Original Paper

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Contributors: KC led on the data collection, analysis, write-up and drafting the manuscript. AS conceptualized the study and SCB and AS commented on drafts of the manuscript.
Healthcare robotics – a qualitative exploration of key challenges and future directions

Abstract
Background: The emergence of robotics is transforming industries around the world. Robot technologies are evolving exponentially, particularly as they converge with other functionalities such as Artificial Intelligence to learn from their environment, from each other, and from humans.

Objective: To understand the emerging role of robotics in healthcare and identify existing and likely future challenges to maximizing the benefits associated with robotics and related convergent technologies.

Methods: We conducted qualitative semi-structured one-to-one interviews exploring the role of robotic applications in healthcare contexts. Using purposive sampling, we identified a diverse range of stakeholders who were involved in conceiving, procuring, developing and/or using robotics in a range of national and international healthcare settings. Interviews were digitally recorded, transcribed verbatim and analyzed thematically, supported by NVivo 10 software. Theoretically, this work was informed by the sociotechnical perspective, where social and technical systems are understood interdependent.

Results: We conducted 21 interviews and these accounts suggested that there are significant opportunities of improving the safety, quality and efficiency of healthcare through robotics, but our analysis identified four major barriers that need to be effectively negotiated to realize these: 1) no clear pull from professionals and patients; 2) the appearance of robots and associated expectations and concerns; 3) disruption of the way work is organized/distributed; and 4) new ethical and legal challenges requiring flexible liability/ethical frameworks.

Conclusions: Sociotechnical challenges associated with the effective integration of robotic applications in healthcare settings are likely to be significant, particularly for patient facing functions. These need to be surfaced and tackled for effective innovation and adoption.

Keywords: Robotics; healthcare; sociotechnical
Background and significance

We are in the midst of what has been described as the Fourth Industrial Revolution, where industries/sectors across the globe are being transformed through the use of a variety of increasingly interconnected robotic applications.[1] These have demonstrably increased productivity, resource efficiency and customer responsiveness in, for example, the manufacturing and retail sectors (see Figure 1). [2,3] Amazon, for instance, now has a 100,000 robot fleet designed to navigate large warehouse spaces and pick items from shelves. This represents a 50% increase on the previous year such that robots now constitute around one-third of the workforce.[4,5]

There is emerging policy interest in seeing a similar transition in healthcare; this is being fueled by the drive to improve the quality and safety of care whilst simultaneously controlling expenditure.[6] Early developments currently taking place have begun to replace individual aspects of human performance with robotic capabilities including, for example, precision (e.g. surgical robots), logistic/mechanical tasks (e.g. service robots), and complex cognitive tasks (e.g. rehabilitation robots) (see Figure 1, Table 1).[7]

Table 1: Taxonomy of healthcare robotics

<table>
<thead>
<tr>
<th></th>
<th>Autonomous</th>
<th>Semi-autonomous</th>
<th>Operational</th>
<th>Healthcare delivery, patient/staff facing</th>
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<tbody>
<tr>
<td>Service robots (e.g. stock control, cleaning, delivery, sterilization)</td>
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<tr>
<td>Surgical robots</td>
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<tr>
<td>Telepresence robots (e.g. screens on wheels)</td>
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<tr>
<td>Companion robots</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cognitive therapy robots</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Robotic limbs and exoskeletons</td>
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<tr>
<td>Humanoids</td>
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</table>

Deployments of robots in healthcare settings are likely to rise as a result of increasing technological capabilities, their reduced costs, and the increasing pressure to curb healthcare costs. However, robots are potentially highly disruptive innovations and it is therefore important to understand the sociotechnical challenges likely to be encountered as they are deployed in order to find mitigating strategies.[8] Such insights can support the development of an informed robotics
strategy for health care that addresses these upcoming challenges (e.g. by training staff and designing existing spaces appropriately), thus supporting the aim of transformation of healthcare through health information technology (HIT). In order to inform these important deliberations, we undertook an exploratory qualitative study to identify key sociotechnical challenges associated with introducing robotics in healthcare settings from the standpoint of key stakeholders.

Methods
We conducted an interview-based qualitative case study, consulting a range of stakeholders from various backgrounds and disciplines.[9] In doing so, healthcare robotics was conceptualized as the case. Other case studies currently in progress as part of a wider project exploring next generation technologies in healthcare settings include the integration of patient/person generated data with electronic health records (EHRs), innovative information infrastructures, and novel approaches to secondary data analysis.

