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In the Nexus of Transformation: Innovations, Challenges and the Future of Digital Oncology

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Introduction

Digital technology and oncology are two continuously advancing fields, the nexus of which promises an exciting transformation in how we deliver cancer care and the outcomes we achieve for our patients. Digital health in oncology or digital oncology, involves the integration of various technologies and data-driven solutions as tools to enhance the cancer care pathway from prevention, screening, earlier and faster diagnosis, patient-specific management, radiotherapy treatment planning and delivery to surveillance. As health systems globally continue to face challenges including increasing demand, access, and workforce shortages, digital health technologies (DHTs) have been posited as an important solution.

In recent years, numerous health-tech companies have emerged with cancer care–focused products and services aimed at providers, payers, clinicians and patients. However, whilst digital oncology may have the potential to transform how we deliver cancer care, there are a number of (current) challenges and limitations that lead some to view it with tempered enthusiasm. We believe it is important for oncologists to keep abreast of these tools, products and services, and to be aware of their limitations, so that we may engage in and inform their development, advocate for our patients, and facilitate access to the best possible care.

In this editorial, we first present a snapshot of the present and speculate on the future of digital health along the cancer care pathway. We then go on to explore the key challenges and limitations of digital oncology.

Digital Health Along the Cancer Care Pathway

We may soon start to see digital health impacting all aspects of cancer care, to streamline workflows, decrease costs, provide a more personalised and efficient experience, reduce toxicity and improve outcomes for patients (Figure 1). Examples include the following:

1) Cancer screening, earlier and faster diagnosis

Artificial intelligence (AI)-based platforms that facilitate analysis of routinely collected electronic health record (EHR) and medical imaging data may be able to identify patients at risk of developing specific cancers and thus inform screening programmes [1]. Digital pathology and radiology tools underpinned by AI can assist in analysing scans and pathology slides, aiding in earlier and faster detection and diagnosis [2]. DHTs will also utilise liquid biopsies to detect circulating tumour DNA (ctDNA) and other biomarkers, allowing for less invasive and more frequent monitoring [3].

2) Treatment decision support, radiotherapy and personalisation

Continuously learning, validated AI tools that integrate multiple data sources e.g. clinical, imaging, genetic and biological may provide recommendations to assist oncologists with treatment decisions such as dose de-escalation or whether or not to offer adjuvant chemotherapy [4,5]. AI is

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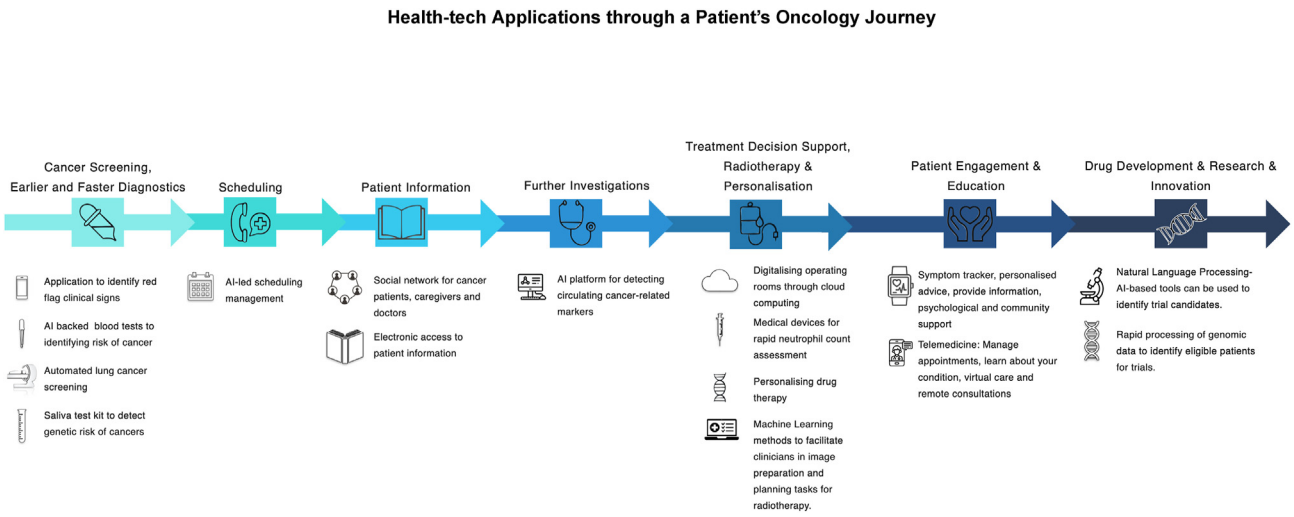

