to doctors to make the diagnosis. As over 50% of cases do not require human review, the clinicians are able to give complex cases more focus, as well as managing higher case volumes with lower staffing numbers. Overall, using the digital service also reduces the time to diagnosis for this group of patients.

AI tools to assist in cancer diagnoses

There is increasing evidence that artificial intelligence can interrogate standard histology H+E slides to identify molecular alterations without the need for more complex molecular or immunostaining techniques. Progress to date has been limited by the huge datasets created by single histology slides – gigapixels of data per slide which are computationally difficult to handle. However, new approaches appear to be making whole slide interpretation more feasible.[24] Rather than assessing the entire histology slide in 'one go', the slide is divided up into smaller fields called tiles. Each tile is then processed separately by the artificial intelligence and the outputs are statistically aggregated. To help explain the output of the AI model, often the parts of the whole slide image that were most responsible for making the final prediction are indicated so that these can be reviewed by a pathologist.

These developments have enabled progress to be made in developing AI models that may be able to support histological and cytological assessments. An AI model which can predict molecular pathways and key mutations in colorectal cancer in routine histology images.[25] Lymphocyte infiltration and necrotic tumour cells were used by the AI to determine underlying genomic issues of microsatellite instability and hyper-mutation. If externally validated, such AI approaches should lead to quicker turnaround times and cost reductions.

Another example of AI making progress in pathology interpretation has come in the field of prostate cancer. A recent paper demonstrated good performance of an AI in diagnosing prostate cancer, grading it and quantifying it.[26] Combined with humans, the AI yielded good results and appeared to reduce the 'human' to 'human' variability in reporting. Whilst the training set was reasonably large, 589 men and over 1000 slides, this was only validated against a local dataset, and has not been externally validated.

Paige ai (prostate cancer detection)

https://www.paige.ai/

On market soon. NHSX funded for initial health system adoption.

This AI diagnostic software supports the interpretation of prostate cancer histology sample images. The AI identifies the areas of the slide of most interest and provides automatically focused images. Pathologists still diagnose and grade the tumour but the whole process is accelerated as the pathologist does not have to scan the entire slide to identify relevant areas. This is another example where AI is being used not to replace humans but instead to facilitate doctors to focus on work where they add maximal value and help more patients. By improving workflow rather than seeking to replace human decision-making, the barrier to adoption here is lower than compared to diagnostic AI.

Odin-Vision (endoscopy enhancement)

https://odin-vision.com/

On market later. NHSX funding for development and clinical evaluation.

FORE-AI is an AI tool which can assist doctors to detect and characterise polyps during colonoscopy, developed by Odin-Vision. A number of potentially cancerous or cancerous polyps can be missed during colonoscopy, even in the best clinician's hands. FORE-AI enhances and draws attention to areas of the bowel wall that it interprets as abnormal. The colonoscopist then determines if the abnormality is relevant or not and if it requires biopsy or treatment. This is another example of where a human will remain in charge of patient care, but the AI will act as decision-support, mitigating the risk of human error. Odin Vision has been awarded funding to further evaluate FORE-AI in multiple hospitals.

IBX Medical Analytics (Prostate cancer diagnosis)

https://ibex-ai.com/press/uk-ai-award/

On market later. NHSX Funding for real world testing.

IBX Medical Analytics have developed an artificial intelligence tool to detect cancer and other clinically important features in prostate gland biopsies. This has been developed using data from 600 men from 6 hospitals, and is currently being evaluated by Imperial College London for clinical and cost effectiveness.

Compared to Paige which streamlines clinician workflow, this product intends to *make diagnoses* on samples. In the long term this could have dramatic effects on care pathways but the barriers to reach that point will be much higher.

Care co-ordination, remote monitoring and post treatment follow up

Digital tools to assist in care coordination and monitoring

This market has exploded, and at time of writing there are some excellent products but also some very mediocre offerings. At present the demand for disease specific apps appears good but many experts think this will be short lived and that there will be a rationalisation of the market in the coming years.

I have looked for examples of products in this space that appear to have an offering that is above average. As far as I am aware these products are available for use at present. Some can be used by individual patients in isolation, others really only yield value when also utilised by clinical teams as well as the patient.

