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OPINION PIECE

Neurosurgical robots and ethical challenges to medicine

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ABSTRACT: Over the last 20 yr, neurosurgical robots have been increasingly assisting in neurosurgical procedures. Surgical robots are considered to have noticeable advantages over humans, such as reduction of procedure time, surgical dexterity, no experience of fatigue and improved healthcare outcomes. In recent years, neurosurgical robots have been developed to perform various procedures. Public demand is informing the direction of neurosurgery and placing greater pressure on neurosurgeons to use neurosurgical robots. The increasing diversity and sophistication of neurosurgical robots have received ethical scrutiny due to the surgical complications that may arise as well as the role of robots in the future. In this paper, we address 3 ethical areas regarding neurosurgical robots: (1) Loss of neurosurgical skills due to increasing dependency on robots; (2) How far do we want to go with neurosurgical robots? (3) Neurosurgical robots and conflict of interest and medical bias.

KEY WORDS: Neurosurgical robot systems · Neurosurgical skills · Moral agency · Anatomical variation · Medical bias · Bioethics

1. INTRODUCTION

Over the last 20 yr, neurosurgical robots have been increasingly assisting in neurosurgical procedures. Surgical robots are considered to have noticeable advantages over surgeons, such as reduction of procedure time, submillimetric precision, superior axial movement range and surgical dexterity, and no fatigue, that are evidenced by improved healthcare outcomes (Panesar & Britz 2019, Fiani et al. 2020). Furthermore, surgical literature correlates increasing age of surgeons with loss of manual dexterity (Kappert et al. 2008, Staub & Sadrameli 2019).

The advent of medical robots was first evident in the field of neurosurgery in the 1980s via the Animation PUMA 200 robot that offered high stereotactic performance during intracerebral biopsy (Kwoh et al. 1988, Bagga & Bhattacharyya 2018). Since then, several neurosurgical robots have been developed for applications including implant placement confirmation, navigation, optics, precision tool guidance and neuroregistration (von Langsdorff et al. 2015, Tan et al. 2016, Pillai et al. 2019, Kaushik et al. 2020a,b, Zhang et al. 2020).

In recent years, neurosurgical robots have been developed to perform minimally invasive procedures involving endovascular techniques, thrombectomy, stenting and embolization (Panesar & Britz 2019). The move towards minimally invasive surgery is in response to public demand for more efficient and

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safer surgery, as well as a reduced risk of iatrogenic litigation, which is common in traditional surgical procedures.

Currently, there are several operating neurosurgical robotic systems preforming a wide range of surgical tasks. These include the Pathfinder, SpineAssist, Minerva and Renaissance systems. John Hopkins University has developed the robotic Steady Hand system that enables neurosurgeons to perform high-precision dissection without tremor. Shinsu University in Japan has developed the NeuRobot — a remote-controlled endoscopic device equipped with various tumour-resecting devices (Gonen et al. 2017, Bagga & Bhattacharyya 2018). Similarly, current neurosurgical robots like Neuromate and ROSA can perform more time-efficient multi-projectory procedures (Pillai et al. 2019), while robot-assisted stereo-electroencephalography (SEEG) has been demonstrated to be more accurate and safer in patients with hard to pinpoint seizures (González-Martínez et al. 2016).

Neurosurgical robot systems are categorised according to 3 types:

1. Dependent or master/slave systems: designed for neurosurgeons to perform total motor control.

2. Shared control: hybrid systems that allow only specific hand movements, thus reducing hand tremor (He et al. 2014).

3. Autonomous robots: perform programmed motions or can instigate positional calculations (Zamorano et al. 2004, Doulgeris et al. 2015, Menaker et al. 2018).