Fig 1. An overview of digital oncology applications along the cancer care pathway. This diagram highlights how patients, clinicians, and healthcare professionals engage in digital tools supporting and enhancing care.

being used clinically for auto-segmentation of organs-at-risk and tumour volumes, and for radiotherapy treatment planning [6]. It has also demonstrated promise with plan optimisation, adaptive planning, treatment delivery and quality assurance [7–11].

3) Patient engagement and education

Mobile apps provide patients with tumour-specific educational material, oral systemic anti-cancer therapy and supportive medication reminders, and symptom management advice [12]. Social platforms empower patients to take ownership of their health and allow patients and survivors to share experiences, advice and emotional support with sessions that can be facilitated by clinical nurse specialists [13].

4) Virtual care and remote consultations

With adoption accelerated in response to COVID-19, telemedicine platforms have enabled virtual consultations, providing patients with access to oncologists and clinical nurse specialists without the need for physical clinic attendance, improving convenience and flexibility. Similarly, remote and continuous monitoring of patients undergoing treatment via virtual platforms and wearable devices can facilitate real-time assessment and early intervention for treatment toxicity or failure [14,15,11]. These may also be used for post-treatment surveillance, and can improve access to care, particularly for patients living in remote settings.

5) Research and clinical trials

The two key challenges to delivering successful clinical trials are appropriate patient selection and effective monitoring. Natural language processing-based AI tools can learn trial protocols and search through EHRs to rapidly identify patients eligible for enrolment. Digital twins—virtual models that provide simulations of physical patient data—can be used to derive external control arms, expedite enrolment and increase statistical power. Data from EHRs, mobile apps and wearable devices can facilitate real-time monitoring and collection of additional real-world data, to complement and enhance traditional trial data [16].

Challenges and Limitations

Digital oncology faces several important challenges and limitations that must be addressed in order for it to maximally improve efficiency and quality of care. These include the following:

1) Data curation and governance:

The large datasets required for training and validation of AI-driven DHTs present a number of issues that risk progress. These include the time and cost associated with comprehensive curation, quality of real-world data, secure storage, institutional silos, scattered data, and broader access. This is particularly apparent when patients are referred from network hospitals to a treatment hub, e.g. for radiotherapy, and then referred back for on-going surveillance. Efforts to address these issues include development of robust national and international frameworks for safe and ethical storage and handling of data, and approaches such as cloud-based datasets and federated learning [2,17].

2) Interoperability:

The full potential of DHTs will only be realised if the data they use or generate can be exchanged with other systems in a manner that is secure, seamless and standardised. For example, an app designed to monitor patients on treatment

will be of limited use if it can only collect heart rate and activity data from wearable devices made by a specific vendor and/or cannot import these data to a particular EHR. This depends on interoperability at a technical, syntactic, semantic and organisational level [18].

3) Regulatory challenges, evidence and value

As well as safety, DHTs must prove evidence of clinical, financial, operational and experiential value for successful adoption. This evidence is critical for all players in digital oncology—patients, oncologists, providers, regulators and vendors. For vendors, evidence drives better product development, attracts customers and investors, and supports regulatory approval [19]. Despite this obvious need for evidence and the significant excitement surrounding digital oncology, the evidence base remains limited with few DHTs evaluated to the same standard as for other oncological interventions. This is attributed to the speed and iterative nature of development common to DHTs being incongruent with traditional robust evaluation methods such as prospective validation or randomised controlled trials [2,20]. Lack of evidence therefore leads to lack of implementation and vice-versa [21]. In response to this, NHS England and the National Institute of Health and Care Excellence have developed the evidence standards framework to support payers in identifying tools that are likely to deliver the most benefit [22,23]. Innovative approaches to evidence generation such as simulation-based research are required. This utilises clinical and computational simulation to assess efficiency, accuracy and reproducibility. This involves and can offer an equitable approach to generate evidence for low-risk digital interventions [20,24].

