



National Quantum
Computing Centre

Insights Paper 2024–25

**The convergence of healthcare
and pharmaceuticals with
quantum computing:
A new frontier in medicine**

➤ The NQCC works across government, industry and the research community to drive quantum readiness in the UK and support the long term strategic goal of employing quantum computing to deliver prosperity and security for societal good.

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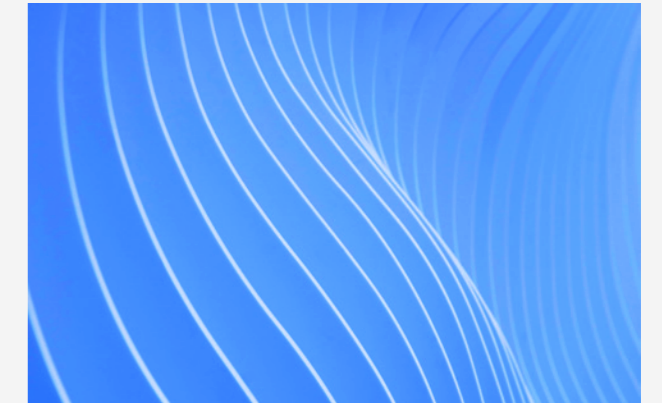
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➤ The UK is at the forefront of the global quantum revolution, with a clear national strategy to position itself as a leader in quantum computing and its applications across critical industries. As the UK's national laboratory for quantum computing, the National Quantum Computing Centre aims to play a central role in accelerating this transformation.

This Insights Paper reinforces our commitment to driving sector-wide adoption of quantum computing, offering a clear analysis of the opportunities, challenges, and actions required to harness the full benefits of quantum computing in healthcare and pharmaceuticals, as the development of this emerging technology continues at pace.

The UK's Quantum Missions provide an ambitious framework for realising the societal benefits of quantum. The vision, by 2035, is of UK-based quantum computers capable of solving complex problems, going beyond the capabilities of classical supercomputers, and unlocking new frontiers in drug discovery, genomics, and AI-driven medical research.

This paper highlights the challenges that must be addressed – from hardware and algorithm scalability and real-world applications to regulatory and ethical considerations and workforce readiness. The pathway to realising quantum's healthcare potential will require targeted investment, cross-sector collaboration, and a robust skills pipeline.

With this publication, we hope to inform and provide guidance for key stakeholders as we work together to translate quantum innovations into real-world healthcare impact.

Dr Simon Plant

Deputy Director for Innovation
National Quantum Computing Centre

A unique opportunity to redefine the future of healthcare and pharmaceuticals

Quantum computing is a rapidly developing emerging technology that aims to address computational challenges that are beyond the reach of even the most advanced conventional supercomputers. For the healthcare and pharmaceutical industries, which rely heavily on computational methods to drive innovation, this emerging technology offers the potential to bring about a step change in areas such as drug discovery, personalised medicine, clinical trial optimisation, medical imaging and healthcare logistics.

Achieving this transformation requires concerted effort, sustained investment and overcoming significant technical, strategic, and regulatory hurdles. This insights paper, developed by the UK's National Quantum Computing Centre (NQCC), synthesises findings from workshops, sectoral consultations, expert interviews, and background research. It aims to provide stakeholders with a high-level understanding of the opportunities, challenges, and necessary steps for the successful integration of quantum computing in healthcare and pharmaceuticals.

Key insights include:

Potential impacts across healthcare and pharmaceuticals: Quantum computing holds the potential to address some of the most complex challenges in healthcare and pharmaceuticals. Applications include molecular simulations for drug discovery, advanced genomic analysis, precision medicine, and optimisation of healthcare logistics. By enabling faster, more accurate computational methods, quantum computers could accelerate breakthroughs that were previously constrained by the limits of conventional computing.

Early-stage progress and technical challenges: Current explorations are in the research and development phase with early proofs-of-concept having demonstrated encouraging results. However, widespread adoption of quantum computing is currently limited by the capabilities of the hardware. The need for scalable algorithms and hybrid quantum-classical models remains a critical focus for ongoing research and development. Integration challenges with existing digital infrastructure and computational workflows in addition to data protection are also key considerations.

Strategic collaboration and ecosystem building: Advancing quantum applications in healthcare requires a multidisciplinary approach. Collaboration between academia, industry, government and the broader private sector is essential to drive progress, share knowledge, and address technical and operational challenges. Pre-competitive consortia, open innovation models, and strategic partnerships will play a pivotal role in creating a sustainable ecosystem for innovation.

Developing talent and regulatory preparedness: The successful utilisation of quantum computing in the near to medium term in healthcare and pharmaceuticals requires specialised skills within the workforce that understands both quantum technologies and life sciences. Developing quantum literacy, fostering interdisciplinary education, investing in knowledge transfer partnerships and establishing forward looking regulatory frameworks will be critical.

Balancing long-term ambitions with near term opportunities: While the long-term vision for quantum computing involves solving complex biological and clinical problems, near-term applications such as hybrid quantum-classical approaches in specific use-cases might offer immediate value. Strategic investments should focus both on fundamental research and scalable solutions that demonstrate practical benefits while paving the way for more advanced applications.

Grand challenges can catalyse innovation: Targeted large-scale collaborative initiatives around priority use-cases such as cancer detection, rare diseases, anti-microbial resistance or chronic diseases, similar to the Human Genome Project (HGP), could serve as focus points for progress, helping to align stakeholders and creating measurable benchmarks for success.



> This paper outlines actionable insights for industry leaders, policymakers, and funding bodies, to navigate the opportunities and challenges around accelerating the adoption of quantum computing technologies in healthcare and pharmaceuticals.

Sustained investment, a focus on solving real-world problems and fostering collaboration will be vital as quantum computing evolves from experimental to foundational technology.

As quantum computing matures, it offers a unique opportunity to redefine the future of healthcare and pharmaceuticals. By addressing strategic challenges and developing a flexible roadmap, the UK has the potential to position itself as a global leader in this transformative field. This paper aims to serve as a guide for stakeholders to navigate this emerging landscape, ensuring that quantum computing contributes to better health outcomes, enhanced patient care, and a more efficient healthcare system.

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Introduction

Quantum computing represents an emerging frontier in computational technology, leveraging the principles of quantum mechanics to address certain problems that are computationally infeasible for classical computers. This emerging field holds significant promise for healthcare and pharmaceuticals, offering potential breakthroughs in drug discovery, medical imaging, clinical trial optimisation, and the realisation of personalised medicine.

By utilising quantum phenomena such as superposition and entanglement, quantum computers have the potential to process complex datasets and model intricate biological systems with unprecedented efficiency. However, at the moment, quantum computing remains at an early stage of development, with most activities currently confined to the R&D space.

The UK's National Quantum Computing Centre (NQCC), established as part of the National Quantum Technologies Programme (NQTP), aims to play a pivotal role in fostering quantum readiness. Its mission is to accelerate the scaling, development, and adoption of quantum computing, with a strategic focus on key sectors such as healthcare and pharmaceuticals. By building a robust quantum computing ecosystem, the NQCC aims to position the UK as a global leader in this emerging field, driving economic growth and delivering widespread societal benefits.

Recent advances in quantum computing have demonstrated early-stage applications in healthcare and pharmaceuticals, including quantum chemistry for molecular simulations, drug-target interaction predictions, and quantum machine learning for medical imaging [1] [2] [3] [4]. Early-stage studies exploring hybrid quantum-classical approaches have shown encouraging results in diagnostics and predictive modelling. While these proof-of-concept efforts show great potential, significant technical challenges remain. Current quantum hardware faces limitations in scaling the performance and capacity of quantum processing units, including the reduction of error rates, while the development of robust algorithms capable of addressing real-world problems is still ongoing.

Recognising the opportunities and challenges, the NQCC hosted its inaugural "Quantum Computing in Healthcare and Pharmaceuticals" (QCHP) workshop on the 14 March 2024, at the Royal Society in London [5].

This event convened experts from academia, industry, national laboratories, government, and technology developers to assess the global quantum healthcare landscape, identify the UK's strengths, and explore collaboration models.

This insights paper builds on extensive sectoral consultations, literature reviews, and evidence presented at workshops and conferences to explore the transformative potential of quantum computing in healthcare and pharmaceuticals. It is structured in two parts:

- **Context and background:** Establishes a foundational basis through expert interviews, literature reviews, and bilateral discussions, equipping readers with the technological and sectoral context.
- **Strategic directions:** Synthesises findings from the QCHP workshop and sector-specific consultations, exploring emerging opportunities, collaboration models, and recommended pathways for progress.

While the insights collected in this paper span various areas, their realisation will require a concerted effort involving government, academia, public, private and third-sector stakeholders.

This document aims to serve as a guide for shaping roadmaps, funding priorities, and partnerships, ultimately fostering the utilisation of quantum computing in healthcare. By laying the groundwork for integrating quantum technologies into healthcare, this paper envisions a future where quantum computing, within the next 10–20 years, contributes to improved patient outcomes and more efficient healthcare delivery in the UK.

Ecosystem highlights

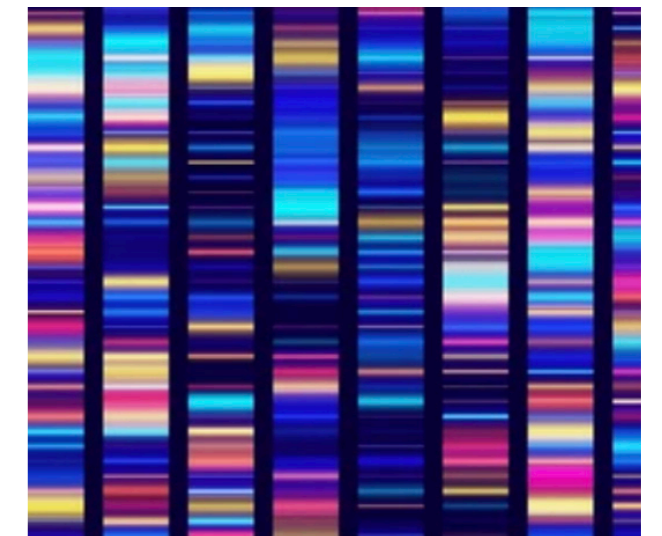
Across the quantum computing and healthcare ecosystem, exciting initiatives are already shaping the development of transformative solutions to complex medical challenges. These efforts reflect the increasing potential of quantum computing to complement existing technologies, addressing areas such as drug discovery, genomic analysis, and personalised medicine.



World's first quantum computer dedicated to healthcare

Cleveland Clinic, in partnership with IBM, has launched the first quantum computer dedicated to healthcare research leveraging the IBM Quantum System One. Located at the Lerner Research Institute, this resource supports a decade-long Discovery Accelerator initiative focused on applying quantum computing to key research areas such as protein structure prediction, drug discovery, cardiovascular risk prediction, genomic analysis and artificial intelligence for neurodegenerative diseases.