Ethics and permissions
This study was reviewed and received Institutional Review Board approval from the Centre of Population Health Sciences at The University of Edinburgh, U.K. Participants gave written informed consent to participate and transcripts were anonymized. In order to protect participants, all information that could potentially lead to identification of individuals was removed.

Sampling and recruitment
Participants were sampled through Google searches using search terms relating to robotics and healthcare. In doing so, we sampled purposefully for maximum variability ensuring presentation from a range of countries and professional backgrounds (including engineers, system developers, suppliers, academics, visionaries/futurists, users of robots in healthcare settings and strategists).[10] This sampling strategy was complemented by snowball sampling additional participants through recommendations of interviewees.[11] Overall, we identified 68 participants. Of these, 42 email addresses were publicly available. The rest were sent invitations via LinkedIn through the account of the first author (KC). The initial email included an invitation to participate and an overview of the work. If participants expressed an interest (17 did), they were sent an information sheet and a consent form. The remainder were sent a follow-up email approximately two weeks later (resulting in a further nine that were interested in participating). After further discussions, four potential participants decided not to participate, mainly due to concerns surrounding signing of the consent form and the interview being audio-recorded (although an option of not recording was offered). Industry representatives were in particular not comfortable sharing potentially sensitive commercial information.
**Data collection**

Interviews were conducted over Skype, digitally recorded, and transcribed verbatim by a professional transcriber. These ranged from 30-90 minutes, depending on the schedule of the participant and also the number of issues that they wanted to discuss. We explored the most promising areas surrounding healthcare robotics, their benefits/risks, anticipated/observed challenges, and potential ways to address these. A sample interview guide can be viewed in Table 2.

<table>
<thead>
<tr>
<th>Table 2: Sample interview topic guide</th>
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<tbody>
<tr>
<td><strong>Their vision surrounding robotics and automation in healthcare</strong></td>
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<tr>
<td>• Most promising developments to look out for, benefits</td>
</tr>
<tr>
<td>• What processes lend themselves best to automation?</td>
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<tr>
<td>• Any risks, issues that are particularly relevant to robotics</td>
</tr>
<tr>
<td>• Convergence of robotics, artificial intelligence and big data analytics: how is the area of robotics defined?</td>
</tr>
<tr>
<td><strong>Experiences of technological innovation in healthcare</strong></td>
</tr>
<tr>
<td>• Experiences and lessons learnt</td>
</tr>
<tr>
<td>• User involvement in design</td>
</tr>
<tr>
<td>• Anything we can learn from other sectors?</td>
</tr>
<tr>
<td>• Which factors hinder developments and how might these be addressed?</td>
</tr>
</tbody>
</table>

We stopped recruiting further participants when we reached thematic saturation i.e. when no new themes emerged during the concurrent analysis.[12] In order to ensure that participants’ voices were reflected accurately, we performed member checking through sending the results to all participants and giving them the opportunity to comment and correct any inadvertent misunderstandings.[13] This resulted in minor clarifications to the results, consisting mainly of adding further details and context.

**Data analysis**

Transcribed interviews were uploaded to NVivo10 software, which supports the management and interrogation of data.[14] Helps to arrange qualitative data into meaningful headings and sub-headings. We began the coding process as soon as interviews were transcribed in order to allow emerging findings to feed into future interviews; this involved sorting data into meaningful headings and subheadings for on-going thematic analysis.

We approached the analysis with an initial coding framework based on the available empirical literature (the deductive component, see Table 3).[15] This allowed us to provide initial structure to our findings that remained close to the research question and the sociotechnical perspective underpinning it. The coding framework was informed by our previous theoretical work surrounding the evaluation of sociotechnical systems.[16] In addition, we also allowed new themes to emerge based on the frequency of occurrence and perceived significance (the inductive
component). During this process, we explored disconfirming evidence and carefully questioned our own (in some instances critical) assumptions about robotics.

In doing so, we carefully differentiated/compared between technological features, participants’ backgrounds, and insights into various sociotechnical aspects surrounding conceptualization, design, implementation and adoption of technologies. Emerging themes were discussed and refined during regular meetings between the authors.

### Table 3: The coding framework

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological dimension (including technological features, technological infrastructures)</td>
<td></td>
</tr>
<tr>
<td>Social/human dimension (including usability, human-technology interaction, attitudes)</td>
<td></td>
</tr>
<tr>
<td>Organizational dimension (including organizational strategy, management, implementation)</td>
<td></td>
</tr>
<tr>
<td>Macro-environmental dimension (regulation, legal and ethical dimensions)</td>
<td></td>
</tr>
</tbody>
</table>

### Results

We interviewed a total of 21 participants (see Table 4). They came from a range of academic/industry/strategic backgrounds and countries (the majority from the U.S.). Some, particularly academics, had mixed clinical backgrounds and had used or investigated robotic applications in healthcare contexts.