4) User experience, access and health inequalities:

It is imperative for vendors of DHTs to actively engage patients and clinicians in product development. DHTs that have not sought early patient and clinician engagement are less likely to be adopted [25]. Patients provide valuable insights into their needs and preferences, and ensure that technologies are user-friendly and meet their expectations. Similarly, clinician involvement is necessary to ensure technologies are safe, accurate, clinically meaningful, and can optimally integrate into clinical workflows.

Whilst virtual consultations, remote monitoring, increasing eligibility to trials and AI-driven treatment personalisation can reduce health inequalities, DHTs have also been accused of exacerbating health disparities [13,26,27], particularly in those with limited access to technology or less confidence in engaging with DHT. A study by the World Health Organization (WHO) found lower rates of DHT use in rural areas, those facing language barriers, those of lower socioeconomic class or lower levels of education, and amongst ethnic minorities [28]. Efforts to address these disparities include adopting a common framework to monitor engagement with DHTs across equity domains and digital literacy programmes [28,30].

Conclusion

The rapid rise in digital oncology is compelling due to the potential it has to positively impact almost the entirety of the cancer care pathway. However, as we have illustrated, there remain several important challenges and limitations that first need to be overcome [29,30]. This will require coordinated efforts and collaboration with technology developers, researchers, payers, providers and patients. Early applications are likely to focus on reducing administrative burden, improving efficiency and patient education, though we may soon start to see DHTs facilitating personalised treatment plans, remote monitoring, and risk-stratified surveillance. The work of the future clinical oncologist will be substantially different from that today.

Author Contributions

MK is the guarantor of integrity of the entire study. MK and SH were responsible for study concepts and design. MK and SH carried out the literature search. MK and SH prepared the manuscript. SH edited the manuscript and provided supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sumeet Hindocha reports a relationship with the radiation research unit at the Cancer Research UK City of London Centre Award that includes funding grants. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] ESMO. The potential of AI to improve cancer care is only going to grow n.d. https://www.esmo.org/newsroom/press-and-media-hub/esmo-media-releases/the-potential-of-ai-to-improve-cancer-care-is-only-going-to-grow (accessed January 23, 2024).
[2] Hunter B, Hindocha S, Lee RW. The Role of Artificial Intelligence in Early Cancer Diagnosis. *Cancers* 2022;14. https://doi.org/10.3390/cancers14061524.
[3] Crosby D. Delivering on the promise of early detection with liquid biopsies. *Br J Cancer* 2022;126:313–315.
[4] Walsh S, de Jong EEC, van Timmeren JE, Ibrahim A, Compter I, Peerlings J, *et al.* Decision Support Systems in Oncology. *JCO Clin Cancer Inform* 2019;3:1–9.