The term autonomy has a variety of meanings and implications. In moral philosophy, 'autonomy' denotes responsibility for one's actions; in this way, autonomy is linked to having personal agency in deciding how to behave (Noorman & Johnson 2014). However, in the field of artificial intelligence (AI), autonomy is often used to describe activities performed by robots which are unsupervised (Wallach & Allen 2013). Although current robots can perform various autonomous tasks, thereby indicating agency, such actions are computational — they derive from electronic circuitry, in contrast to the 'natural' behaviours of humans (Johnson & Verdicchio 2019). In other words, current robotic programs have yet to endow robots with an ability for genuine self-reflective action that originates from themselves (Sparrow 2007). Thus far, robotic programs are the responsibility of humans (Noorman & Johnson 2014).

The increasing diversity and sophistication of neurosurgical robots have received ethical scrutiny due to surgical complications that may arise as well as the role of robots in the future. These include image acquisition distortions and errors in the areas of framing, kinematics, and camera and robot calibration. Also, there are persistent problems in visual confirmation accuracy and brain tissue displacement (Widmann et al. 2012, Vazhayil et al. 2019). Furthermore, neurosurgical robot designs are problematic since they may obstruct a view of a surgical site, or are unable to imitate the tactile dexterity of a neurosurgeon (Kelly 2002). As noted, current problems with neurosurgical robots are mostly design-based and mechanical limitations, and not necessarily related to a neurosurgeon's expertise. Therefore, design makers of neurosurgical robots are working to address current robotic limitations.

New discoveries in neuroscience demand answers to questions regarding the status of neurosurgical robots, their capabilities and limitations, and possible future developments. In this paper, we address 3 ethical areas regarding neurosurgical robots: (1) Loss of neurosurgical skills of humans due to increasing dependency on robots; (2) How far do we want to go with neurosurgical robots? (3) Neurosurgical robots and conflict of interest and medical bias. Related to the third one is the consideration that due to the prevailing trend of incompetent medical professionals not being reported by their colleagues in countries such as the USA (33% of US physicians surveyed had not reported an incompetent colleague) (Klaas et al. 2014), neurosurgical robots may be a beneficial alternative in limiting medical malpractice and ensuring medical safety.

2. LOSS OF NEUROSURGICAL SKILLS DUE TO INCREASING DEPENDENCY ON ROBOTS

According to Aristotle, a habit also includes the acquiring of technical knowledge or learned skills — 'habit-as-routine' for achieving a desired goal (Bernacer & Murillo 2014). In this view, a habit's telos is practical. Along this line, the training of neurosurgeons is based on a 'time-bound apprenticeship model' requiring a long time scale for achieving the necessary motor and knowledge skills (Suri et al. 2016). The close proximity of cortical/subcortical regions, as well as the delicate cyto-architecture of neural structures, demands meticulous precision and anatomical knowhow. Brain tissue is particularly susceptible to neurosurgical forays, an issue that cannot be by-passed. Hence, neurosurgical skill acquisition is painstakingly laborious and demanding (van Loveren 2018). Anatomical variation in brain and intracranial structures is significant. This requires surgeons to base their decisions on a broad knowledge. Since variations concern both the size and structure of brain parts and accompanying vessels (Burlakoti et al. 2017), not all movements of autonomous artificial systems can be pre-programmed. There is a danger that the standard actions of robots may not be suitable for some patient's brains.

The science fiction writer Isaac Asimov noted that increasing dependency on surgical robots would lead to a reduction in surgeons' motor/knowledge skills (Asimov 1991). Consequently, this would violate the principle of 'first, do no harm' (primum non nocere) since patients would be treated by inadequate surgeons (Spillman & Sade 2014). This is a valid point as manual surgical dexterity is acquired by years of ongoing training. On this theme, Weber (2018, p. 607), states:

> If robots completely relieve humans of healthcare duties and responsibilities, including research, what role would humans play in the healthcare workplace, if any? Would humans devolve and lose such motivations as curiosity, or the spirit of inquiry and discovery which drives many scientific discoveries? Humans would most certainly in the above scenario lose the technical facility to design and carry out biological and engineering experimentation.

