*Research Directions: Quantum Technologies*

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## Question

**Cite this article:** Flöther FF and Griffin PF (2023). How can quantum technologies be applied in healthcare, medicine and the life sciences? *Research Directions: Quantum Technologies*. **1**, e7, 1–2. https://doi.org/10.1017/qut.2023.1

Received: 30 January 2023
Accepted: 2 February 2023

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Research Directions

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# How can quantum technologies be applied in healthcare, medicine and the life sciences?

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## Context

Quantum technologies, including computing, communication/security and sensing, have significantly advanced over the last years. Industry-specific applications are now being intensely researched and healthcare, medicine and the life sciences represent one of the focus areas.

For medical quantum computing, the initial focus was on biochemical and computational biology problems (Emani et al., 2021; Fedorov and Gelfand, 2021; Outeiral et al., 2021; Marchetti et al., 2022; Cordier et al., 2022; Santagati et al., 2023); recently, clinical quantum computing experiments have increasingly drawn interest (Prousalis and Konofaos, 2019; Abbott, 2021; Moradi et al., 2022). In the last few years alone, over 40 studies on medical proof-of-concept quantum computing applications have been conducted, spanning genomics, clinical research and discovery, diagnostics and treatments/interventions. In particular, quantum machine learning/artificial intelligence has rapidly evolved and shown to be competitive with classical approaches in certain cases.

As concerns quantum security, the sensitivity of medical data is a key driving force. Due to the risk of "harvest now, decrypt later" attacks (Harishankar et al., 2023), quantum-safe standards are already being developed (NIST Announces First Four Quantum-Resistant Cryptographic Algorithms, 2023), and there are governmental directives around the preparation and implementation of quantum-safe cryptography (Migrating to Post-Quantum Cryptography, 2023).

Finally, quantum sensors seek to enhance diagnosis and treatment through highly sensitive measurements of physical and biological parameters. Diverse examples exist. First, single-photon detection techniques achieve improved low-light resolutions for applications such as cell dynamics (Callenberg et al., 2021). Second, quantum correlations may be harnessed to improve signal-to-noise ratios in magnetic resonance imaging (MRI) and positron emission tomography (PET) (Watts et al., 2021). Third, quantum dots are being used in cancer therapy to enhance the targeting and delivery of drugs to tumours (Ruzycka-Ayoush et al., 2021). Fourth, atomic magnetometers enable accurate non-invasive magnetic sensing and imaging of relevant biological activity, including cardiac (MCG) (Bison et al., 2009), foetal (fMCG) (Strand et al., 2019), muscular (Broser et al., 2018), and brain activity (MEG) (Brookes et al., 2022). The latter is an exemplar of the technology uptake, moving from the first demonstrations (Xia et al., 2006) to complete commercial systems in little over a decade.

This research question entails mapping the landscape of quantum technology applications in healthcare, medicine and the life sciences and providing a near-term and long-term outlook. Key threads include:

1. What is the state of quantum computing applications and which quantum algorithms have shown promise in the sector?
2. What are key technical challenges, for instance around clinical and real-world data, error handling and real-time computations, and how might they be addressed on the path towards full-scale quantum computing implementations?
3. What is the state of quantum communication and security applications and what sector-specific considerations apply?
4. What is the state of quantum sensing applications in the sector?
5. How are the needs of the medical researchers and practitioners guiding development of quantum sensors?
6. What are the challenges to be met, ethical and otherwise, in order to speed up quantum technology translation and achieve widespread adoption by clinicians, medical practitioners and researchers?
7. What role should medicine-focussed quantum computing consortia and ecosystems play?

Quantum technology is poised to become a key enabler for progress towards precision medicine: keeping people healthy through proactive medical care and guidance at the level of an individual. Addressing the research threads above is essential in order to fully realise the technological promises in this space.

## How to contribute to this question

If you believe you can contribute to answering this Question with your research outputs find out how to submit in the Instructions for authors (https://www.cambridge.org/core/journals/research-directions-quantum-technologies/information/author-instructions/preparing-your-materials). This journal publishes Results, Analyses, Impact papers and additional content such as preprints and "grey literature". Questions will be closed when the editors agree that enough has been published to answer the Question so before submitting, check if this is still an active Question. If it is closed, another relevant Question may be currently open, so do review all the open Questions in your field. For any further queries, check the information pages (https://www.cambridge.org/core/journals/research-directions-quantum-technologies/information/about-this-journal) or contact this email (quantumtechnologies@cambridge.org).

**Competing interests.** The authors declare none.

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