By exploring how quantum capabilities can enhance biomedical research, the initiative aims to refine drug design, deepen insights into disease mechanisms, and advance personalised treatment strategies. This approach aligns with Cleveland Clinic's broader commitment to improving patient outcomes through innovative, data-driven healthcare solutions [6] [7].



The Wellcome Leap Quantum for Bio (Q4Bio) Program for transformative applications in healthcare

The Wellcome Leap Quantum for Bio (Q4Bio) program is designed to harness quantum computing for transformative applications in health. It focuses on developing quantum algorithms that could accelerate fields like genomics and drug discovery.

The program will provide up to \$40 million in research funding, with an additional \$10 million available in challenge prizes for teams that successfully demonstrate quantum advantage in healthcare applications.

These efforts aim to push quantum computing towards solving complex biological problems, like protein folding and genomic analysis, by utilising emerging quantum hardware in the next 3-5 years [8].

Part 1

Quantum computing for healthcare and pharma: Context and background

As the complexity of healthcare data and biological models continues to grow, classical systems often struggle to process large, high-dimensional datasets or to simulate intricate molecular and biological interactions with precision.

This is where quantum computing emerges as a transformative opportunity.

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1 What is quantum computing?

Quantum computing is an emerging technology that leverages the principles of quantum mechanics, such as superposition and entanglement, to address computational challenges that classical computers cannot efficiently solve.

Unlike classical systems, which process information sequentially using binary digits (bits), quantum computers operate in fundamentally different ways, using quantum bits, or **qubits**. This unique approach enables quantum computers to explore vast solution spaces simultaneously, identify optimal pathways to solve specific challenges more efficiently and unlock new possibilities for addressing problems of immense complexity.

In healthcare and pharmaceuticals, quantum computing has the potential to transform critical areas such as simulating molecular interactions, analysing large genomic datasets, and optimising clinical trial designs.

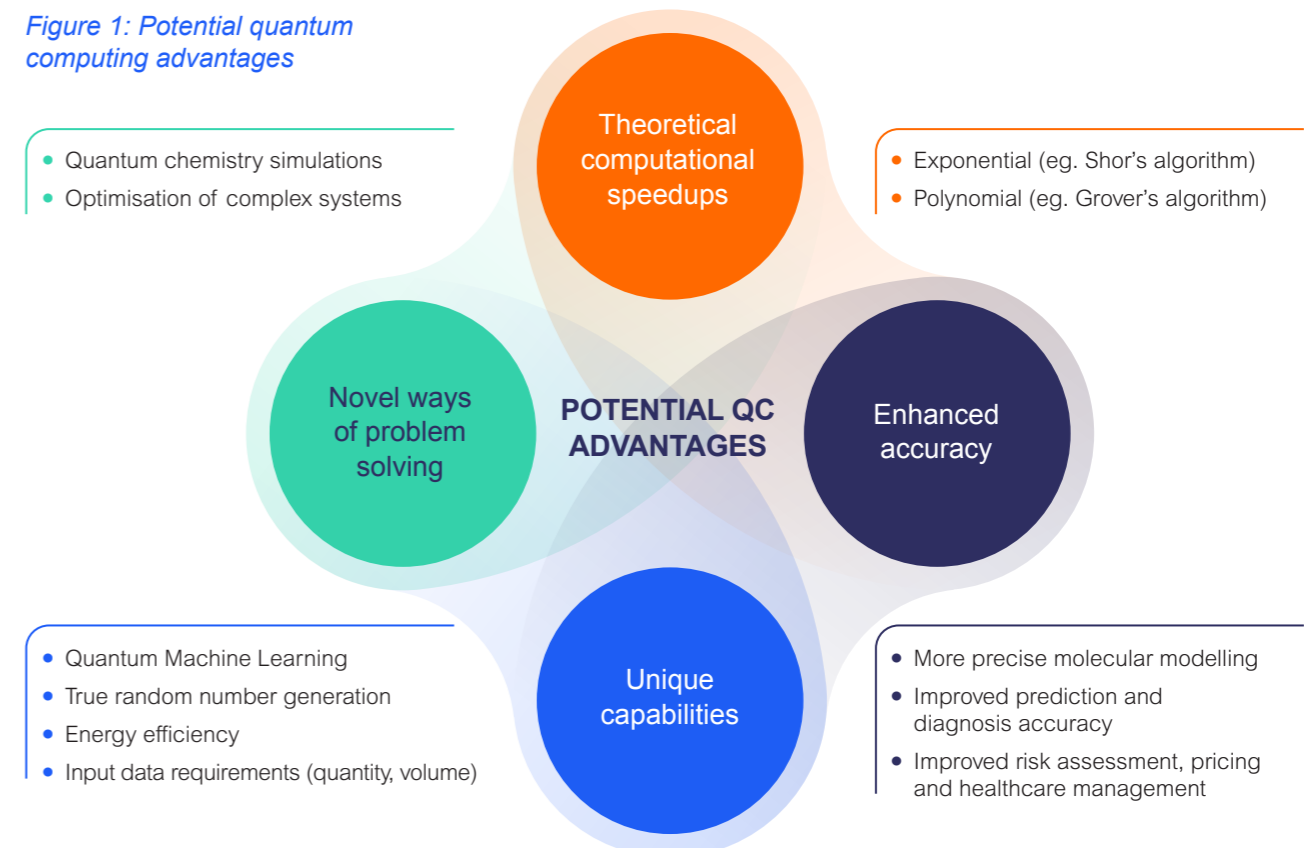
Quantum computing can be broadly categorised into gate-based and analog approaches - including quantum annealing. Gate-based quantum computers use quantum logic gates to perform complex

calculations, making them versatile for various applications. Quantum annealing, on the other hand, is designed specifically for solving optimisation problems by finding the lowest-energy state of a system.

By overcoming the computational limits of classical systems, quantum computing could accelerate breakthroughs that were previously constrained by processing power or algorithmic complexity.

Quantum computing offers a range of use-case dependant potential advantages, extending beyond speed improvements to include solving problems previously considered intractable. Fields that stand to benefit include pharmaceuticals, materials science, energy, finance, logistics, space, and cryptography. However, these advantages are still largely theoretical, with most applications residing in the research and development stage.

Figure 1: Potential quantum computing advantages



Part 1:
Context and background

Building a functional quantum computer involves significant complexity. Like classical computers, quantum systems require a full stack of hardware, software, control layers, and cooling systems, along with scalable algorithms. The unique challenges of quantum computing – such as maintaining qubit stability and minimising error rates – add to its complexity, making scaling particularly difficult.

While significant progress has been made in developing better quantum processing units (QPUs) and error-correction techniques, further advances in hardware and software will be crucial for realising its full potential.

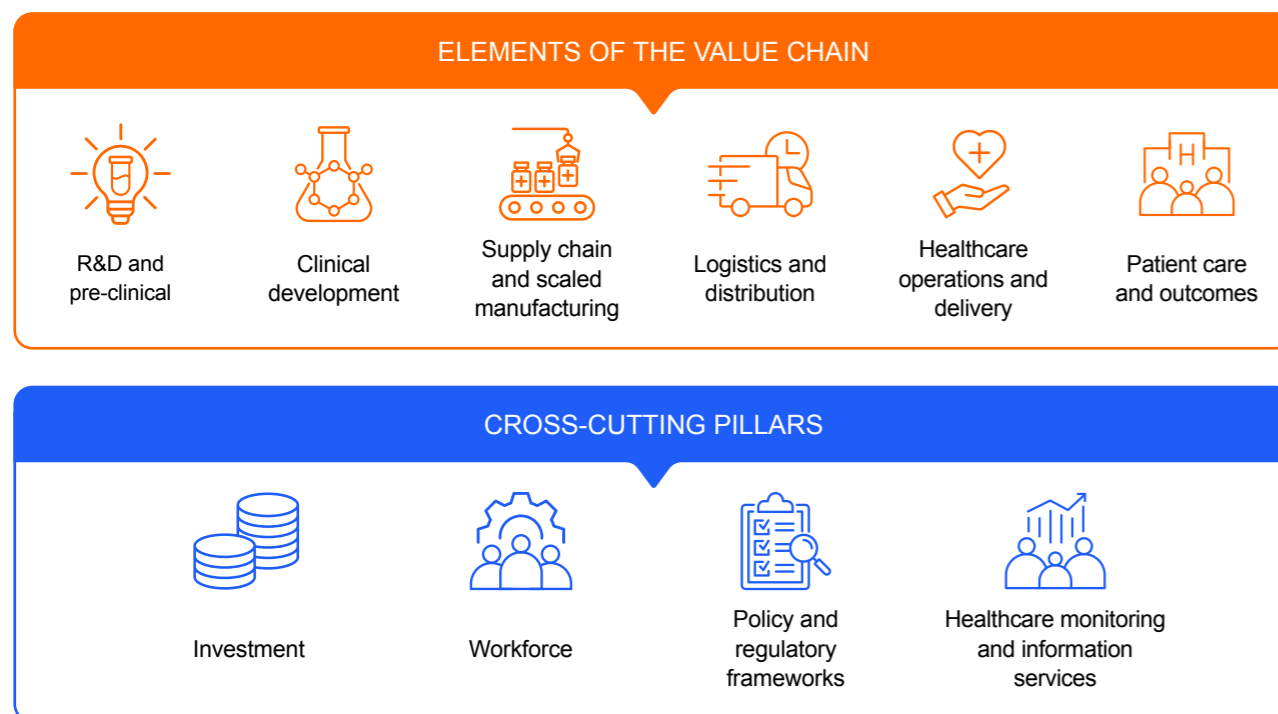
As quantum computing evolves, it is expected to complement classical computing in a hybrid approach, leveraging the strengths of both technologies.

Early applications are likely to focus on niche problems where quantum computing offers clear advantages. Achieving widespread “quantum advantage” – where quantum systems consistently outperform classical ones across various tasks – will require sustained research, significant hardware innovations, and the development of diverse algorithms. This progress is expected to unfold gradually over the next 10–20 years, as quantum computing matures into a reliable and impactful technology.

2 The potential of QC for healthcare and pharma

The healthcare and pharmaceutical industries are vital to improving human health, increasing longevity, and enhancing quality of life. These sectors form a complex ecosystem encompassing research, drug discovery, diagnostics, clinical interventions, and healthcare logistics, all of which contribute to tackling global health challenges. The infographic below illustrates the breadth and depth of this sector, highlighting key components of the value chain.