### Table 4: Participant characteristics

<table>
<thead>
<tr>
<th>Participant number</th>
<th>Background</th>
<th>Country</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant 1</td>
<td>Marketing, service robots</td>
<td>U.S.</td>
<td>F</td>
</tr>
<tr>
<td>Participant 2</td>
<td>Surgeon, user of surgical robots</td>
<td>U.S.</td>
<td>M</td>
</tr>
<tr>
<td>Participant 3</td>
<td>Academic, research into service robots</td>
<td>Norway</td>
<td>M</td>
</tr>
<tr>
<td>Participant 4</td>
<td>Engineer, surgical robots</td>
<td>U.S.</td>
<td>M</td>
</tr>
<tr>
<td>Participant 5</td>
<td>Futurist</td>
<td>U.S.</td>
<td>F</td>
</tr>
<tr>
<td>Participant 6</td>
<td>Marketing, sterilization robots</td>
<td>Italy</td>
<td>F</td>
</tr>
<tr>
<td>Participant 7</td>
<td>Academic, sociotechnical perspective</td>
<td>Switzerland</td>
<td>M</td>
</tr>
<tr>
<td>Participant 8</td>
<td>Technologist, humanoids</td>
<td>France</td>
<td>M</td>
</tr>
<tr>
<td>Participant 9</td>
<td>Academic, mainly surgical robots</td>
<td>U.S.</td>
<td>M</td>
</tr>
<tr>
<td>Participant</td>
<td>Role</td>
<td>Country</td>
<td>Gender</td>
</tr>
<tr>
<td>-------------</td>
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<td>--------</td>
</tr>
<tr>
<td>10</td>
<td>Technologist</td>
<td>U.K.</td>
<td>M</td>
</tr>
<tr>
<td>11</td>
<td>Engineer, telepresence robots</td>
<td>U.S.</td>
<td>M</td>
</tr>
<tr>
<td>12</td>
<td>Academic</td>
<td>Sweden</td>
<td>F</td>
</tr>
<tr>
<td>13</td>
<td>Strategist</td>
<td>Netherlands</td>
<td>M</td>
</tr>
<tr>
<td>14</td>
<td>Journalist</td>
<td>U.S.</td>
<td>M</td>
</tr>
<tr>
<td>15</td>
<td>IT Consultant</td>
<td>U.S.</td>
<td>M</td>
</tr>
<tr>
<td>16</td>
<td>Academic, informatics, rehabilitation and surgical robots</td>
<td>U.K.</td>
<td>M</td>
</tr>
<tr>
<td>17</td>
<td>Business development, humanoids</td>
<td>France</td>
<td>M</td>
</tr>
<tr>
<td>18</td>
<td>Manager, robotics organization</td>
<td>France</td>
<td>M</td>
</tr>
<tr>
<td>19</td>
<td>Academic, surgical robots</td>
<td>Australia</td>
<td>M</td>
</tr>
<tr>
<td>20</td>
<td>Academic, ethicist</td>
<td>U.K.</td>
<td>F</td>
</tr>
<tr>
<td>21</td>
<td>Academic, psychologist</td>
<td>U.K.</td>
<td>F</td>
</tr>
</tbody>
</table>

We identified a range of themes and sub-themes. These are summarized in Table 5.

### Table 5: Themes identified in our work

- No clear pull from professionals and patients
  - Robots have negative publicity
  - Lack of acceptance - trust is a social phenomenon and essential for healthcare
  - Robots are transcending the human-machine interaction
  - Lack of exposure to robots, particularly in Western cultures

- The appearance of robots
  - Too robotic – psychological association with death, terminator, fear of replacing human being
  - Too human – expectations too high

- Changes to the way healthcare work is organized and distributed
  - Changes to roles (replacing human capabilities versus augmenting them)
  - Changes to workflows

- New ethical and legal challenges
  - No existing liability and ethical frameworks
  - Anticipating challenges will be crucial in the future
  - Regulation is key to promote routine use
Overall, participants stated that the area of robotics in healthcare settings was still in its infancy and that the move from paper-based to EHRs currently took strategic priority over investments in robotics. Particularly the more novel developments surrounding humanoids were still seen to be a long way off in terms of routine deployment in health and care settings, whilst service robots were seen to hold the biggest short-term promise. However, it was also acknowledged that there was significant potential and that the pace of developments as well as increasing convergence of applications meant that robotics were likely to become routine aspects of healthcare delivery at some point.

