Human Health and Equity in an Age of Robotics and Intelligent Machines

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Advances in robotic technologies and intelligent machines will transform the way clinicians care for members of our community within a variety of health care settings, including the home, and, perhaps of far greater importance, offer a means to create a much more accessible, adaptable, and equitable world for every member of society. Robotics have already entered the health care ecosystem, and their presence is rapidly expanding. Surgical robots have become a common fixture in many medical centers. Outside of North America, robotic systems have emerged to meet an acute and growing labor shortage within skilled nursing facilities in Japan and were recently used to limit social contact and mitigate the risk of COVID-19 in China and South Korea (Khan et al., 2020). Regardless of the setting or application, key challenges to fully integrating robotics into health care include the development of algorithms and methods that enable shared human-robot autonomy and collaboration in the real world, as well as technology deployment that is both cost-effective and culturally centered so that all communities may benefit. Exploiting the transformative potential of these technologies will require intensive collaboration among policy makers, regulators, entrepreneurs, researchers, health care providers, and especially those who would stand to benefit from or may be subject to risks due to the use of these technologies. This paper outlines areas in which robotics could make the largest and most immediate impact, discusses existing and emergent challenges to their implementation, and identifies areas in which implementers will need to pay specific attention to ensure equitable access for all.

The earliest and most well-recognized advances in medical robotic technologies began in the realm of surgical tools (Dupont et al., 2020). The emergence of robot-assisted surgery was enabled by the development of operator-controlled robotic arms that could achieve a high level of precision and maneuverability, facilitating a range of complex procedures. While the extent to which these tools improve clinical outcomes continues to be defined, several studies support their capacity to reduce surgeon fatigue and allow minimally invasive surgery under circumstances that would be challenging or infeasible for laparoscopic techniques (Law et al., 2020; Prete et al., 2018). Moreover, the ability of these systems to autonomously perform an ever-increasing subset of surgical tasks has been demonstrated, as they integrate and act upon visual cues with decision-making driven by machine learning algorithms. Significantly, with the emergence of ultra-fast, high-bandwidth networks, the feasibility of deploying and operating such systems remotely, at sites where an emergent intervention may be required, has been established. The potential benefit may be substantial for those in acute need but otherwise located in a hazardous environment or a low-density population setting, remote from experienced surgical specialists. Between 2001 and 2019, rural areas of the United States experienced a 29% decrease in general surgeons, and "in 2019, 60% of non-metropolitan counties had no active general surgeon" (Larson et al., 2020). Given the shortage of experienced surgeons in many remote rural counties, the development of economical teleoperated robotic systems would provide needed access to care most often to poorer communities, reducing inequities without the expense, burden, or delays associated with coordinating care at a tertiary site.

One in seven Americans has a mobility disability and relies on technology to navigate the world (Okoru et al., 2018). While technology has changed the ways people with physical disabilities interact with their surroundings, recent innovations have dramatically improved the ability of devices to sense and respond to the local environment in a manner coordinated with the user.

For example, advanced lower limb prostheses are enhancing accessibility by incorporating microprocessor-controlled joints that modulate resistance to motion to enable ambulation over irregular terrains, including ascending and descending stairs, with reduced fatigue and improved safety. Upper limb orthoses, like their lower limb counterparts, were historically designed as passive devices, but body-powered or myoelectric devices that use residual neuromuscular activity to control motion have been recently introduced. Successfully incorporating enhanced motive power within bionic limbs promises to greatly improve mobility, robustness, dexterity, and function with expanded access to all aspects of the physical world. Within the general class of mobility assistive devices, powered wheelchairs and patient transfer devices are designed with sensing and guidance technology. Seamless integration of sensing and planning capabilities will lead to further improvements in safe and efficient navigation through complex environments and provide broader equity of access to all environments for all people.