Figure 2: The healthcare and pharmaceuticals value chain



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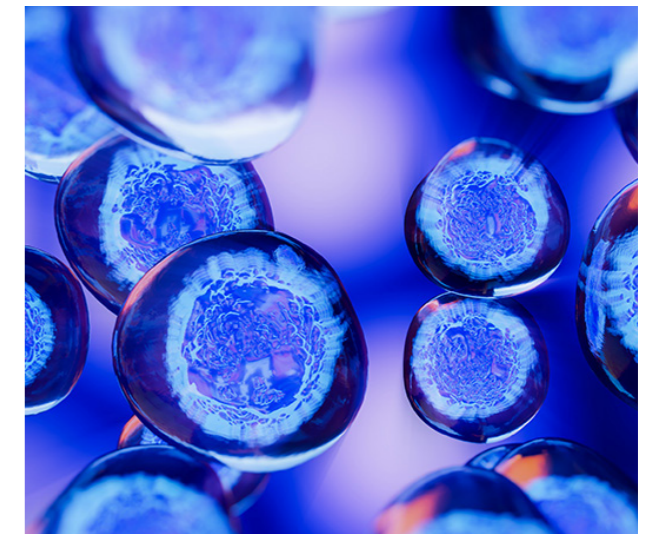
Contributing more than 10% to GDP in the UK per year [9], these sectors are undergoing rapid transformation driven by technological advancements, shifting demographics, and rising patient expectations. At the same time, they face significant challenges, including aging populations, chronic diseases, antimicrobial resistance, rare diseases, and emerging pathogens. Addressing these issues requires long-term, collaborative efforts across governments, civil society, and the private sector to develop innovative, scalable solutions.

Computational methods have long played a central role in healthcare and pharmaceutical innovation. Recent advances in artificial intelligence (AI), machine learning (ML), and high-performance computing (HPC) [10] [11] [12] have further accelerated progress. For example, AI and ML now streamline drug discovery by screening millions of compounds to identify viable candidates, drastically reducing development timelines [13] [14] [15]. They enhance diagnostic precision [16], often rivalling human accuracy in early disease detection, and are instrumental in developing personalised medicine by analysing genomic and clinical datasets [17] to tailor treatments.

AI is also reshaping clinical trials by improving patient recruitment and protocol design, reducing time-to-market for new therapies [18]. In healthcare operations, machine learning has been used to optimise resource allocation, predict patient admission rates, and improved supply chain management [19], driving efficiency across the sector. However, these advances also highlight rapidly approaching limits of classical computing.

Quantum computing: Addressing the limits of classical computing

As the volume of healthcare data and the complexity of biological models continue to grow, classical systems will reach their limits in processing large, high-dimensional datasets and in simulating intricate molecular and biological interactions with precision. This is where quantum computing emerges as a transformative opportunity.



Key advantages of quantum computing for healthcare and pharmaceuticals

Quantum computing offers distinct benefits that position it as a promising tool to address computational challenges in healthcare and pharmaceuticals:

- **Accelerated problem solving:** Quantum computers may offer the potential to perform highly complex computations at speeds unattainable by classical computers. For example, simulating molecular interactions or optimising protein-ligand binding could be achieved in a fraction of the time, potentially reducing drug discovery timelines.
- **Enhanced solution precision:** By directly modelling quantum phenomena, such as electron behaviour and molecular reactions, quantum computing has the potential to offer highly accurate simulations. This precision is crucial for tasks like calculating electronic structures and predicting complex biological behaviours, leading to more effective therapeutics.
- **Improved cost and energy efficiency:** Quantum computers have the potential to perform certain computations more efficiently, resulting in reduced energy consumption and operational costs. This is particularly advantageous for resource-intensive tasks, such as complex large-scale molecular simulations or large-scale genomic data analysis. While more research is needed to generate further supporting evidence, early proof-of-concept explorations demonstrate promising future directions.



Applications in quantum chemistry

One of the most promising areas for quantum computing in healthcare is quantum chemistry, which underpins critical aspects of drug discovery and material science. Classical methods in quantum chemistry rely on approximation techniques to model molecular structures, reactions, and energy levels. While effective for simpler systems, these methods struggle with highly entangled molecules or systems involving many electrons, leading to computational bottlenecks.

Quantum computing has the potential to overcome these limitations by simulating molecular systems with accuracy and efficiency [20]. Early-stage hybrid quantum-classical approaches are already showing potential in tasks such as protein-ligand binding affinity predictions, enabling more effective molecular optimisation and reaction modelling. These methods allow quantum computers to complement classical computing, focusing on specific areas where quantum advantages are clear [21] [22] [23].

Beyond chemistry: Expanding applications

The benefits of quantum computing extend beyond chemistry. Current classical methods face challenges in simulating complex biological systems, such as the blood-brain barrier, and accurately predicting drug behaviours in the human body. There is potential for quantum systems to tackle these problems by enabling large-scale automation in virtual screening and providing high-fidelity simulations for drug design and delivery optimisation.

➤ Quantum systems can tackle optimisation challenges in healthcare logistics, including streamlining clinical trial design, enhancing patient recruitment, and optimising resource allocation, while also strengthening current methods for securely sharing sensitive healthcare data.

In addition, as healthcare datasets – especially in genomics and proteomics – grow in size and complexity, classical models often struggle to generate useful insights.

While quantum computing is not suited for directly processing large datasets, it has the potential to enhance healthcare data analysis by addressing classical bottlenecks in complex computational problems. In particular, quantum algorithms may aid in uncovering intricate correlations in high-dimensional biomedical data, optimising simulations for drug discovery, and improving precision medicine strategies. Furthermore, quantum computers have the potential to tackle optimisation challenges in healthcare logistics, including streamlining clinical trial design, enhancing patient recruitment, and optimising resource allocation, while also strengthening current methods for securely sharing sensitive healthcare data.

Emerging fields and future prospects

The integration of quantum computing with high-performance computing (HPC) in the emerging field of Quantum-Centric High-Performance Computing (QCHPC) is poised to unlock further possibilities. As healthcare evolves, quantum computing's integration with AI, ML, and HPC [24] will likely redefine the boundaries of innovation in the sector. With sustained investment in research and collaboration, quantum computing is poised to complement existing technologies and contribute to significant advancements in patient outcomes and healthcare delivery.



Untapped potential in rare diseases and women's health

Quantum computing has the potential to significantly impact two historically underserved areas of medicine: rare diseases and women's health.

Both fields face challenges due to the limited size and complexity of available datasets, which are not well suited for traditional AI approaches that typically require large volumes of data to produce reliable insights.

Rare diseases

Rare diseases, affecting only a small percentage of the population, present unique challenges for research and treatment development. Limited patient data, combined with high costs, makes it difficult to develop effective diagnostics and therapies. Classical machine learning models often struggle with such small datasets, leading to delays in diagnosis and limited treatment options for patients. Quantum computing's potential to process complex, high-dimensional data could help unlock meaningful insights from these constrained datasets, potentially accelerating research and improving patient outcomes.

Women's health

Historically under-represented in clinical research, women's health issues often rely on smaller and less comprehensive datasets. This gap complicates the development of effective diagnosis and treatments for conditions such as chronic diseases and cancers that predominantly affect women. Quantum computing's ability to extract insights from sparse but information-rich datasets could advance research in this field.

For instance, quantum machine learning algorithms may enable more accurate predictions and personalised interventions using limited yet valuable data [25] [26] [27]. While still in exploratory stages, early developments in quantum computing signal promising opportunities to advance diagnostics, treatment design, and patient care in these underserved areas.

3 Current status

3.1 QC IN HEALTHCARE AND PHARMA: USE-CASES AND OPPORTUNITIES

The application of quantum computing in healthcare and pharmaceuticals is in a period of rapid growth, with most advances focused on proof-of-concept studies and experimental applications. More than 40 quantum computing proof-of-concept studies [2] [3] [28] [29] [30] in healthcare have been published in recent years, exploring a broad spectrum of applications including genomics, diagnostics, clinical research, treatment interventions, and healthcare operations optimisation. These studies highlight the potential of quantum computing to advance healthcare and pharmaceuticals, though full-scale quantum advantage has yet to be realised.

While these do not represent the whole breadth of opportunities, several common themes stand out in the literature:

- Molecular simulations and drug discovery:** Recent quantum algorithms show promise in drug discovery, particularly in simulating how molecules interact and proteins fold [31], offering the potential to predict drug-target interactions and binding affinities through advancements in quantum chemistry [32]. Research has successfully modelled basic molecular properties and chemical bonds, with applications in drug design and protein interactions. While these advances are encouraging, current quantum computers can only handle simple molecules or specific complex cases [33] that are less common in industry. The field still needs to address more challenging aspects of drug development, such as molecular forces, energy states, and solvent effects – calculations that demand substantial computational power.
- Quantum machine learning for diagnostics and prediction:** Quantum machine learning algorithms show promise in medical image classification and disease prediction. This is a rapidly developing field with recent studies presenting novel approaches to breast cancer histopathological image classification using a combination of classical and quantum methods [34] [35].

- Optimisation in healthcare operations:** Approaches such as quantum annealing, and gate-based optimisation algorithms are being applied to problems like patient scheduling and treatment planning. For example, papers have explored the optimisation of radiotherapy treatment planning using quantum annealing and quantum inspired algorithms [36].
- Genomic analysis:** Early work is exploring quantum algorithms for DNA sequence alignment and variant calling. These algorithms show potential for rapid sequence alignment in next-generation sequencing applications [37] [38].
- Personalised medicine:** Quantum-assisted analysis of multiomic data for personalised treatment recommendations is an emerging area with precision oncology promising early detection of cancer [39] [40].

Throughout these areas, there is potential for quantum computing to enhance healthcare data security and privacy. It is our understanding that this remains a largely pre-competitive space for the sectors with much of the work being shared and published. However, we acknowledge that certain research conducted within organisations such as large pharmaceutical companies may not be accessible in the public domain due to intellectual property considerations.

For a deeper exploration of these areas and the UK organisations pioneering quantum healthcare exploratory studies, readers are encouraged to consult to Innovate UK's comprehensive report on quantum computing's potential in healthcare [41].