A study by Parker et al. (2014) of 16 surgical residents who had worked on robot assisted laparotomies concluded that working with surgical robots had a negative impact on the residents' surgical skills. They had, however, replaced those skills with a new set of skills related to the control of robot-using procedures. Of course, we do not intend to close the case based on this one study. However, it does point to what many in the medical field have been concerned about. Increasing reliance on neurosurgical robots may eventually limit the finely tuned hand motor skills required in neurosurgery. If this happens, then future robots may become true quasi-biological entities as they will have surpassed the surgical skills of their human counterparts. As long as robots are always available in all circumstances requiring surgical intervention, this development will not produce negative consequences. However, when situations arise where no robot is available when surgical intervention is necessary, this will be detrimental to human health or even life.

Alternatively, if we agree that neurosurgical robots represent a surgical advancement, and therefore an important tool in the neurosurgeon's arsenal, then exclusion of neurosurgical robot-assisted training may in turn be harmful to patients (Spillman & Sade 2104). Many surgeons have expressed the view that surgical robots have a positive benefit in surgical outcomes due to their minimal invasiveness and precision (Herron & Marohn 2008, Tan et al. 2016). Clearly, more studies are needed in order to ascertain whether medical robots are reducing surgeons' preparedness, and if so what the ethical consequences are.

3. HOW FAR DO WE WANT TO GO WITH NEUROSURGICAL ROBOTS?

The increasing interest in neurosurgical robots is also a response to the changing medical environment. The high time demands placed on neurosurgeons, as well as considerable hospital investments in neurosurgical robots, mean that they will in all likelihood play greater roles in the future. Although current neurosurgical robots have not yet been designed to be true autonomous AI units, what if such robots come into existence in the future? What will the role of the neurosurgeon be in future surgical scenarios? Will they be relegated to a supplementary role or to just making decisions at the highest clinical levels? In that case, how will the physician–patient relationship be affected by AI supplanting humans? Notwithstanding the increased technologization of biomedicine, the human factor has always played a pivotal role at primary, secondary and tertiary levels. Ethics still informs the behaviour of most neurosurgeons and ensures that the principle of primum non nocere is not compromised. Surgical decisions are also based on moral principles, where pros and cons on surgical procedures and their pre- and post-op care are weighed up. This is often a collaborative process involving surgical and nursing staff. Could even the most exquisitely precise and efficient humanoid neurosurgical robot be capable of engaging in such a moral domain requiring cognitive and affective sensibilities? Could future neurosurgical robots be designed to have moral agency? Chakraborty (2018) notes that humanoid robots do not possess the ability to navigate through the moral realm. Even if future humanoid neurosurgical robots could be programmed to display various kinds of emotions, the processes of self-reflection and existential experience are complex psychoneuroendocrinological processes that are biological, messy and spontaneous. Since neurosurgery, like all other forms of surgery, is also a moral endeavour, humanoid neurosurgical robots will find it difficult to engage in concepts and sentiments such as empathy, fear, irrationality, absurdity, truth, sorrow and humour that are vital in directing an individual's moral compass (Davidson 1984, Chakraborty 2018). However, Chakraborty (2018) reminds us that since AI is a human construct, humans will be ultimately responsible for the creation and behaviour of robots. After all, moral structures are beyond the capability of any AI, since the enaction of morality is evidence of self-reflection. Will future AI have the ability to self-reflect? This is impossible to determine at this time. However, if future AI becomes self-reflective, it will be based on digital processes. We have no idea how this will manifest.

Here, we arrive at a moral dilemma; the more tasks that are given to neurosurgical robots, the less surgical and ethical engagement a neurosurgeon has (Weber 2018). In their responsibility gap theory, Fosch Villaronga & Millard (2018) explain what would happen if robots had the ability to change 'the rules by which they act' (Fosch Villaronga & Millard 2018, p. 235). Would this require a change in their status corresponding to humans? (Weber 2018). Moreover, how would neurosurgeons enact responsibility for autonomous neurosurgical robots if they lacked control over them? (Stahl & Coeckelbergh 2016).