According to estimates from the Bureau of Labor Statistics, the U.S. health care sector has lost approximately half a million workers since February 2020, with nearly one in five health care workers leaving the workforce since the COVID-19 pandemic began, most notably from nursing care facilities (Wager et al., 2021). Almost all nursing homes and assisted living communities in the U.S. now face staff shortages, and over half are experiencing difficulty recruiting registered and licensed nurses, and certified nursing assistants (Bernstein and Van Dam, 2021). Over half of all states will not be able to meet their demand for home health aides, nurses, and mental health workers (Bateman et al., 2021). The health care labor shortage is now a global crisis, exacerbated by COVID-19 and a rapidly aging population. Robotic work aides have been introduced to assist health care workers in the care of people who are frail, physically or cognitively debilitated, or recovering from illness. Robotic assistants have been introduced into both hospitals and clinics to autonomously retrieve supplies and equipment and to transport medications and specimens. Robots have been designed to engage in tasks that include patient transfers between bed and chair, mobility, toileting, communication, and monitoring. Affective, or social, robots that engage in conversation for companionship have also been introduced to promote well-being, support individuals with cognitive impairments, and address the challenge of social isolation and motivate behavior to enhance mental and physical health (Kubota and Riek, 2021). In Japan, the widespread implementation of robotic assistants in nursing homes to close the workforce gap has improved efficiency and a decreased burden on health care workers. In the process, staff retention has improved, and employment has increased by augmenting the number of care workers and nurses on flexible contracts (Eggleston et al., 2021).

A fundamental problem associated with all of the aforementioned applications is the ability to infer individual preference through the design of intelligent machines that can effectively collaborate with humans through a process of shared autonomy. Human preferences vary widely, and the challenge for robotic devices is the requisite ability to adapt to each individual's needs, with distinct robotic applications requiring varying degrees of shared autonomy. A non-ambulatory person may be willing to receive a high level of support from a mobility assistive device, but for those who are ambulatory, a greater level of human control and agency may be expected with synchronized human-robot responses. Likewise, even minute differences in the expected behavior of a limb prosthesis or surgical robot could lead to a catastrophic consequence. The ability of robots to understand and adapt to user preferences is also important for robots that provide cognitive support to maintain engagement and adherence to treatment.

There are many barriers to adopting robotic technologies in health care, including usability, safety, capability, patient preference, and evidence of clinical effectiveness. Crucially, affordability may be the single greatest barrier to widespread implementation of these technologies. The high cost of surgical robotic systems, even apart from the necessary complementary training, maintenance, and consumables, precludes their use in all but the most well-funded medical centers. While health care systems bear the expense of robotic surgery, patients bear the direct burden of cost for limb prostheses and orthoses, with the cost of myoelectric prostheses in the tens of thousands of dollars. New pricing and payment structures may be needed for affective robots and assistive devices because of the potential reluctance of health care payers to cover the cost of these devices given their mixed use as consumer products. Motivated by a looming health care labor shortage, which appeared well before the pandemic, policy makers in Japan introduced tax policies to promote innovation in the health care robotics sector, along with initiatives to support their adoption, with over one-quarter of long-term care facilities in Japan now employing one or more robots (Kubota and

Riek, 2021). Ensuring affordability of new technologies directly intersects with health equity, mainly to ensure people who have been systematically and historically underserved in health care can access and use new technologies as they become available, especially minoritized individuals and people with disabilities.

The ability to recognize the full potential of health care robots and intelligent machines will require that both technical and socioeconomic issues be addressed. Health care leaders should support the development of a shared cross-sectoral vision among policy makers, regulators, entrepreneurs, engineers, and caregivers, with patients and communities in need being centered in all conversations. It has been three decades since the passage of the Americans with Disabilities Act, and more needs to be done to ensure that policies support the development and dissemination of technologies that enable a more accessible world for all. Ensuring broadband access to underserved communities in association with the development of low-cost surgical robots can redistribute human expertise where needed, reduce existing disparities in care, and ensure health equity. We are in the midst of an unprecedented crisis in the American health care workforce with critical labor shortages that adversely impact care in hospitals and rehabilitation centers, skilled nursing facilities, and in-home health care support. Health care robotics will not completely solve this problem, but public policies that recognize the ability of robotic technologies to mitigate this challenge are needed, which will undoubtedly reduce stress, burnout, and further degradation of the existing health care workforce. Effective integration of autonomy between humans and robots, either one-on-one or within larger groups, is part of a broader human-machine "alignment problem" that recognizes the risks that can arise when systems that reflect our biases or lack our values perform in a manner that we do not want or expect. If we are to succeed in using robotic systems and intelligent machines in our effort to create a more accessible, adaptable, and equitable world, we will need to proceed with caution and humility.

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