Many of these products have the same core services: advice and support, symptom tracking, medication reminders, a diary for appointments. Less common are functions that allow integration with wearable data, clinical trials and integration with clinical teams.

The use of digital technology in cancer care can impact wider quality of life goals. For example, there is evidence from a systematic review that even relatively a simple eHealth digital application can improve physical activity in patients recovering from breast cancer.[27]

My MHealth HAYA Connected Cancer Care

https://mymhealth.com/haya

Available now.

My MHealth, in partnership with AstraZeneca, has developed a specific cancer care app and remote monitoring platform – the HAYA Connected Cancer Programme. This app aims to provide patient support and improve adherence with treatment plans. It can deliver real-time monitoring of patient's symptoms and observations, which can be fed back to clinicians so that clinical decisions and hospital visits can be changed in light of the users symptoms. The app is available for use by any patient whose clinical team wish to engage with it, regardless of the treatment they are receiving, nor is it limited to patients receiving Astra Zeneca medications.

Key features of the product include patients being able to: record symptoms and observations; make documents before, during or after their consultation; communicate with their clinical team using secure video chat; access general and specific information and educational topics associated with lung cancer (other cancer diagnoses in production); and create a concerns check list to support the development of a personalised cancer care plan.

From the perspective of healthcare professionals, the app allows the review and export of information for every patient. It can be configured as to which observations or symptoms are being reported; record care interactions; support building the treatment summary; allow one way and two way video consultations.

None of this requires AI. However, it is intended that in time AI could be used within the app with to enable personalized, stratified follow-up.

Careology

https://www.careology.health/

Available now.

Careology is designed to support patients in the cancer journey and is recommended by Macmillan Cancer Support. The app shares much of the same functionality as the HAYA app. The Careology app: allows patients to log appointments, symptoms, medications, and data from wearables. It also allows patients to share their symptoms, medication log and wearable data with their clinical team so that clinical advice can be delivered virtually – with the hope of enabling earlier intervention and reducing hospital attendances. It can also allow clinical teams to conduct virtual ward rounds of their patients in the community to monitor for complications developing.

TIYGA Health

https://www.tiyga.health/

Available now.

TIYGA is a digital app which allows patients to report details relevant to their health and care providers to support personalised care. It is not specific to oncology, but can be used in groups of oncology patients. Data capture can be tailored to suit individual needs, which healthcare professionals can then access and review. As such, it can be used to help patients to adhere with their treatment plan. TIYGA is one of the 'simpler' products on the market. What it lacks in functionality may be compensated for in easier implementation. (This points to a key challenge for digital healthcare at present: taking care to avoid purchasing digital functionality that is not actually required.)

BRIAN

https://www.thebraintumourcharity.org/living-with-a-brain-tumour/brian/

Available now.

BRIAN is an example of a disease specific digital app. It has been developed by the Brain Tumour Charity and is free to access. In addition to core functions such as appointment and medication reminders and symptom diaries, the app also utilises gamification to allow tracking of cognitive performance. Tasks are undertaken which test co-ordination or memory, and performance is logged so that subtle changes over time can be identified. The aim is to facilitate research examining remote follow up and whether cognitive testing and wearables are more sensitive at detecting deterioration in clinical condition compared to conventional follow up.

Further examples of products in this area

All available now:

- **Vine Health** (see digital enablers of research section)

- **HUMA Medopad** (see digital enablers of research section)
- **The Cancer App** - core functions to support a patients cancer journey. https://www.the-cancer-app.com/
- **BELONG beating Cancer Together** – facilitates access to clinicians for advice and provides a search function to help patients identify clinical trials that may be available. https://cancer.belong.life/
- **Untire** – aimed to support patients with one of the biggest problems faced during their cancer journey, fatigue. It provides information, holistic advice, links to an online community of support. https://untire.me/

'Hospital at Home'

Even prior to the Covid-19 pandemic, there was a move to try to manage more patients in the community who would otherwise be treated in hospital. The pandemic has brought the "hospital at home" model into sharper focus for the NHS.

At present I am however unaware of any products that have demonstrated safe management of a significant number of patients in the community without using humans to run and administer the service. A large number of platforms *claim* to be effective in this space, but close scrutiny often reveals that the level of integration is still suboptimal, and humans are still very much involved in reviewing the data that comes in from outside hospital. Until AI is utilised within platforms designed to support the management of 'hospital at home' patients, my belief is that the routine use of these products will not be possible owing to insufficient human staff to view and react to the large volumes of data generated and submitted.