“I am quite taken by the fact of how quickly changes come about...in my lifetime as a surgeon in the late ‘80s we completely switched over a two year period from an open surgical approach to a minimal and key hole...” Participant 2, Surgeon, U.S., Male

**No clear pull from professionals and patients**

A perception of concerns amongst the public, patients and healthcare staff were viewed to hold back progress, leading to a lack of demand and/or acceptance for some robotic applications in healthcare settings. Attitudes were seen to be heavily influenced by negative publicity and modern science fiction.

“...[patients] think when you say robot...you mean Terminator so people are afraid...” Participant 8, Technologist, France, Male

Such negative attitudes were seen to be due to a range of factors. Some mentioned the importance of the clinician-patient relationship and patient trust in particular as an aspect of care that was perceived to require human input. Therefore, applications that were considered to be carrying out healthcare professional tasks, were viewed as particularly contested. Conversely, purely service-based robots carrying out back-end functions were often seen as better suited to automation.

“...to put your trust into a robot is still not there. I think a walker with robotic features is easier to adopt in the market by the people using it than a lifting robot.” Participant 13, Strategist, Netherlands, Male

From a healthcare provider point of view, negative attitudes were also seen to be influenced by perceived threats to professional roles.

“...a good anesthesiologist [costs] about $350 per hour, it's a heck of a wage, and the machine can be rented for about $150 so it's a lot more cost-effective. That company have abandoned the product, not because it didn't function, it functioned extremely well. But it was very unpopular and it had all sorts of doctor, patient unions and lobbying groups that had kittens about this idea of this robot that could basically put them all out of a job.” Participant 5, Futurist, U.S., Female
Lack of exposure to robots was seen as a major barrier to developing positive attitudes amongst patients and staff. This was seen to be due to the fact that many existing applications such as pharmacy robots mainly operated in the back-office (lack of exposure) and a resulting “fear of the unknown”, particularly in Western cultures where robots are not routinely embedded in other aspects of everyday life.

“…in Japan people believe that robots also have a kind of soul and that’s why they approach robots as if they are like normal people. I believe in the rest of the world probably people …will be much more skeptical and I don’t believe that people will accept that particularly caring for people will be performed by robots.” Participant 7, Academic, Switzerland, Male

Some participants suggested that public engagement campaigns, training of healthcare staff and public dissemination of positive robotic case studies could help to promote positive attitudes and acceptance of robotic applications amongst healthcare staff and patients.

**The appearance of robots**

Humanoids presented a particularly interesting illustration of the tension between human hopes/expectations of robots and apprehension of their use in healthcare settings. They also represent an important sociotechnical example as human and technical dimensions blur in challenging and highly visible ways.

One reason identified in the interviews for humanoids, in particular, not being very successfully integrated within healthcare settings was the contested nature of robotic appearances. On the one hand, human features were seen as desirable in order to provide patients and staff with an experience of care as close to the real thing as possible.

“We’ve tried to make it as approachable and friendly looking as possible because some people might think it’s cold and now you’re not having a direct person to person interaction in the flesh. So, we try to do our best to really make it as close as possible to the person being there, you know with good audio, good video, the physical look of the robot.” Participant 11, Engineer, U.S., Male

On the other hand, if robots were designed too human-like, there was significant apprehension of users, potentially being due to a fear of the robot replacing humans and imagined parallels with the aforementioned Terminator vision of robots. This was particularly true for intimate tasks that often represented important aspects of the patient-provider relationship.

“…there’s a fear that the robot becomes almost like a near-human doppelganger [a ghostly counterpart] that replaces the human being, because it has capabilities that we don’t, so there’s still this almost like mythical status of the robot that’s certainly
something that hovers around popular consciousness.” Participant 21, Manager, U.K., Female

An additional undesired consequence was that when robots were designed as too human-like, they often fell short of human expectations of what they could do, resulting in disappointment and lack of engagement with and trust of the robot if they did not perform as expected.

“...your expectations go up when you make robots human like.” Participant 16, Academic, U.K., Male

Some also mentioned that the difficulty of placing humanoid robots firmly within either human or robotic categories was responsible for potential feelings of aversion. This was further exacerbated by a struggle to establish whether to perceive the robot as a friend or foe.