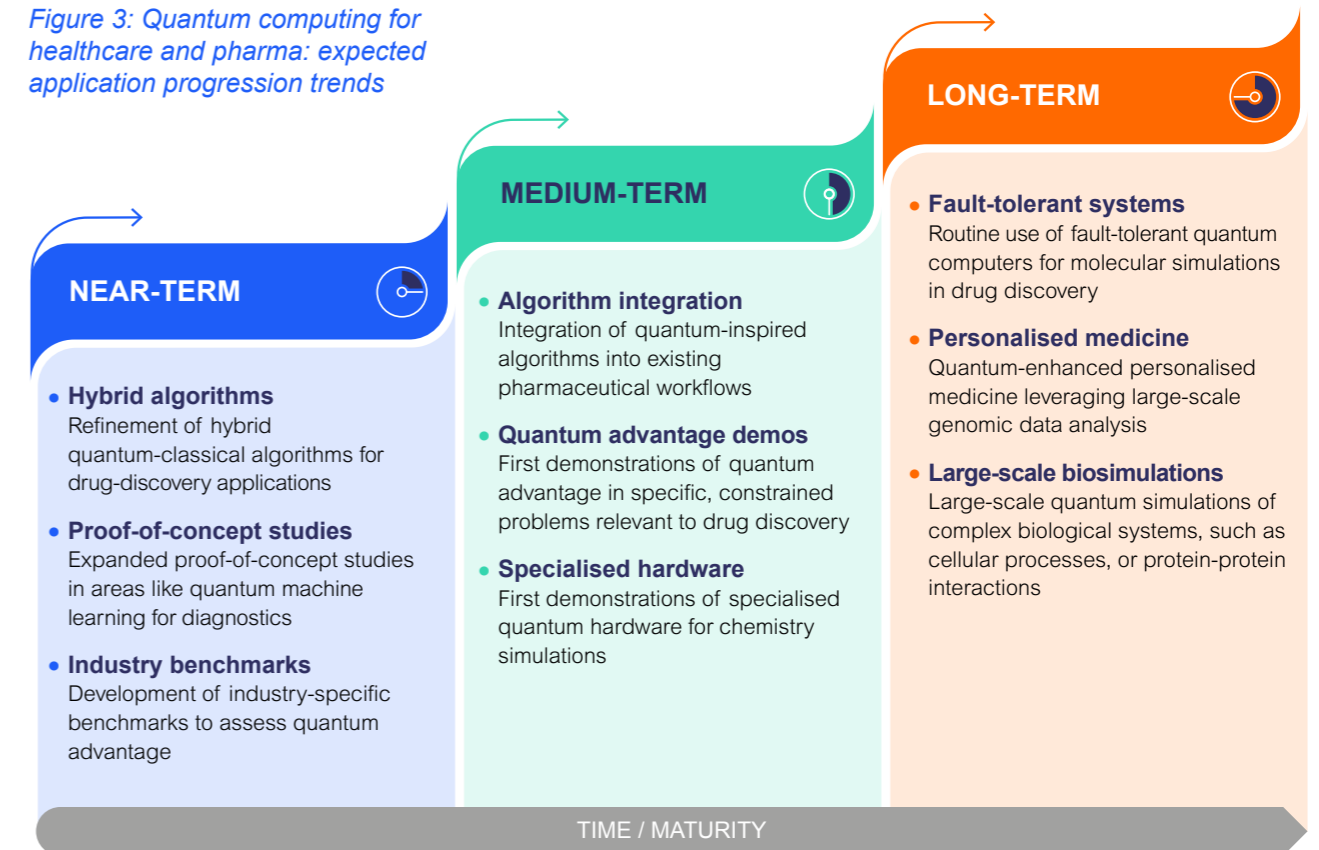
It is important to note that most current studies use small-scale quantum systems (typically <100 qubits) and often rely on hybrid quantum-classical approaches or quantum-inspired algorithms running on classical hardware.

Despite these limitations, this growing body of research highlights the expanding potential of quantum computing across various facets of medicine and pharmaceutical development.

3.2 FUTURE DIRECTIONS

According to industry associations, 82% of life-science organisations agreed that quantum computing will have a commercial impact within the next decade [42]. Based on current research trends and industry insights, it is possible to outline potential milestones for quantum computing in healthcare and pharmaceuticals across the following timeframes, as shown in Figure 3.

Figure 3: Quantum computing for healthcare and pharma: expected application progression trends



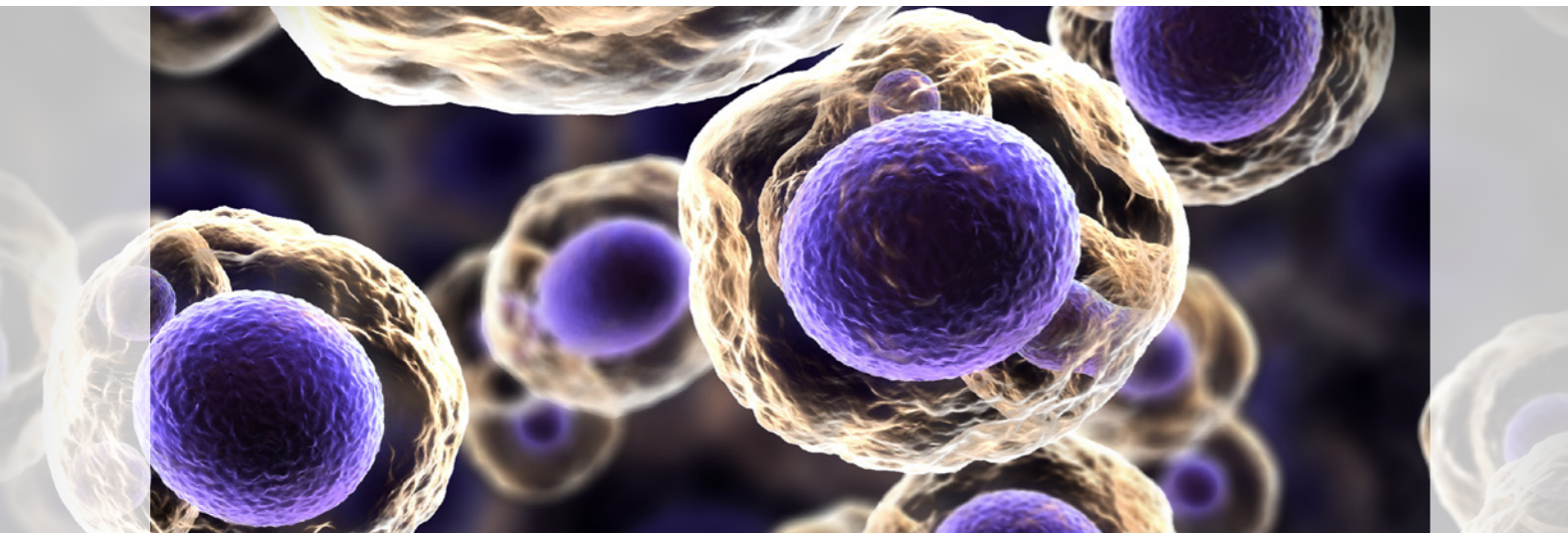
It is important to note the above is based on current projections and may evolve as the field progresses. Factors such as technological breakthroughs, regulatory changes, and shifts in funding priorities could accelerate or decelerate certain milestones.

Key drivers for this roadmap include:

- Progress in quantum hardware development, such as qubit counts and error correction.
- Development of scalable quantum algorithms specifically tailored for healthcare and pharmaceutical applications.
- Facilitation of efficient collaborative pathways between quantum computing experts and healthcare professionals.

- Workforce development focusing on the specific skills and talents necessary for the integration of quantum computing into healthcare and pharmaceutical sectors
- Strategic funding into sector priority areas
- Regulatory adaptations to accommodate quantum-enhanced drug discovery and medical applications

As the field progresses, it will be crucial for stakeholders to regularly reassess and update this roadmap, ensuring that efforts remain aligned with the most promising and impactful applications of quantum computing in healthcare and pharmaceuticals across the following timeframes, as shown in Figure 3.



3.3 GLOBAL INITIATIVES

The global landscape of quantum computing in healthcare and pharmaceuticals is evolving rapidly, with numerous initiatives driving advancements across research, infrastructure, and applications. These efforts underscore the growing confidence in quantum computing's potential to transform the sector.

The UK Government's National Quantum Strategy has defined a dedicated Quantum Healthcare Mission, aiming for NHS trusts to benefit from integrated quantum sensing-enabled solutions by 2030 to improve early disease detection, diagnostics, and treatment pathways. In parallel, the Quantum Computing Mission targets the development of UK-based quantum systems surpassing classical supercomputers by 2035, creating a strong foundation for life sciences innovation. These strategic missions reinforce the UK's leadership in global quantum initiatives and signal an increasing focus on delivering real-world healthcare benefits.

This strategic push in the UK is complemented by a range of initiatives both domestically and internationally, aimed at advancing quantum applications in healthcare and life sciences.

Cleveland Clinic and IBM collaboration

Cleveland Clinic, in partnership with IBM, has pioneered the integration of quantum computing in healthcare by launching the world's first quantum computer dedicated to accelerating drug development, genomic research, and medical imaging. In 2023, this collaboration

expanded to explore the application of AI methodologies to enhance surgical precision in epilepsy and optimise patient care. This effort leverages advanced data from Cleveland Clinic London's BioResource in collaboration with the Hartree Centre in the UK [6] [7] [43].

Wellcome Leap's Quantum for Bio (Q4Bio) program

The Wellcome Leap Quantum for Bio (Q4Bio) program [3] focuses on developing next-generation quantum algorithms to unlock unprecedented capabilities in drug discovery and genomics. Phase 2 of the competition, announced in 2024, has seen significant participation from academia, industry, and technology developers across the UK.

QuPharma project

Launched in 2022 and funded through UK Research and Innovation's Industrial Strategy Challenge Fund (ISCF), the QuPharma project [44] aims to develop a quantum computer specifically for pharmaceutical applications. Led by SEEQC and partnering with Riverlane, the National Quantum Computing Centre (NQCC), BASF, Merck, Oxford Instruments, Medicines Discovery Catapult, University of Oxford, and STFC Daresbury, the project combines quantum algorithms with high-performance computing to potentially accelerate drug discovery tenfold. The initiative is scheduled to conclude in 2025.



➤ The global market for quantum computing in healthcare was valued at \$85 million in 2023 and is projected to reach \$503 million by 2028, with a compound annual growth rate (CAGR) of 42.5%.

NIH Quantum Computing-Algorithm Prize Challenge

In 2024, the National Institutes of Health (NIH) launched the Quantum Computing-Algorithm Prize Challenge Competition [45], focusing on solving translational biomedical problems using quantum computing. With cash prizes totalling \$1.3 million, the challenge seeks innovative design solutions for novel applications of existing quantum-enabled technologies in clinical, translational, and biomedical problem areas.

Novo Holdings' investment in quantum technologies

In May 2024, Novo Holdings, the controlling shareholder of Danish pharmaceutical company Novo Nordisk, announced a commitment of DKK 1.4 billion (€188 million) to invest in quantum technologies. This initiative aims to establish a vibrant start-up ecosystem in the Nordics, with a particular focus on quantum computing, sensing, and algorithms for healthcare and life sciences.

This effort is closely aligned with recent initiatives by the Novo Nordisk Foundation, including the establishment of the Novo Nordisk Foundation Quantum Computing Programme (NQCP), which aims to develop one of the world's first fully functional and generally applicable quantum computers. Another notable effort is The Quantum Foundry, a limited liability company fully owned by the Novo Nordisk Foundation, dedicated to advancing quantum materials and quantum chips as well as the associated fabrication tools.

QPARC, Japan

The Quantum Practical Application Research Consortium (QPARC) in Japan is a collaborative effort involving industry leaders, academic institutions, and government agencies to advance quantum computing applications. Established to bridge the gap between theoretical research and practical implementation, QPARC focuses on developing quantum algorithms and software tailored for real-world applications, including drug discovery and materials science.

Building confidence and market growth

The initiatives highlighted above underscore significant investments and interdisciplinary collaboration spanning quantum computing hardware, software, and algorithms. They reflect growing confidence in the technology's potential and represent strong endorsements of its future utility in healthcare and life sciences.