4. NEUROSURGICAL ROBOTS, CONFLICT OF INTEREST AND MEDICAL BIAS

According to the 3rd law of robotics, Asimov stipulates that: 'A robot must protect its own existence' (Spillman & Sade 2014, p. 814). Here, the collusion between robotic companies and the medical field has established the necessity of medical robots, especially in the light of the COVID-19 pandemic. It has been estimated that by 2021 artificial intelligence in healthcare is worth a projected 6.6 billion USD (Dolic et al. 2019). Second, hospitals in many countries are heavily investing in and advertising medical robots. It has been suggested that such robotic investment may pressure trainee surgeons to downplay the accuracy or other problems associated with medical robots. Consequently, neurosurgeons need to scrutinize all advertising and fiduciary practices undertaken by hospitals in order to prevent their services being marketed incorrectly (Spillman & Sade 2014).

Neurosurgery, like other medical disciplines, is highly competitive. In order to get ahead in his/her career, a neurosurgeon may invest more time and training into a specific robotic-assisted technique than other more cost-effective and non-robotic techniques (Sharkey & Sharkey 2013). The increasing innovation in robotic neurosurgery leads to a greater risk of potential harm to patients by neurosurgeons and their healthcare institutions compared to standard neurosurgical procedures (Sharkey & Sharkey 2013).

For example, studies by Barocas et al. (2010) and Jin et al. (2011) concluded that robotic surgery was not more effective than conventional surgery, while Hu et al. (2009), who examined the medical records of prostatectomies conducted during 2003 to 2007, found that even minimally invasive robotic surgery produced more risk of erectile dysfunction, genitourinary complications and incontinence, even though patients had shorter stays in hospital (Sharkey & Sharkey 2013). This is likely due to stereotyped actions of robots in bodies of patients that display normal biological variability in the size and shape of the structures being operated on. Jin et al. (2011) further showed potential bias by hospital websites, of which 86% claimed that surgical robots were clinically superior. Two more things were telling in this study: first, hospital websites overestimated the benefits of surgical robots; second, no hospital mentioned the potential risks of using robotic surgery (Jin et al. 2011). Similarly, Munshi (2019) concluded that research-based data have shown that conventional surgical oncology is just as effective as robot surgical oncology. The caveat here is that no new technology, no matter how well it is marketed, must in any way compromise the principle of primum non nocere. It is because humans act according to biases that neurosurgeons must not overestimate the putative superiority of a 'revolutionary innovation' unless it is subjected to multiple rigorous randomised controlled trials. It is more important that patients are able to find an experienced neurosurgeon than to choose between conventional or robotic surgical approaches (Perez & Schwaitzberg 2019).

Finally, an ethical concern about neurosurgical robots is that they are expensive and may be diverting needed resources from other medical areas. Although the use of neurosurgical robots is increasing, this is mainly in wealthier countries that can afford this technology. The exorbitant costs of robotic technology ultimately translate into higher cost burden to patients. For instance, robotic surgery in India can cost twice as much as conventional surgery (Munshi 2019). In other words, neurosurgical robotic technology will remain out of the reach of the global poor for a long time to come.

5. CONCLUSION

Although the use of neurosurgical robots is increasing in several countries, there needs to be more research into their areas of effectiveness and ongoing developments. Second, the nature of such robots demands far more ethical attention, since they are now accessing the human brain/mind. Further advances in neurosurgical robots, such as possible complete automation, will demand a rethink of the robot–surgeon relationship. Additionally, the large hospital investment in neurosurgical robots needs to be transparent regarding robotic limitations and possible risks. It is crucial that ethical guidelines inform the use of medical robots now and in the future. On this point, the COVID-19 pandemic has been instrumental in increasing the use of medical robots in many countries. Consequently, the use of medical robots, such as the CloudMinds humanoid robot in Wuhan which has received global media coverage, has been important in fostering people's trust in AI (Saniotis et al. 2020). Secondly, while some theorists have vented concerns about the anthropomorphization of AI, the COVID-19 crisis has cemented both the utility of medical robots and their various benefits.

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