In order to address these problems, developers tended to design humanoid robots intentionally as non-human-like to ensure a visible demarcation between human and robotic features. This included, for example, designing them to roll on wheels rather than having legs, or by designing them in the shape of an animal that most people had no experience of interacting with (e.g. a baby seal). This strategy was considered to be successful in promoting acceptability across contexts.

**Disruption of the way work is organized/distributed**

All participants acknowledged that the integration of robotic applications with existing healthcare professional work practices was important, but difficult to achieve due to tensions between standardization through automation and the often unpredictable nature of healthcare professional work.

The design of robotic applications that interacted with humans and that spanned departmental and professional boundaries (i.e. as autonomous robots) was seen as particularly problematic, as these transcended capabilities that were previously situated firmly within the human realm (e.g. moving around, emotional support).

“...when it comes into practice we all ran into problems. What if an elderly person is moving away from a robot, can it follow the elderly person? What if it falls and it’s a person with mild dementia is that person able to put the robot back on its feet again?” Participant 13, Strategist, Netherlands, Male

In contrast, robotic applications that were designated to particular uses (such as surgery where they were basically represented a sophisticated tool) or confined to back-office functions in controlled environments (such as pharmacy robots), were seen as less difficult to implement, as they had fewer challenging sociotechnical implications.
“...this is why robots have been so successful in industry, like in car manufacturing because they have these repetitive tasks and there are no humans in their way, they don’t have to make decisions, they don’t have to understand anything.” Participant 14, Journalist, U.S., Male

It was therefore argued that in order to promote integration, robots should be viewed as augmenting human capabilities and as empowering professionals in their role.

“...when people talk about nurses and doctors and automation in a hospital for example the automation isn’t about replacing the nurses and doctors, it’s about augmenting their role so that they’re more efficient so that they’re not doing endless amounts of paperwork they spend a bit more time with patients.” Participant 10, Technologist, U.K., Male

This would, however, require some shift in skill-sets towards supporting robotic capabilities and functions, particularly for the lower skilled tasks. Envisioning and anticipating those changes was viewed as an important activity for educators, decision makers and managers in healthcare settings.

New ethical and legal challenges
Robotic applications engender new ethical and legal challenges surrounding their use in highly human social settings and interviewees gave many examples. Some of these tackled the physical environment:

“There was one lady who got trapped in an elevator together with one of the robots and another one got run over.” Participant 3, Academic, Norway, Male

Whilst others described psychological challenges such as the perceived risk to become too emotionally attached to a robot (particularly in care settings where patients are vulnerable).

“...if you look at the target audience this will be vulnerable people, disabled people, sick people, the elderly...so it’s important that we have robots that do not transport a feeling that is not real, like companionship robots for example. They should be designed in a way that it’s always clear that it’s always a robot and not a substitute for a human.” Participant 20, Academic, U.K., Female

Ethical dimensions surrounding non-use of technology were also mentioned. These included issues of whether healthcare professionals should be forced to use robotic applications if this was a safer alternative than human delivered care.

“I’m particularly trying to answer the questions like if we show that you can do something more safely with the robot does that mean that people should use the robots if they know there’s a safer alternative...should they be forced to use a robot
assistant because they know it’s a safer way of doing it…” Participant 19, Academic, Australia, Male

Some had therefore begun developing ethical frameworks for robotic applications. A defining characteristic here was that both human and machine perspectives were represented, so that the guiding principles were both machine logic as well as human logic (including their reaction to machine behavior), implying a new sociotechnical approach to HIT ethics is developing.

“… the idea is that the framework is understandable by both humans and machines so that if a machine needs guidance, a human can work through the framework and figure out where it got stuck and make a judgement call or vice versa machines can begin to understand how humans themselves are making a certain decision and provide guidance or insight into that.” Participant 5, Futurist, U.S., Female

Additionally, interviewees noted that there was a lack of clear, established liability rules surrounding robotics, made all the more problematic given the perceived hype surrounding robotics and a certain keenness of getting these into use quickly. This meant that when accidents happened (such as robots running over humans), these often had to be solved ad-hoc, further contributing to negative public attitudes and inhibiting innovation.

Participants suggested that therefore a more deliberative approach was needed to create clear liability rules surrounding product and consumer safety across different settings in which robotic applications were used, including healthcare. However, it was seen to be crucial to find a balance between developing over-arching rules and allowing innovation to flourish.