The global market for quantum computing in healthcare was valued at \$85 million in 2023 and is projected to reach \$503 million by 2028, with a compound annual growth rate (CAGR) of 42.5% [46]. This predicted growth underscores the increasing interest and optimism surrounding quantum computing in the healthcare sector. In the coming years, sustained investment in research, infrastructure, and interdisciplinary collaboration will be crucial to unlocking the full potential of quantum computing in healthcare.

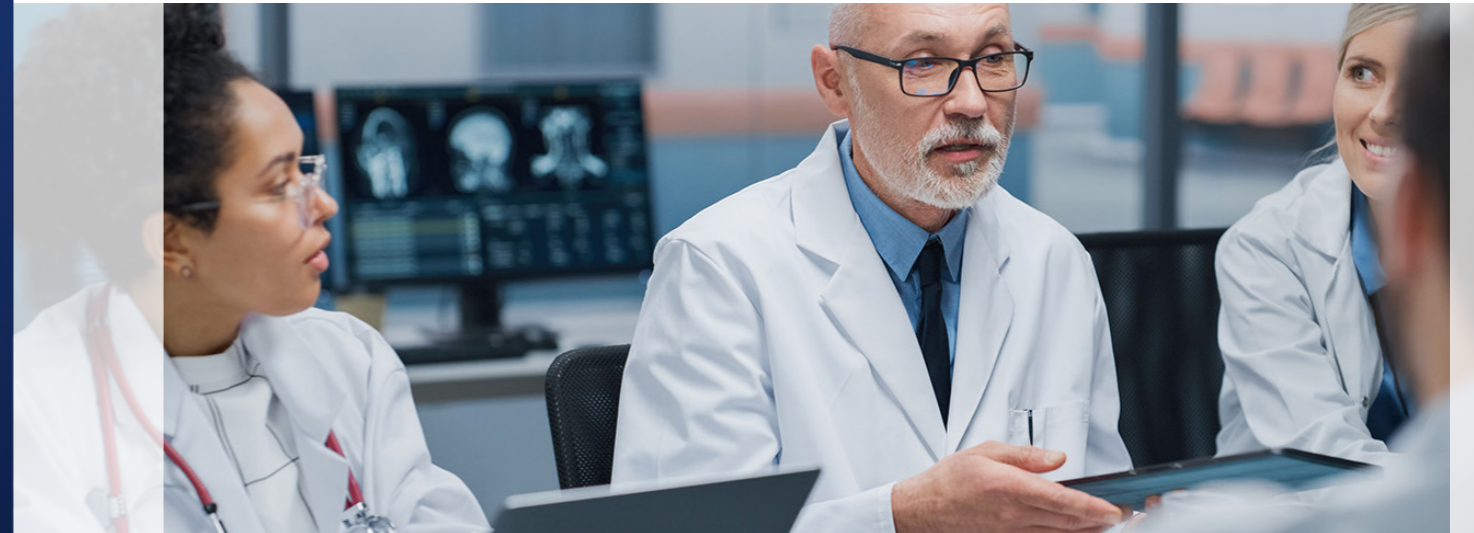
Part 2

Sectoral insights: Navigating the quantum frontier in healthcare

Grand challenges have historically played a pivotal role in accelerating innovation and discovery in the biosciences. Notable examples include the Human Genome Project and the BRAIN Initiative.

In the realm of quantum computing for healthcare, a similar approach could be transformative.

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Unlocking quantum potential in healthcare and pharmaceuticals

In March 2024, the National Quantum Computing Centre (NQCC) hosted its inaugural Quantum Computing for Healthcare & Pharmaceuticals (QCHP) workshop at the Royal Society in London, bringing together leading experts from healthcare, pharmaceuticals, and quantum computing sectors.

Stakeholders from industry, academia, national labs, and government convened to examine the current quantum computing landscape in healthcare, identify collaboration opportunities, assess the UK's strengths in a global context, and outline strategic next steps.

Key discussions centred on quantum computing's potential in drug discovery, diagnostics, and healthcare optimisation, as well as the challenges of scaling quantum algorithms and developing real world applications.

The following sections explore the strategic challenges and opportunities raised by the sector as crucial steps towards advancing the practical adoption of quantum computing in healthcare and pharmaceuticals.

Section 1 presents key insights from the workshop, supplemented by bilateral consultations, sectoral conferences, and literature survey.

Section 2 consolidates these insights into actionable considerations for policy makers, executives, and funding bodies to guide future strategic planning and collaboration.

➤ **Advancing quantum healthcare requires bridging the gap between theoretical potential and practical application.**

1 Strategic challenges and considerations

1.1 TECHNICAL CHALLENGES

The sector identified various technical challenges:

Figure 4: Technical challenges towards the adoption of quantum computing in healthcare and pharmaceuticals



1.2 SKILLS AND TALENT

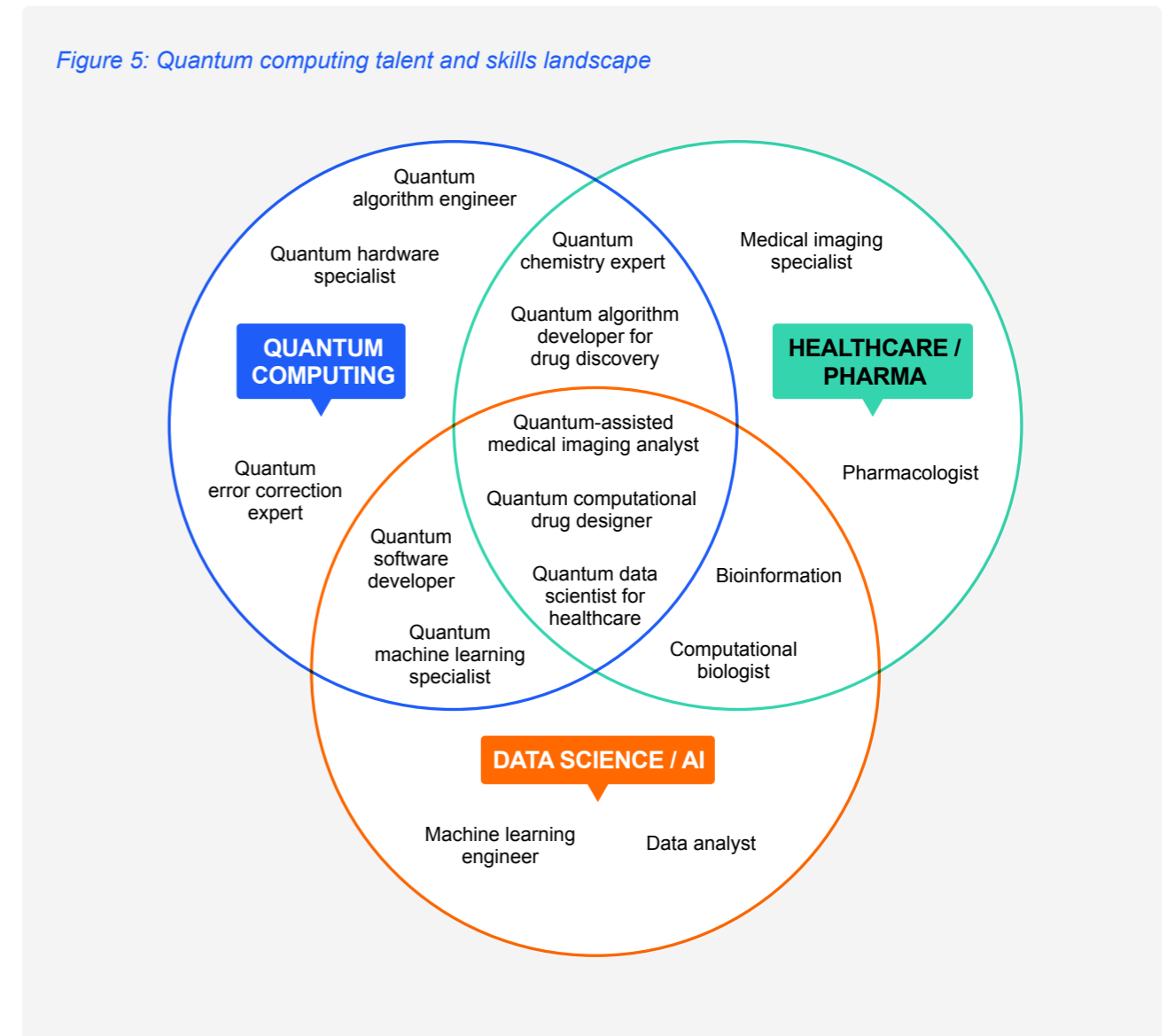
Sector consultations have highlighted a critical need for developing talent and skills at the intersection of quantum computing and healthcare:

- **Quantum literacy:** Increasing general quantum literacy among decision makers in healthcare and pharmaceutical sectors is crucial for informed strategic planning.
- **Attracting talent:** The healthcare and pharmaceutical sectors need to compete with other industries to attract top quantum computing talent.

- **Upskilling current workforce:** Organisations could invest in training programmes to help existing healthcare and pharma professionals understand quantum computing capabilities and limitations.
- **Curriculum development:** Universities and other higher education institutions could develop specialised courses and degree programmes that bridge quantum computing and healthcare disciplines.

An indication of the different types of roles that would need to support the integration of healthcare and quantum computing can be found in Figure 5.