[5] Pitt E, Bradford N, Robertson E, Sansom-Daly UM, Alexander K. The effects of cancer clinical decision support systems on patient-reported outcomes: A systematic review. *Eur J Oncol Nurs* 2023;66:102398.
[6] Hindocha S, Zucker K, Jena R, Banfill K, Mackay K, Price G, *et al*. Artificial Intelligence for Radiotherapy Auto-Contouring: Current Use, Perceptions of and Barriers to Implementation. *Clin Oncol* 2023;35:219–226.
[7] Huynh E, Hosny A, Guthier C, Bitterman DS, Petit SF, Haas-Kogan DA, *et al*. Artificial intelligence in radiation oncology. *Nat Rev Clin Oncol* 2020;17:771–781.
[8] Krishnamurthy R, Mummudi N, Goda JS, Chopra S, Heijmen B, Swamidas J. Using Artificial Intelligence for Optimization of the Processes and Resource Utilization in Radiotherapy. *JCO Glob Oncol* 2022;8:e2100393.
[9] Santoro M, Strolin S, Paolani G, Della Gala G, Bartoloni A, Giacometti C, *et al*. Recent Applications of Artificial Intelligence in Radiotherapy: Where We Are and Beyond. *NATO Adv Sci Inst Ser E Appl Sci* 2022;12:3223.
[10] Li G, Wu X, Ma X. Artificial intelligence in radiotherapy. *Semin Cancer Biol* 2022;86:160–171.
[11] Beg S, Handa M, Shukla R, Rahman M, Almalki WH, Afzal O, *et al*. Wearable smart devices in cancer diagnosis and remote clinical trial monitoring: Transforming the healthcare applications. *Drug Discov Today* 2022;27:103314.
[12] Becca - the breast cancer support app. *Breast Cancer Now* 2018, https://breastcancernow.org/information-support/support-you/becca. [Accessed 23 January 2024].
[13] Parikh RB, Basen-Enquist KM, Bradley C, Estrin D, Levy M, Lichtenfeld JL, *et al*. Digital Health Applications in Oncology: An Opportunity to Seize. *J Natl Cancer Inst* 2022;114:1338–1339.
[14] Jacobsen M, Rottmann P, Dembek TA, Gerke AL, Gholamipoor R, Blum C, *et al*. Feasibility of Wearable-Based Remote Monitoring in Patients During Intensive Treatment for Aggressive Hematologic Malignancies. *JCO Clin Cancer Inform* 2022;6:e2100126.
[15] Chow R, Drkulec H, Im JHB, Tsai J, Nafees A, Kumar S, *et al*. The Use of Wearable Devices in Oncology Patients: A Systematic Review. *Oncologist* 2023. https://doi.org/10.1093/oncolo/oyad305.
[16] Zhang B, Zhang L, Chen Q, Jin Z, Liu S, Zhang S. Harnessing artificial intelligence to improve clinical trial design. *Commun Med* 2023;3:191.
[17] Kondylakis H, Kalokyri V, Sfakianakis S, Marias K, Tsiknakis M, Jimenez-Pastor A, *et al*. Data infrastructures for AI in medical imaging: a report on the experiences of five EU projects. *Eur Radiol Exp* 2023;7:20.
[18] Lehne M, Sass J, Essenwanger A, Schepers J, Thun S. Why digital medicine depends on interoperability. *NPJ Digit Med* 2019;2:79.
[19] Budget impact analysis: health economic studies. GOVUK n.d. https://www.gov.uk/guidance/budget-impact-analysis-health-economic-studies (accessed January 23, 2024).
[20] Guo C, Ashrafian H, Ghafur S, Fontana G, Gardner C, Prime M. Challenges for the evaluation of digital health solutions-A call for innovative evidence generation approaches. *NPJ Digit Med* 2020;3:110.
[21] Dadhania S, Williams M. What is so Special About Digital Health in Cancer? *Clin Oncol* 2023;35:147–149.
[22] Greaves F, Joshi I, Campbell M, Roberts S, Patel N, Powell J. What is an appropriate level of evidence for a digital health intervention? *Lancet* 2019;392:2665–2667.
[23] Evidence standards framework (ESF) for digital health technologies | Our programmes | what we do | about | NICE [n.d].
[24] Lau K, Halligan J, Fontana G, Guo C, O'Driscoll FK, Prime M, *et al*. Evolution of the clinical simulation approach to assess digital health technologies. *Future Healthc J* 2023;10:173–175.
[25] How to involve and engage patients in digital health tech innovation—An Evidence Based Guide n.d. https://eprints.whiterose.ac.uk/188974/1/ppie_guide.pdf (accessed January 23, 2024).
[26] Griffin JM, Kroner BL, Wong SL, Preiss L, Smith AW, Cheville AL, *et al*. Disparities in Electronic Health Record Portal Access and Use among Patients with Cancer. *J Natl Cancer Inst* 2023. https://doi.org/10.1093/jnci/djad225.
[27] Patel S, Goldsack JC, Cordovano G, Downing A, Fields KK, Geoghegan C, *et al*. Advancing Digital Health Innovation in Oncology: Priorities for High-Value Digital Transformation in Cancer Care. *J Med Internet Res* 2023;25:e43404.
[28] Digital health not accessible by everyone equally, new study finds n.d. https://www.who.int/europe/news/item/21-12-2022-digital-health-not-accessible-by-everyone-equally-new-study-finds (accessed January 24, 2024).
[29] Aristidou A, Jena R, Topol EJ. Bridging the chasm between AI and clinical implementation. *Lancet* 2022;399:620.
[30] Digital health in radiation oncology: Imagining the future of patient management n.d. https://appliedradiationoncology.com/articles/digital-health-in-radiation-oncology-imagining-the-future-of-patient-management (accessed January 24, 2024).