Discussion

Principal results
Although there is substantial technological progress in the field of healthcare robotics, their integration into healthcare settings is likely to be far from straightforward. We have identified a number of concerns that are often shaped by preconceptions surrounding the appearance of robotic applications and associated (often conflicting) desires for human and technological features. In addition to these negative attitudes which result in a lack of user pull and demand, robotics also do and will change the way healthcare work is organized and distributed with some applications augmenting and others replacing human skill. These changes require new ethical and liability frameworks as new situations may emerge that blur the line between human responsibility and technological autonomy.

Limitations
In undertaking this study, we have elicited the perspectives and experiences of a wide range of stakeholders from various international settings to bring together
knowledge and deliberate on potential future challenges of implementing and optimizing robotic applications in healthcare settings. We have identified a range of sociotechnical challenges associated with various technological features. This builds on previous work which has often focused on specific systems that are already being used in specific settings.[17-20] Our focus, in line with our taxonomy (Figure 2), was on different aspects of robotic hardware function. Although these were necessarily combined with some software capability, including artificial intelligence AI), software was not the focus of our work.

The response rate to interview invitations was low (only 21 out of 68 individuals agreed to be interviewed), this in part reflecting concerns about disclosing commercially sensitive information, and we may therefore have missed some important considerations (despite having achieved thematic saturation within our sample), particularly from cultures that have integrated robotics within everyday life (e.g. Japan).

Comparison with prior work
There is an increasing recognition that sociotechnical considerations are important when considering technological applications including robotics,[21,22] but only a limited number of studies have examined such issues with regards to robotic applications in healthcare.[23-25] Where it exists, primary research has concentrated on particular technologies in specific environments, including some in healthcare.[26,27] However, when compared to other HIT, autonomous applications (such as humanoids) in particular present specific sociotechnical challenges, as social and technical dimensions are progressively, visibly and disruptively interconnected. As a result, there is a danger that these sociotechnical challenges will lead to an increasing range of problems integrating robotic applications within particularly human-dense social environments such as healthcare.

Ethical dimensions surrounding robotics, especially relating to trust and acceptance, have received relatively high levels of attention, perhaps due to perceived negative public attitudes surrounding robotic systems.[28-30] Our work has supported existing research highlighting that these issues pose important sociotechnical barriers to progress. Humans have to re-negotiate their roles within increasingly technological environments and this negotiation is characterized by a conceptual struggle between a desire for progress and an apprehension towards the increasingly human side of machines.

However, although important as a subject of ongoing debate, these issues are unlikely to ever be fully resolved. Some have found that trust and positive attitudes towards robotic applications can be promoted through exposure;[31,32] and, increasing exposure is likely to be key in going forward. As robotic applications become more visible in everyday environments, they are likely to become more acceptable in healthcare settings. Lack of exposure is likely to be a transient issue as there are now many examples of other industries/countries where robots and humans routinely alongside each other.
Implications for research, policy and practice
We have begun charting a range of sociotechnical challenges that are likely to test the routine integration and optimization of robotics into healthcare settings.

New ethical and regulatory frameworks are now needed that are nimble enough to keep up with changing environments and the increased in and convergence of robotic functionality. This may need to involve training a new generation of professionals who specialize in high risk settings such as healthcare, as existing regulations simply cannot keep up with the pace of technological advancements. Work may also need to involve drawing on ongoing efforts in other industries where these challenges have begun to be addressed. Healthcare robotics is an emerging field that will need inclusive, designated working groups at national and international levels, as many functions are patient/staff-facing and humans and machines need to co-exist and collaborate in high risk environments. Robotics in designated controlled environments (such as service robots) are likely to be less problematic and are therefore expected to present the highest gains in the short term as they present with a limited number of sociotechnical challenges when compared to other applications that blur social and technical dimensions even further (e.g. humanoids).

Conclusions
Sociotechnical challenges surrounding the implementation of robotics in healthcare settings are significant, although these are likely to vary with different robotic applications and in different cultural contexts. These need to be anticipated and, if possible, proactively addressed. Health care settings are characterized by their care work; the provocation is to preserve and indeed intensify or augment this within an increasingly automated and technological environment. This can only be done if we anticipate the challenges associated with new technologies and systematically address them as we integrate them within existing social orders. Our research should be seen as a stepping-stone to stimulate wider discussions surrounding these challenges. It can also help to guide healthcare organizations and policy makers as they make important strategic decisions associated with purchasing, developing and deploying robotic applications.

Acknowledgements
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Conflicts of Interest
None declared.

Abbreviations
HIT: health information technology
EHR: electronic health record
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