Figure 5: Quantum computing talent and skills landscape



1.3 POLICY AND REGULATORY LANDSCAPE

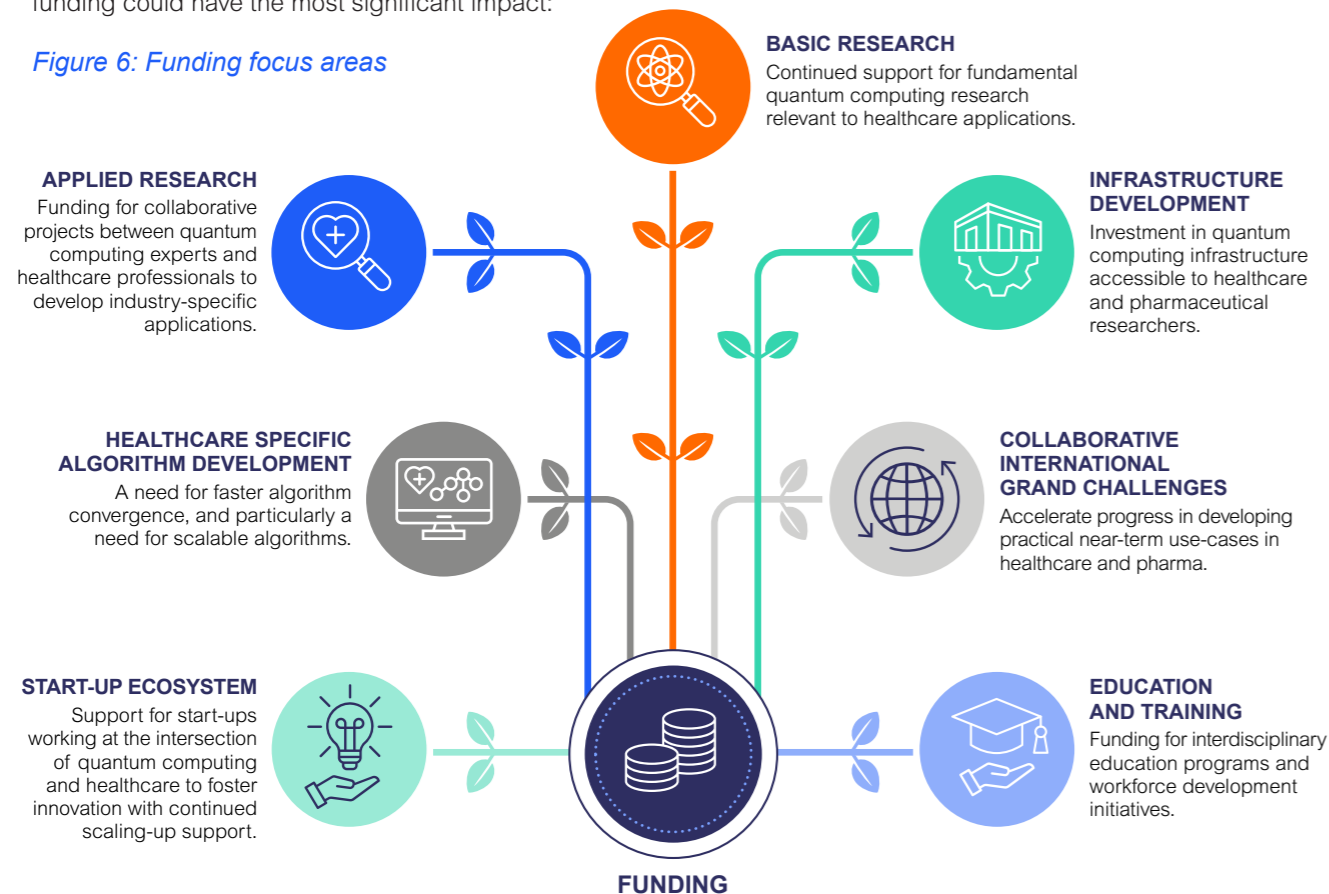
As with any emerging technology, the integration of quantum computing into healthcare and pharmaceuticals will not be possible without a strong and supportive pro-innovation regulatory framework. Various policy and regulatory considerations emerging from the sector are summarised as follows:

- **Regulatory frameworks:** It is anticipated that regulators may need to consider the merits of developing guidelines related to applications of quantum computing at a sufficiently mature stage. For example, as quantum computing in its most mature form (expected in a 10-20 year timeframe) is predicted to pose a risk to current data encryption methods, new policies for protecting sensitive health data are required.

1.4 FUNDING FOCUS AREAS

Workshop participants identified key areas where funding could have the most significant impact:

Figure 6: Funding focus areas



1.5 COLLABORATION REQUIREMENTS

Feedback from the sector captured during the workshop discussions and breakout sessions underscored the critical importance of collaboration in advancing quantum computing for healthcare, stressing that progress in this complex field cannot happen in isolation.

Key points included:

- **Cross-sector partnerships:** Encouraging collaborations between academia, industry, and government to accelerate research and development.
- **Interdisciplinary teams:** Forming teams that combine expertise in quantum computing, healthcare, pharmaceuticals, and regulatory affairs.
- **Pre-competitive consortia:** Establishing industry consortia to address common challenges and share resources in pre-competitive areas.
- **International collaboration:** Fostering global partnerships to tackle large-scale healthcare challenges while navigating data sharing and IP considerations.
- **Open-source initiatives:** Supporting open-source projects for quantum software development relevant to healthcare applications. Collaboration and information sharing are encouraged by using or contributing to open-source initiatives in the AI and genomics sectors. Through pooled knowledge, open-source projects offer a platform for the creation and enhancement of AI algorithms for genome sequencing. Research in quantum computing can continue to adopt this model for success.
- **Clinical trial collaborations:** Clinical genetic data can be accessed through working with pharmaceutical companies and clinical trial activities. Real-world patient data can be used to enhance and test AI applications in genome sequencing, leading to more accurate and therapeutically meaningful outcomes.

➤ Many organisations are making strategic alliances with technology and algorithm developers to access interdisciplinary expertise for proof-of-concept investigations and to ensure internal upskilling and knowledge transfer.

- **Mergers and acquisitions:** Businesses in the healthcare industries may merge or buy other companies to pool resources and expertise. Fusing quantum technologies with state-of-the-art AI technologies and established tools can spur innovation and produce all-encompassing solutions.
- **Data licensing and sharing:** Large-scale (genomic or other) dataset acquisition and curation are areas of expertise for some organisations. By granting licenses or sharing these datasets with quantum-focused businesses, quantum-enhanced machine learning models can be developed and trained, improving the precision and applicability of data-based investigations.
- **Crowdsourcing and citizen science initiatives:** Including the public in citizen science or crowdsourcing projects can be a useful data acquisition method.
- **Strategic alliances with technology platform developers:** Many organisations are making strategic alliances with technology and algorithm developers to access interdisciplinary expertise for proof-of-concept investigations and to ensure internal upskilling and knowledge transfer.
- **Global expansion and market access:** AI-powered genome sequencing firms are able to collect a vast array of genetic variations by expanding their operations worldwide and acquiring access to varied populations. This tactic improves the AI models' resilience and generalisability to various racial and geographic groups.

1.6 CONSIDERATIONS FOR ORGANISATIONS

There are a number of strategic factors organisations should consider when exploring quantum computing:

LONG-TERM VISION	Given the nascent state of the technology, organisations need to balance near-term experimentation with long-term planning.
RISK MANAGEMENT	Companies should assess the potential risks and benefits of early adoption versus waiting for more mature solutions.
PARTNERSHIPS, COLLABORATIONS AND ACCESS TO TECHNOLOGY	Establishing partnerships between healthcare organisations, pharmaceutical companies, and quantum technology providers is crucial for driving innovation.
INTELLECTUAL PROPERTY	Early movers in quantum healthcare applications may have opportunities to secure valuable IP, potentially shaping the future of the industry.
ETHICAL CONSIDERATIONS	As quantum computing enables more powerful data analysis and personalised medicine, organisations should proactively address ethical implications and potential biases. While still some time away, its integration into clinical practice will need proactive considerations for ethical implications and data privacy, while human oversight will remain crucial in decision-making processes.
IN-HOUSE QUANTUM TALENT VS EXTERNAL COLLABORATIONS	Organisations early in their journey can choose to collaborate externally with quantum computing experts to pursue proof-of-concept projects. However, companies have found an internal quantum team of experts to be beneficial in tackling organisation-specific use-cases without the fear of IP exposure. Such internal capabilities can also help to get successful buy-in from executive management.
ACCESS TO SYNTHETIC AND REAL-WORLD DATA	While quantum computing has already shown promise in certain use-cases by using publicly available datasets, availability of and experimentation on synthetic and, where possible, real-world data is a crucial next step for practical adoption and understanding performance.

2 Advancing quantum healthcare: strategic directions

The insights presented in the previous sections offer a detailed analysis of the current state, challenges, and emerging opportunities for quantum computing in healthcare and pharmaceuticals. The commentary and evidence presented throughout this report has been further consolidated into key themes that form the basis for actionable recommendations and strategic directions outlined below, aimed at decision-makers, funding bodies, and stakeholders across the sector.

These considerations emerge directly from dialogue and discussion with the sector, and the subsequent evidence collected. They are designed to inform the next phase of investment, collaboration, and innovation in quantum computing for healthcare and pharmaceuticals.

2.1 STRATEGIC ROADMAP DEVELOPMENT

2.1.1 Living roadmap creation

- Creation of a dynamic, “living” roadmap that evolves with the field, providing clarity on current and future opportunities. The roadmap should strike a balance between identifying overarching research themes and establishing timelines, providing strategic direction for the sector. Due consideration should be given to the future maintenance of the roadmap, preferably by the same organisation.
- As a first step, stakeholders should align on outstanding research priorities. As the industry progresses, the roadmap can evolve to include more granular use-cases, classified by their impact and revenue potential, implementation benefits, and projected timelines.
- Establishment of grand challenges as milestones to mark clear progress and focus efforts.

2.1.2 Benchmarking and standardisation

- Development of user-informed benchmarks for quantum applications in healthcare and pharmaceuticals [50].

- Facilitate the definition of standardised benchmarking across industries.
- Creation of standardised testing protocols for quantum algorithms in healthcare.

2.2 RESEARCH AND DEVELOPMENT INITIATIVES

2.2.1 Focused research areas

- Identification and prioritisation of high impact near-term applications, for example, molecular dynamics, quantum chemistry simulations, and machine learning applications.
- Clear identification of the limitations of classical computational methods to identify where quantum can add value.
- Investment in the development of scalable quantum algorithms specifically for healthcare applications.
- Further exploration of hybrid quantum-classical approaches to address near-term challenges.

2.2.2 Infrastructure development

- Establishment of appropriate centres at the intersection of quantum and healthcare/ pharmaceuticals to position the UK as a pioneer in the field.*

* The UK Quantum Biomedical Sensing Research Hub (Q-BIOMED) is a pioneering initiative launched in December 2024, aiming to harness quantum technology to enhance early disease diagnosis and treatment. Supported by £24 million in funding from UK Research and Innovation (UKRI) and the National Institute for Health and Care Research (NIHR), Q-BIOMED brings together six leading universities – University College London (UCL), University of Cambridge, University of Oxford, University of Warwick, Cardiff University, and Heriot-Watt University – alongside NHS trusts, industry partners, charities, and patient groups. The hub focuses on developing quantum sensors capable of detecting cells and molecules with unprecedented sensitivity, potentially transforming healthcare through innovations in biomedical imaging, ultra-sensitive in-vitro diagnostics, novel cancer treatments, and single-cell analysis.

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- Provision of access to quantum computing testbeds and other critical infrastructure for researchers and industry partners.
- Development of quantum-ready data infrastructure to support future applications.

2.3 COLLABORATION AND ECOSYSTEM BUILDING

2.3.1 Cross-sector partnerships

- Foster collaborations between academia, industry, and government bodies.
- Facilitate international partnerships to leverage country specific strengths.
- Establishment of pre-competitive consortia to address common challenges in the sector. For example, the Pistoia Alliance is a life sciences membership organisation, which was organised to facilitate pre-competitive collaboration and foster R&D innovation and currently has an active QC community of interest.

2.3.2 Open innovation models

- Support mission-led innovation and open innovation models similar to AlphaFold [48].
- Creation of frameworks for sharing both successes and failures in research to accelerate knowledge transfer.
- Organisation of hackathons and challenge prizes to solve specific quantum computing problems in healthcare.

2.4 TALENT DEVELOPMENT AND EDUCATION

2.4.1 Specialised education programs

- Development of Centres for Doctoral Training (CDTs) focused on quantum software development and applications in chemistry, pharmaceuticals, and materials science.*

- Creation of quantum computing literacy programs for regulators and healthcare professionals.
- Investment into training of quantum application engineers who can bridge the gap between quantum technology and business needs.