A paper published this year evaluated a hospital at home model of care in the United States. For patients undergoing oncology treatment the hospital at home service demonstrated a reduction in hospital stay of 1.1 days, a reduction in emergency department visits of 45% with no difference in adverse outcomes, and a significant cost saving. The programme assessed was based on a digital platform for administration without use of wearable devices or remote symptom reporting. The intervention typically consisted of three nurse practitioners and five registered nurse visits during the initial week.[28] The gains shown in this model, whilst not entirely applicable to the UK, do demonstrate that straight forward service reconfiguration and redesign can yield significant benefit. However, if observation data for example from wearables were added to this, then I would anticipate the inclusion criteria could be broadened, so delivering greater benefit.

A study conducted in Wales in 2020 studied the use of a digital platform (Aparito) in the first step towards being able to provide a 'virtual oncology ward'. The study aimed to identify the development of Covid-19 within a patient group who were at home during cancer treatment. The study used wearable devices to determine heart rate, movement, blood oxygen saturation. This was married with a platform on which participants could register symptoms. The patient responses and wearable device data were viewable on a clinician dashboard.[29]

The study demonstrated acceptable participation levels (although not as high as might be expected) and positive feedback on the intervention. This study is now being developed to investigate if the platform and wearable technology can assess oncology patients for development of medical deterioration in both in-patient and out-patient settings.

HUMA (Medopad digital platform)

https://huma.com/

Available now

HUMA provides a platform to support a digital "hospital at home" and decentralised clinical trials. The platform can use real time health data from smart phones to support patients, clinicians and researchers. During Covid-19 it was used to support patients who were unwell but not requiring hospital treatment, to be managed at home. It is currently being used in 20 NHS Trusts in 15 disease categories for monitoring (rather than utilizing the AI components).

By facilitating data capture from patients outside the hospital, the app can reduce the burden on hospitals by allowing patients to be triaged whilst at home. It may enable the movement of some treatment or treatment recovery, to the community on the basis that patients can still be observed rather than needing to remain in hospital for observation. Remote patient monitoring may be able to reduce hospital and emergency attendances, reduce hospital lengths of stay and improve patient experience and self-management. However, the scale of realisation of all these theoretical benefits will depend upon the deployment environment.

The AI component uses digital phenotyping and bio-marker measurements to provide more comprehensive and objective views of health and disease. The aim is to provide predictive health and personalised medicine treatment plans based upon the data captured on individual patients.

HUMA is being piloted currently in the Cwm Taf Morgannwg and Betsi Cadwaladr health boards.

Follow up

Brain tumour monitoring

On market later. Feasibility testing funded by NHSX.

Not all brain tumours are fast growing. Some are slow growing and are managed by observation until they reach a size where the risks and benefits of surgery or radiotherapy are justified. This serial assessment of scans is labour-intensive and is well suited to AI techniques.

One AI system developed at the University of Cambridge measures the volume of brain tumours on MRI scans. The AI will learn which features of the scans can predict tumours that are likely to grow and will need monitoring frequently, and those which are going to be indolent and therefore can be monitored less frequently. If successful, this would allow resources to be directed to patients at greatest risk of disease progression and reduce the burden of investigation on patients who do not require intensive follow up.

Treatment and treatment planning

Perhaps one of the biggest issues in providing cancer treatment today for clinicians is assimilating the vast amounts of research and trial data available, and translating that into treatment plans appropriate for their patients. The difficulty in doing this is illustrated by the unwarranted variation in clinical practice, such as variations in lung cancer resection rates or chemotherapy regimens. It is generally recognised that if all patients were treated according to best practice guidelines (if the patient agreed to that treatment plan) there would be an improvement in outcomes and reduction in costs.