2.4.2 Workforce transition

- Development of programs to upskill the current healthcare and pharmaceutical workforce in quantum technologies.
- Address fears of job displacement by building frameworks to support quantum computing augmenting as opposed to replacing human work.

2.5 POLICY AND REGULATORY PREPAREDNESS

2.5.1 Proactive regulatory frameworks

- Engagement with regulatory bodies to facilitate knowledge transfer.
- Engagement with regulatory bodies to assess the need for and facilitate the development of guidelines for validation of quantum-enhanced processes in healthcare and pharmaceuticals.
- Investigation of the need for the establishment of quantum-specific ethical guidelines, particularly for personalised medicine applications.
- Creation of regulatory sandboxes to test and refine quantum healthcare applications in controlled environments.

2.5.2 Data protection and standards

- Implementation of quantum-resistant encryption for protecting health data.
- Development of protocols for secure data sharing in quantum-enabled collaborative research.
- Understand the requirements for and facilitating the standardisation of healthcare data to facilitate quantum computing applications.

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2.6 FUNDING AND RESOURCE ALLOCATION

2.6.1 Long-term funding strategies

- Advocacy for sustained, long-term funding for both private-sector and academic quantum computing research.
- Develop streamlined grant processes.
- Establishment of a clear funding calendar and longer call timetables to allow for more comprehensive project planning.

2.6.2 Targeted investment areas

- Balance funding between hardware development, algorithm research, and end-user application development.
- Support proof-of-concept projects that demonstrate clear business benefits and have potential for scaling.
- Investment into quantum-safe cryptography research and practical implementation.

2.7 INDUSTRY ADOPTION AND COMMERCIALISATION

2.7.1 Prioritisation

- Identification and prioritisation of most impactful use-cases that could bring quantum computing's "ChatGPT moment" in healthcare.
- Focus on areas where quantum computing can significantly outperform or enhance current computing resource.
- Develop an in-depth use-case library to guide industry adoption.

2.7.2 Technology transfer

- Creation of mechanisms to accelerate the transition of academic research into commercial applications.
- Support start-up ecosystems focusing on quantum computing applications in healthcare.
- Facilitation of Knowledge Transfer Partnerships (KTPs) between academia and industry.



2.8 PUBLIC ENGAGEMENT AND AWARENESS

2.8.1 Stakeholder education

- Organise regular workshops and seminars by various stakeholders help to raise awareness about quantum computing capabilities in healthcare and pharmaceuticals.
- Development of educational materials for policymakers and healthcare administrators.

2.8.2 Public outreach

- Engagement of the public early in the quantum journey, outlining potential benefits and addressing concerns in order to develop trust in the technology.
- Creation of public-facing content to explain the impact of quantum computing on everyday life.

Regular review and adjustment of these strategies will be crucial as the field rapidly evolves.

* In 2024 the UK announced an investment of more than £1 billion to establish 65 new Centre for Doctoral Training (CDTs) within engineering and physical sciences. Organisations such as the NQCC aim to work closely with the quantum CDTs and support them through a range of activities intended to enrich the student experience, from providing dedicated training packages to community events and access to quantum computing resources.

3 Grand challenges

Grand challenges have historically played a pivotal role in accelerating innovation and discovery in the biosciences. Notable examples include the Human Genome Project, which revolutionised genomics and personalised medicine, and the BRAIN Initiative [49], which has dramatically advanced our understanding of neural circuits. These ambitious, goal-oriented projects not only catalysed technological breakthroughs but also fostered unprecedented collaboration across disciplines and sectors.

In the realm of quantum computing for healthcare, a similar approach could be transformative. By setting well-defined, high-priority challenges – such as quantum-accelerated drug discovery for a specific disease or quantum-enhanced early cancer detection – government and research bodies could effectively channel resources, align diverse stakeholders, and create a focused ecosystem of innovation. The sector saw value in having neutral independent bodies similar to the NQCC, to lead these efforts.

Such grand challenges would not only drive technological advances but also provide clear benchmarks for progress, attract talent and investment, and demonstrate the tangible impact of quantum computing in healthcare. This approach would help to corral momentum around specific high-priority use-cases, bridging the gap between theoretical quantum advantages and practical healthcare applications, ultimately accelerating the adoption of quantum computing for transforming medicine and improving patient outcomes.

4 Conclusion: Realising the quantum advantage in healthcare and pharmaceuticals

The journey towards precision medicine and improved healthcare should lead to improved patient outcomes, lower costs, and better working practices for healthcare professionals. Biopharmaceutical innovation is behind some of the greatest achievements in modern medicine.

Quantum computing presents an unparalleled opportunity to reshape healthcare and pharmaceuticals, tackling some of the most pressing scientific and operational challenges in the sector. The potential impact on human health and wellbeing is profound, with implications that extend far beyond traditional healthcare boundaries. This paper has outlined how quantum computing has the potential to accelerate drug discovery, augment medical imaging, enhance precision medicine, optimise clinical trials, and improve healthcare system efficiencies. While the field remains in its early stages with the technology in the R&D phase, the time to act is now to ensure meaningful progress towards unlocking quantum computing's potential in healthcare and life sciences over the next few years.



The UK Government's National Quantum Strategy provides a clear framework for progress, with Mission 1 (Quantum Computing) and the Quantum Healthcare Mission setting ambitious targets to deliver quantum-enabled solutions across the NHS by 2030 and develop UK-based quantum systems that surpass classical supercomputers by 2035. However, achieving these milestones will require strategic coordination, focused investment, and sector-wide engagement to turn technical potential into practical impact. Looking ahead, we identify five key priorities for the sector:

Figure 7: Key sectoral priorities for the adoption of quantum computing in healthcare and pharmaceuticals



Part 2: Navigating the quantum frontier in healthcare

Positioning the UK as a Global Leader in Quantum Healthcare

The UK has a unique opportunity to lead the global conversation on quantum-driven healthcare transformation. International partnerships with countries that share similar healthcare challenges will be particularly advantageous in advancing quantum medical imaging, drug discovery, and AI-driven diagnostics. By engaging in bilateral initiatives and multilateral collaborations, the UK can accelerate development, reduce duplication of effort, and strengthen its position as a leader in quantum healthcare innovation.

Through our sector engagement and analysis, there was strong support for a 'Grand Challenge' in healthcare to bring a focus and galvanise efforts, particularly where challenges are aligned to national healthcare priorities and areas of risk. To support the delivery of clear and measurable healthcare outcomes under Mission 1 (Quantum Computing), there is a case for considering the establishment of a targeted grand challenge within the UK's quantum strategy, focused on a high-priority medical application. Potential focus areas could include quantum-accelerated drug discovery for cancer treatments and antimicrobial resistance, quantum-powered early disease detection, and the optimisation of NHS operations and resource management.

Such a grand challenge could provide a valuable mechanism to focus investment, foster cross-sector collaboration, and accelerate the translation of quantum technologies into impactful healthcare applications.

Shaping the Future of Quantum Healthcare

The journey towards quantum enabled healthcare is not just about technological advancement – it aligns with a fundamental shift in how we approach human health and well-being. The next decade is pivotal in defining how quantum computing can help to reshape healthcare and pharmaceuticals. To harness this potential, the UK has the opportunity to act decisively by aligning policy, investment, workforce development, and international collaboration toward mission-driven healthcare innovation.

The UK is well positioned to bridge the gap between scientific discovery and real-world application—ensuring that quantum computing is not just a theoretical revolution, but a practical force driving better health outcomes, improved patient care, and a more resilient healthcare system. Through coordinated action, targeted investment, and global leadership, quantum computing can become a cornerstone of 21st-century medical innovation—transforming the way we diagnose, treat, and prevent diseases for generations to come.

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Bibliography

- [1] Y. Cao, J. Romero, J. P. Olson, M. Degroote, P. D. Johnson, M. Kieferová, I. D. Kivlichan, T. Menke, B. Peropadre, N. P. D. Sawaya, S. Sim, L. Veis and A. Aspuru-Guzik, “**Quantum Chemistry in the Age of Quantum Computing**,” *Chemical Reviews*, vol. 119, no. 19, pp. 10856-10915, 2019.
- [2] R. Santagati, A. Aspuru-Guzik, R. Babbush, et. al., “**Drug design on quantum computers**,” *Nat. Phys.*, vol. 20, p. 549-557, 2024.
- [3] F. Flother, “**The state of quantum computing applications in health and medicine**,” *Research Directions: Quantum Technologies.*, p. 1:e10., 2023.
- [4] Outeiral C, Strahm M, Shi J, Morris GM, Benjamin SC, Deane CM., “**The prospects of quantum computing in computational molecular biology**,” *WIREs Comput Mol Sci*. 2021; 11:e1481. <https://doi.org/10.1002/wcms.1481>.
- [5] S. Mohapatra, “**Quantum Horizons: Driving the future of healthcare and pharma**,” *National Quantum Computing Centre*, 2024. [Online]. Available: <https://www.nqcc.ac.uk/blogs/quantum-horizons-driving-the-future-of-healthcare-and-pharma/>.
- [6] “**Cleveland Clinic Consult QD**,” 19 April 2023. [Online]. Available: <https://consultqd.clevelandclinic.org/quantum-computing-debuts-at-cleveland-clinic>.
- [7] “**Cleveland Clinic – Discovery Accelerator – Quantum Computing Projects**,” [Online]. Available: <https://my.clevelandclinic.org/research/computational-life-sciences/discovery-accelerator/our-projects>.
- [8] “**Q4Bio**,” [Online]. Available: <https://wellcomeleap.org/q4bio/>.
- [9] “**Healthcare expenditure, UK Health Accounts: 2020, Data and Analysis from Census 2021**,” *Office for National Statistics*, 2021.
- [10] K. Moulaei, A. Yadegari, M. Baharestani, S. Farzanbakhsh, B. Sabet and M. R. Afrash, “**Generative artificial intelligence in healthcare: A scoping review on benefits, challenges and applications**,” *International Journal of Medical Informatics*, vol. 188, no. 1386-5056, 2024.
- [11] H. S. Adams, “**High-performance computing & AI technology in healthcare**,” *Healthcare Digital*, March 2023.
- [12] N. Lewandowski and B. Koller, “**Transforming Medical Sciences with High-performance Computing, High-performance Data Analytics and AI**,” *Technology and Health Care*, vol. 31, no. 4, pp. 1505-1507, 2023.
- [13] P. Kirkpatrick, “**Artificial intelligence makes a splash in small-molecule drug discovery**,” *Nature Articles*, 17 May 2022.
- [14] M. K. Jayatunga, M. Ayers, L. Bruens, D. Jayanth and C. Meier, “**How successful are AI-discovered drugs in clinical trials? A first analysis and emerging lessons**,” *Drug Discovery Today*, vol. 29, no. 6, 2024.
- [15] A. Zhavoronkov, Y. Ivanenkov and A. Aliper et. al., “**Deep learning enables rapid identification of potent DDR1 kinase inhibitors**,” *Nature Biotechnology*, vol. 37, no. September 2019, p. 1038–1040, 2019.
- [16] K. ELKarazle, V. Raman, P. Then and C. Chua, “**How Generative AI Is Transforming Medical Imaging: A Practical Guide**,” in *Applications of Generative AI*, Springer, Cham, 2024, p. 371–385.
- [17] S. Vadapalli, H. Abdelhalim, S. Zeeshan and Z. Ahmed, “**Artificial intelligence and machine learning approaches using gene expression and variant data for personalised medicine**,” *Briefings in Bioinformatics*, vol. 23, no. 5, 2022.
- [18] S. Skin, D. Burkhalter, G. Calado et. al., “**Artificial Intelligence Applied to clinical trials: opportunities and challenges**,” *Health Technol.*, vol. 13, no. March, pp. 203 - 213, 2023.
- [19] S. Maleki Varnosfaderani and M. Forouzanfar, “**The Role of AI in Hospitals and Clinics: Transforming Healthcare in the 21st Century**,” *Bioengineering*, vol. 11, no. 4, p. 337, 2024.