In addition, as cancer pathways evolve – with changes to screening, precision medicine and so on – the numbers and types of patients that are referred to treating teams will change. Early diagnosis can mean less treatment is required and less invasive surgery. However, for patients who are down staged from late-stage disease to mid-stage disease it may mean more treatment. For example, palliative radiotherapy in most instances requires much less planning and delivery time compared to radiotherapy being administered with curative intent. Patients with late stage oesophageal, gastric or pancreatic cancer do not receive surgery; however if these patients are diagnosed early, they would require surgery – but there may be insufficient surgical capacity to accommodate this. Therefore, improving workflows with digital tools will be critical as treatment volumes change driven by more cancer being diagnosed earlier.

There are now a number of research papers and products in this area. Most relate to radiotherapy planning or medical oncology chemotherapy regime guideline support. There are also digital and AI tools which are not cancer specific but which will influence treatment and treatment planning – for example patient safety tools that may detect adverse drug interactions and the development of dangerous side effects. Robotics in surgery is another area of growth. The evidence base around robotic surgery is poor and does not always demonstrate the benefits that could be realised in the real world. For example, surgical robots are often evidenced by the impact they have in high volume centres with 'expert' users. Whereas more patients have surgery outside major centres and so greater value would be realised if robotic assisted surgery improved outcomes for surgeons outside 'expert' centres or in reducing the training time and learning curve required to deliver particular procedures.

Digital tools to assist in cancer treatment and treatment planning

Roche Pharmaceuticals (Navify MDT software -non-AI)

https://www.navify.com/

Available now.

Cancer multi-disciplinary team (MDT) meetings involve a wide range of healthcare professionals to discuss patients who have recently been diagnosed, treated or relapsed with cancer to determine what the next treatment, if any, should be. As cancer volumes, case complexity and treatment options have increased the traditional way of running MDT meetings has become unsustainable. Many MDT meetings are overloaded, leaving only 1-2 minutes to discuss each patient which leads to a risk of error and clinician exhaustion. It is widely recognised there is variation in practice between clinicians within an MDT and between MDTs, and addressing caseload will help address this. In addition, as the volume of publications is so great it is now impossible for any single clinician to keep pace with all advances. Therefore, systems that highlight guidelines when appropriate to cases may also help to reduce unwarranted variation and speed up the delivery of best practice as new treatments become available.

Navify uses digital technology to support the preparation and conduct of cancer MDT meetings. It supports the curation of the meeting and the presentation of content using a suite of APIs. Studies conducted by the developers in the USA suggest that using Navify reduces the likelihood of cases being deferred owing to missing information and to speed up the time taken to discuss breast cancer and gastro-intestinal cancer cases. The platform also identifies literature and clinical trials relevant to particular cases. Additional functionality extends beyond the MDT, facilitating digital pathology workflows and communicating tests results to patients.

AI tools to assist in cancer treatment and treatment planning

Deontics (MDT clinical decision support - AI powered)

https://deontics.com/

On market soon. Funded by NHSX for real world testing.

The Deontics AI platform has also been designed to increase the efficiency and effectiveness of cancer MDT meetings. Deontics claims that it can be used to triage 'non-complex' cancer cases: using its platform, cases that can be treated by standard protocolized guidelines do not need to be discussed at a formal MDT meeting. Instead, the case is reviewed by a single clinician with the software providing the clinician with evidence as to what the local and national guidance recommends for the patient under consideration. If the clinician agrees with these proposals, then the patient is seen in clinic for the next steps of their pathway. If the clinician feels that discussion in an MDT is required, then the case can reviewed at the next full MDT meeting.

The intention is that this will create time for more in-depth discussion of complex cases within MDT meetings, and help to minimise unnecessary variation in 'routine' cases. However, by keeping human interpretation at the apex of decision making, informed variation is still permissible. The platform also has digital tools which allow patients to describe their priorities for treatment and the acceptability of side effects so that these can be fed into the decision-making process.

Prediction of on-treatment response

Recent work has used AI to assess responses to cancer drug therapy. For example, an AI model has been developed that was able to accurately predict early on-treatment response in **metastatic colorectal cancer** more accurately than by reviewing tumour size changes alone.[30]

In the management of metastatic colorectal cancer, the use of anti-vascular endothelial growth factors can be affected by the difficulty in monitoring response. Unlike conventional chemotherapy, newer agents such at these and other immunotherapies may have less initial impact upon the size of a tumour. Instead, they often cause qualitative changes in tumour features – but it is difficult for radiologists to be consistent in interpreting these changes using standard scanning techniques. Conventional assessment criteria are heavily influenced by size criteria and therefore there is a risk that these agents may be deemed ineffective and treatment terminated early. These uses of AI offers an opportunity to get patients onto appropriate treatment more quickly, to keep them on treatment if it is working, or get them off treatment that is not helping.

Mirada Medical Ltd (Radiotherapy planning software)

https://mirada-medical.com/

On market soon. Funded by NHSX for Initial health system adoption

Mirada Medical Ltd are developing a range of AI tools to support radiotherapy planning. They have products to support clinical oncologists with planning and contouring scans and with the checking and review of treatment planning. The hope is that this will both support clinical oncologists' workflow and also remove some of the lower value work that they currently have to perform.

TheraPanacea (Radiotherapy planning software)

https://www.therapanacea.eu/

On market soon.

When planning radiotherapy, clinical oncologists have to swap between viewing MRI and CT scans. They use the MRI scans to define the tumour and normal anatomy and compare it to landmarks on the CT scan, as this is what is used to align the radiotherapy beam. Radiotherapy planning in complex cases can involve the oncologist having to switch between scans on many tens of occasions. This clearly creates significant cognitive burden for clinicians, is a source of unwanted variation in treatment, and is time consuming. TheraPanacea has developed an AI model to automatically overlay MRI and CT scans in a seamless manner. The fused images offer a chance to avoid wasted time switching between images and instead have more time to consider the really complex issue of planning the best way to treat a patient. It will hopefully also decrease errors and variation in planning.

TheraPanacea also offers an AI tool to support automated contouring (identification and drawing around) of the tumour on scans and the surrounding tissues which need sparing from the radiotherapy beam. Again, this may be able to support improvements in workflow for clinical oncologists.

Use of digital platforms to enable research

A potentially strong role for social media and other digital platforms is in supporting research. It may be able to help reach parts of the community not engaged with medical research ordinarily, and reduce the costs associated with large scale research. Facebook advertising, paper letters, news media, partner communications, snowboard recruitment, in-person recruitment and posters have been compared. Facebook advertisements generated the most recruits and worked out much cheaper than paper-based letters. (All methods resulted in a gender imbalance in recruitment with more women responding than men.)[31] Whilst this study was undertaken in Canada and therefore cannot be extrapolated to Wales in a straightforward manner, it points to the fact that digital methods of communicating with patients and service users may be able to drive down the costs associated with collecting patient feedback, opinions or outcomes.

Vine Health

https://www.vinehealth.ai/

Available now (but proof of AI component awaited)

Vine Health has developed a digital platform to provide personalised patient support programmes and assist clinical research. It is able to capture patient reported outcomes and quality of life data, as well as detect adverse reactions in real time. It is CE marked and available for use in the UK and Europe. The overall aims are to increase patient engagement in their care, allow efficient clinical care, capture data on outcomes to allow predictive analytics, and run decentralised clinical trials.

The capture of care and outcomes does not itself require AI. However, AI drives the background predictive analytics, aiming to identify patterns in the data that can indicate a patient is at risk of complications. An initial small study has reviewed use of the Vine Health app in patients with brain cancer. It demonstrated patient acceptability and a subjective improvement in care; however, this work has not been published in paper format (conference abstract only) and there was no assessment of the AI component within this study.[32]

Product	Diagnosis and screening	Diagnostics	Care co-ordination and remote monitoring	Treatment	Follow up	Significant workflow or capacity effect
PinPoint Data Science	[blue]					*
Kheiron Medical Technology MIA	[green]					*
Lunit	[purple]					*
Behold.AI	[green]	[green]				*
Faculty ai – NHSx	[blue]					*
Advanced Expert Systems	[yellow]					
Paige ai		[green]				*
Odin vision	[blue]	[blue]				
IBX		[orange]				*
MyMHealth HIYA			[purple]			
Careology			[purple]			
TIYGA			[purple]			
Brian Brain Tumour app			[purple]			
Medopad			[purple]			
Roche navify				[purple]		
Deontics				[orange]		*
Mirada				[green]		*
TheraPanacea				[purple]		*
Vine Health			[purple]			

- [green] Initial Health system adoption funding
- [orange] Real world testing funding
- [blue] Development and clinical evaluation funding
- [yellow] Feasibility testing funding
- [purple] On the market