- [20] F. A. Evangelista and V. S. Batista, “**Editorial: Quantum Computing for Chemistry**,” *Journal of Chemical Theory and Computation*, pp. 7435-7436, 2023.
- [21] Lau B, Emani PS, Chapman J, Yao L, Lam T, Merrill P, Warrell J, Gerstein MB, Lam HYK., “**Insights from incorporating quantum computing into drug design workflows**,” *Bioinformatics*. 2023 Jan 1;39(1):btac789. doi: 10.1093/bioinformatics/btac789. PMID: 36477833; PMCID: PMC9825754.
- [22] Domingo, L., Djukic, M., Johnson, C. et al., “**Binding affinity predictions with hybrid quantum-classical convolutional neural networks**,” *Sci Rep* 13, 17951 (2023). <https://doi.org/10.1038/s41598-023-45269-y>
- [23] Avramouli, M.; Savvas, I.K.; Vasilaki, A.; Tsiourlianos, A.; Garani, G., “**Hybrid quantum neural network approaches to protein-ligand binding affinity prediction**,” *Mathematics* 2024, 12, 2372. <https://doi.org/10.3390/math12152372>
- [24] “**A New Frontier for Drug Discovery and Development: Artificial Intelligence and Quantum Technology**,” Centre for Trustworthy Technology, 2024.
- [25] R. Y. Li, et. al. “**Quantum processor-inspired machine learning in the biomedical sciences**,” *Patterns*, vol. 2, no. 6, p. 100246, 2021.
- [26] “**Patterns Paper Shows Benefits of Modeling Complicated Small Datasets Using Unconventional, Quantum Computing-inspired Algorithms**,” *Massbio*, May 2021. [Online]. Available: <https://www.massbio.org/news/member-news/patterns-paper-shows-benefits-of-modeling-complicated-small-datasets-using-unconventional-quantum-computing-inspired-algorithms/>.
- [27] M. Caro, H. Huang, M. Cerezo, et. al., “**Generalization in quantum machine learning from few training data**,” *Nat Commun*, vol. 13, no. 4919.
- [28] T. J. S. Durant, E. Knight, B. Nelson, S. Dudgeon, S. J. Lee, D. Walliman, H. P. Young, L. Ohno-Machado and W. L. Schulz, “**A primer for quantum computing and its applications to healthcare and biomedical research**,” *Journal of the American Medical Informatics Association*, vol. 31, no. 8, p. 1774-1784, August 2024.

- [29] N. S. Blunt, J. Camps, O. Crawford, R. Izsák, S. Leontica, A. Mirani, A. E. Moylett, S. A. Scivier, C. Sünderhauf, P. Schopf, J. M. Taylor and N. Holtzmann, “**Perspective on the current state-of-the-art of quantum computing for drug discovery applications**,” *J. Chem. Theory Comput*, vol. 18, no. 12, p. 7001–7023, 2022.
- [30] Y. Nam, J. Chen, N. Piseni, et. al., “**Ground-state energy estimation of the water molecule on a trapped-ion quantum computer**,” *npj Quantum Inf*, vol. 6, no. 33, 2020.
- [31] S. Pal, M. Bhattacharya, S. Lee, et. al., “**Quantum Computing in the Next-Generation Computational Biology Landscape: From Protein Folding to Molecular Dynamics**,” *Mol Biotechnol*, vol. 66, p. 163-178, 2024.
- [32] W. Li, Z. Yin, X. Li, et. al., “**A hybrid quantum computing pipeline for real world drug discovery**,” *Sci Rep*, vol. 14, no. 16942, 2024.
- [33] J. Goings, A. White, J. Lee, C. Tautermann, M. Degroote, C. Gidney, T. Shiozaki, R. Babbush and N. Rubin, “**Reliably assessing the electronic structure of cytochrome P450 on today’s classical computers and tomorrow’s quantum computers**,” *Proc Natl Acad Sci U S A.*, vol. 119(38):e2203533119., 2022.
- [34] V. Azevedo, C. Silva and I. Dutra, “**Quantum transfer learning for breast cancer detection**,” *Quantum Mach. Intell.*, vol. 4, no. 5, 2022.
- [35] H. Guleria, A. Luqmani, H. Kothari, P. Phukan, S. Patil, P. Pareek, K. Kotecha, A. Abraham and L. Gabralla, “**Enhancing the breast histopathology image analysis for cancer detection using variational autoencoder**,” *Int. J. Environ. Res. Public Health*, vol. 20, no. 5, p. 4244, 2023.
- [36] J. Pakela, H. Tseng, M. Matuszak, R. K. T. Haken, D. McShan and I. E. Naga, “**Quantum-inspired algorithm for radiotherapy planning optimization**,” *Med Phys.*, vol. 47, no. 1, pp. 5-18, 2020.
- [37] G. Varsamis, I. Karafyllidis, K. Gilkes, U. Arranz, R. Martin-Cuevas, G. Calleja, P. Dimitrakis, P. Kolovos, R. Sandaltzopoulos, H. Jessen and J. Wong, “**Quantum gate algorithm for reference-guided DNA sequence alignment**,” *Computational Biology and Chemistry*, vol. 107, 2023.

The convergence of healthcare and pharmaceuticals with quantum computing: A new frontier in medicine

- [38] K. Nałęcz-Charkiewicz and R. Nowak, “**Algorithm for DNA sequence assembly by quantum annealing**,” *BMC Bioinformatics*, vol. 23, p. 122, 2022.
- [39] L. Wei, D. Niraula, E. D. H. Gates, J. Fu, Y. Luo, M. J. Nyflot, S. R. Bowen, I. M. E. Naqa and S. Cui, “**Artificial intelligence (AI) and machine learning (ML) in precision oncology: a review on enhancing discoverability through multiomics integration**,” *British Journal of Radiology*, vol. 96, no. 1150, p. 20230211, 1 October 2023.
- [40] S. Ramesh, T. Tomesh, S. Riesenfeld, et. al., “**Quantum computing for oncology**,” *Nature Cancer*, vol. 5, p. 811–816, May 2024.
- [41] IUK, “**Quantum for Life: How UK life sciences and healthcare can benefit from quantum technologies**,” October 2024. [Online]. Available: <https://iuk-business-connect.org.uk/perspectives/explore-quantums-potential-in-healthcare/>.
- [42] Pistoia Alliance, “**Almost one third of life science companies set to begin quantum computing evaluation this year**,” July 2020. [Online]. Available: <https://www.pistoiaalliance.org/news/almost-one-third-of-life-science-companies-set-to-begin-quantum-computing-evaluation-this-year/>.
- [43] “**Cleveland Clinic Newsroom**,” 6 June 2024. [Online]. Available: <https://newsroom.clevelandclinic.org/2024/06/06/cleveland-clinic-ibm-and-the-hartree-centre-collaborate-to-advance-healthcare-and-life-sciences-through-artificial-intelligence-and-quantum-computing>.
- [44] “**Quantum Enhanced Computing Platform for Pharmaceutical R&D - QuPharma**,” UK Research and Innovation, [Online]. Available: <https://gtr.ukri.org/projects?ref=10005792#/tabOverview>.
- [45] “**NIH Quantum Computing Challenge**,” NIH National Centre for Advancing Translational Sciences, 2024. [Online]. Available: <https://www.challenge.gov/?challenge=nih-quantum-computing-challenge>.



- [46] “**Quantum Computing in Healthcare Market**,” *MarketsandMarkets*, May 2023.
- [47] “**NQCC’s Quantum STATES principles for responsible and ethical quantum computing**,” NQCC, 2024. [Online]. Available at: <https://www.nqcc.ac.uk/blogs/launching-the-nqccs-quantum-states-principles-for-responsible-and-ethical-quantum-computing/>
- [48] “**AlphaFold Protein Structure Database**,” [Online] <https://alphafold.com/>
- [49] “**The Brain Research Through Advancing Innovative Neurotechnologies® (BRAIN) Initiative - Revolutionizing our understanding of the human brain**,” National Institutes of Health, [Online]. Available: <https://braininitiative.nih.gov/>.
- [50] Lall, D., Agarwal, A., Zhang, W., Lindoy, L., Lindström, T., et al. (2024). “**A Review and Collection of Metrics and Benchmarks for Quantum Computers: Definitions, Methodologies and Software**,” *arXiv preprint arXiv:2502.06717*. Available at: <https://arxiv.org/abs/2502.06717>.

Appendix A: Methods used

This insights paper was developed using a multi-faceted approach:

- **Literature review:** Comprehensive analysis of recent academic publications, industry white papers, and market reports on quantum computing in healthcare and pharmaceuticals.
- **QCHP Workshop:** A one-day interactive event bringing together experts from industry, academia, government, and policy sectors to discuss the current state and future prospects of quantum computing in healthcare and pharma.
- **Bilateral discussions:** In-depth interviews with key stakeholders conducted before and after the workshop to gather additional insights and validate findings.

- **Expert panel review:** Draft insights and recommendations were reviewed by a panel of experts in quantum computing and healthcare to ensure accuracy and relevance.
- **Collaborative synthesis:** Integration of insights from all sources, with iterative refinement based on feedback from workshop participants and expert reviewers.

This approach ensured a comprehensive and balanced view of the current landscape and future directions for quantum computing in healthcare and pharmaceuticals.

Appendix B: Conferences and workshops

Quantum Computing for Healthcare and Pharma Workshop

Organised by NQCC at the Royal Society, London
March 2024

Visit to Cleveland Clinic and IBM Yorktown headquarters

Part of UK-US delegation
April 2024

Quantum Computing Applications in Industry & Science

STFC Hartree Centre, University of Liverpool
July 2024

Quantum Computing for Lifesciences

Pistoia Alliance Webinar Series
September 2024

Qu-Pharma Discussion Dinner

Balliol College, University of Oxford
October 2024

IBM Quantum Computing Discovery Day

IBM Innovation Studio, London
November 2024