Bibliography

References

1. Plackett, R. *et al.* Use of Social Media to Promote Cancer Screening and Early Diagnosis: Scoping Review. *J. Med. Internet Res.* **22**, e21582 (2020).
2. Vos, S. C., Sutton, J., Gibson, C. Ben & Butts, C. T. Celebrity Cancer on Twitter: Mapping a Novel Opportunity for Cancer Prevention. *Cancer Control* **26**, 107327481982582 (2019).
3. Harmon, D. M., Young, C. D., Bear, M. A., Aase, L. A. & Pruthi, S. Integrating online community support into outpatient breast cancer care: Mayo Clinic Connect online platform. *Digit. Heal.* **7**, 205520762110489 (2021).
4. Luo, Y. *et al.* Effectiveness of a Mobile Device–Based Resilience Training Program in Reducing Depressive Symptoms and Enhancing Resilience and Quality of Life in Parents of Children With Cancer: Randomized Controlled Trial. *J. Med. Internet Res.* **23**, e27639 (2021).
5. Barr, P. J. *et al.* An Audio Personal Health Library of Clinic Visit Recordings for Patients and Their Caregivers (HealthPAL): User-Centered Design Approach. *J. Med. Internet Res.* **23**, e25512 (2021).
6. Fristedt, S., Smith, F., Grynne, A. & Browall, M. Digi-Do: a digital information tool to support patients with breast cancer before, during, and after start of radiotherapy treatment: an RCT study protocol. *BMC Med. Inform. Decis. Mak.* **21**, 76 (2021).
7. Phase 2a Quantitative Data. The NHS Wales Video Consulting Service, Technology Enabled Care (TEC) Cymru. https://digitalhealth.wales/tec-cymru/how-we-can-help/evidence/eval-reports/vc-phase-2a (2021).
8. Salmani, H., Ahmadi, M. & Shahrokhi, N. The Impact of Mobile Health on Cancer Screening: A Systematic Review. *Cancer Inform.* **19**, 117693512095419 (2020).
9. Newman, G. & Johnson, J. M. Utilising Facebook to improve uptake in Breast Screening. *R. Soc. Public Heal.* (2018).
10. NHSx. Screening text reminder programme to increase the uptake of routine screening appointments. https://www.nhsx.nhs.uk/key-tools-and-info/digital-playbooks/cancer-digital-playbook/screening-text-reminder-programme-to-increase-the-uptake-of-routine-screening-appointments/ (2022).
11. Uy, C. *et al.* Text Messaging Interventions on Cancer Screening Rates: A Systematic Review. *J. Med. Internet Res.* **19**, e296 (2017).
12. Hirst, Y. *et al.* Text-message Reminders in Colorectal Cancer Screening (TRICCS): a randomised controlled trial. *Br. J. Cancer* **116**, 1408–1414 (2017).
13. Szanto, Z., Benko, I., Jakab, L., Szalai, G. & Vereczkei, A. The use of a smartphone application for fast lung cancer risk assessment†. *Eur. J. Cardio-Thoracic Surg.* **51**, 1171–1176 (2017).
14. Uthoff, R. D. *et al.* Point-of-care, smartphone-based, dual-modality, dual-view, oral cancer screening device with neural network classification for low-resource communities. *PLoS One* **13**, e0207493 (2018).
15. Ricard-Gauthier, D. *et al.* Use of Smartphones as Adjuvant Tools for Cervical Cancer Screening in Low-Resource Settings. *J. Low. Genit. Tract Dis.* **19**, 295–300 (2015).
16. Tanaka, Y. *et al.* 'Smartscopy' as an alternative device for cervical cancer screening: a pilot study. *BMJ Innov.* **3**, 123–126 (2017).
17. Savage, R. S. *et al.* Development and validation of multivariable machine learning algorithms to predict risk of cancer in symptomatic patients referred urgently from primary care. *medRxiv* 0–1 (2020).
18. Takiddin, A., Schneider, J., Yang, Y., Abd-Alrazaq, A. & Househ, M. Artificial Intelligence for Skin Cancer Detection: Scoping Review. *J. Med. Internet Res.* **23**, e22934 (2021).
19. Zhou, W. *et al.* Multi-step validation of a deep learning-based system for the quantification of bowel preparation: a prospective, observational study. *Lancet Digit. Heal.* **3**, e697–e706 (2021).
20. Verburg, E. *et al.* Deep Learning for Automated Triaging of 4581 Breast MRI Examinations from the DENSE Trial. *Radiology* **302**, 29–36 (2022).
21. Kim, H.-E. *et al.* Changes in cancer detection and false-positive recall in mammography using artificial intelligence: a retrospective, multireader study. *Lancet Digit. Heal.* **2**, e138–e148 (2020).
22. Gould, M. K. *et al.* Recent Trends in the Identification of Incidental Pulmonary Nodules. *Am. J. Respir. Crit. Care Med.* **192**, 1208–1214 (2015).
23. Baldwin, D. R. *et al.* External validation of a convolutional neural network artificial intelligence tool to predict malignancy in pulmonary nodules. *Thorax* **75**, 306–312 (2020).
24. Liu, Y. *et al.* Detecting Cancer Metastases on Gigapixel Pathology Images. 1–13 (2017).
25. Bilal, M. *et al.* Development and validation of a weakly supervised deep learning framework to predict the status of molecular pathways and key mutations in colorectal cancer from routine histology images: a retrospective study. *Lancet Digit. Heal.* **3**, e763–e772 (2021).
26. Huang, W. *et al.* Development and Validation of an Artificial Intelligence–Powered Platform for Prostate Cancer Grading and Quantification. *JAMA Netw. Open* **4**, 1–12 (2021).
27. Dorri, S., Asadi, F., Olfatbakhsh, A. & Kazemi, A. A Systematic Review of Electronic Health (eHealth) interventions to improve physical activity in patients with breast cancer. *Breast*

Cancer **27**, 25–46 (2020).

28. Mooney, K. *et al.* Evaluation of Oncology Hospital at Home: Unplanned Health Care Utilization and Costs in the Huntsman at Home Real-World Trial. *J. Clin. Oncol.* **39**, 2586–2593 (2021).

29. Komarzynski, S. *et al.* Embracing Change: Learnings From Implementing Multidimensional Digital Remote Monitoring in Oncology Patients at a District General Hospital During the COVID-19 Pandemic. *JCO Clin. Cancer Informatics* 216–220 (2021) doi:10.1200/CCI.20.00136.

30. Lu, L., Dercle, L., Zhao, B. & Schwartz, L. H. Deep learning for the prediction of early on-treatment response in metastatic colorectal cancer from serial medical imaging. *Nat. Commun.* **12**, 6654 (2021).

31. Wasfi, R. *et al.* Recruiting Participants for Population Health Intervention Research: Effectiveness and Costs of Recruitment Methods for a Cohort Study. *J. Med. Internet Res.* **23**, e21142 (2021).

32. Gvozdanovic, A. *et al.* Implementation of the Vinehealth application, a digital health tool, into the care of patients living with brain cancer. *J. Clin. Oncol.* **39**, e13582–e13582 (2021).

33. Wherton, J., Greenhalgh, T. & Shaw, S. E. Expanding Video Consultation Services at Pace and Scale in Scotland During the COVID-19 Pandemic: National Mixed Methods Case Study. *J. Med. Internet Res.* **23**, e31374 (2021).

Further Reading

- Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again. Eric Topol 2019.
- AI in Healthcare: Theory to Application. Sandeep Reddy 2019.
- A Buyers Guide to AI in Health and Care. NHSX November 2020. (https://www.nhsx.nhs.uk/ai-lab/explore-all-resources/adopt-ai/a-buyers-guide-to-ai-in-health-and-care/)
- Building Blocks for Artificial Intelligence and Autonomy. Dstl Ministry of Defence 2020 (https://www.gov.uk/government/publications/building-blocks-for-ai-and-autonomy-a-biscuit-book)
- NICE Evidence Standards Framework for digital health technologies 2018 updated 2021 (https://www.nice.org.uk/about/what-we-do/our-programmes/evidence-standards-framework-for-digital-health-technologies)
- List of current FDA approved AI / ML enabled medical devices (https://www.fda.gov/medical-devices/software-medical-device-samd/artificial-intelligence-and-machine-learning-aiml-enabled-medical-devices)

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