Social Determinism of the Da Vinci Surgical System

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Joshua Lim

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Joshua Earle, Department of Engineering and Society

Introduction

The stability, precision, and strength of modern machines and robots have long surpassed the capabilities of human hands. Many mechanisms and manufacturing processes that require extreme precision and steadiness are only possible because of the development of this technology. A particular area where precision and steadiness are very important is in surgical applications. Surgery requires a great deal of dexterity, and oftentimes the quality of a surgeon is heavily influenced by their effectiveness with their hands (Luscan et al., 2023). In fact, during surgical residency, dexterity is one of the factors that is assessed and is a key factor in determining training time (Hanrahan et al., 2018). Of course, there is much more to a surgeon than just a good pair of hands. There are qualities such as surgical wisdom, academic knowledge, bedside manner, teamwork, sharp focus, and morality that are also important for a surgeon to have (Luscan et al., 2023). Placing the burdens of physical stress on a robot during surgery may improve surgery success and the quality of life for surgeons themselves.

The Da Vinci robotic surgical system has been the most dominant and successful robotic medical device. It has been widely accepted by the medical community, and is a prime example of the integration of robotics in the medical community (Marchegiani et al., 2023). It is a fairly recent technology; medical robots have only been developed within the last three decades. Amidst the competition of early development, Da Vinci has proven itself and come out on top, and its development and usage is still continued today.

With the increase of robotics in medical settings, what qualities about robotic devices help with their success and acceptance into the medical community? In this paper, I analyze the development, design, and effectiveness of the Da Vinci system to determine what factors affected its acceptance. I apply the theory of social determinism for my analysis of Da Vinci's

development. Social determinism states that technology develops as a response to social needs and pressures (Gil-Garcia J. Ramon et al., 2014). Technology that is deemed unnecessary or does not fulfill social needs will not be developed. The overarching question I am trying to answer is, what technical qualities make a robotic medical device acceptable by both the patient and medical professional communities?

I perform this analysis by taking a look at the history of medical robots. Understanding the development of medical robots and discovering which models were accepted and rejected can also help us answer the overarching question. Additionally, understanding what events influenced robotic medical device development may give us an idea of external factors that could have made the Da Vinci successful.

Once a history is established, I take a look at two of Da Vinci's stakeholders. These stakeholders are the patients and the medical professionals. To analyze the patient, sources that discuss surgery success rates, surgery costs, and overall trust in the system will give us evidence on patient acceptance. Sources that are critical about the use of Da Vinci and discuss the patients' feelings about the implications of being operated on by a robot will be particularly useful. These will help build an understanding of the public's opinion of the rising use of the Da Vinci. To analyze the medical professionals, sources that discuss ease of use, complexity, ergonomics, and learning curve may present factors that cause medical professionals to reject or accept the use of Da Vinci. Analysis of reliability reports and effect on surgery outcomes in conjunction with medical professional reviews will build a case for the medical community's opinion on the use of the Da Vinci.

Initial Motivations for Surgical Robots

The idea of a surgical robot began about 60 years ago. Initially, the idea was envisioned to be used primarily for military usage. Soldiers fighting on the frontlines often got injured and were the most in need of immediate health care. Due to the hostile and dangerous environment of the frontlines, there was often a lack of human and physical resources to help the injured. As such, the presence of an expendable, remotely controlled surgical robot would be the perfect tool for the job. Medical professionals could control the surgical robot and perform procedures on soldiers while safe in the backlines. This would be faster than having to take a soldier to the nearest hospital (Morrell et al., 2021).

These initial ideas for surgical robots were not intended to perform complicated procedures. The leading cause of mortality rate for soldiers was hemorrhagic shock and polytrauma (George et al., 2018). In layman's terms, soldier mortality is usually determined by bleeding out and having multiple wounds that need to be treated at the same time. The surgical robots that would be brought to the front line would only need to stabilize the patient by controlling the hemorrhaging (George et al., 2018).

From the perspective of the surgeons, hand dexterity has been hailed as a universally important trait for a good quality surgeon (Luscan et al., 2023). In fact, even the etymology of the word "surgeon" comes from the Greek word *kheirougia*, which translates to handiwork (Luscan et al., 2023). Although there are many other non-technical qualities such as wisdom and experience that align with the concept of a great surgeon, these are usually gathered over time and are more frequently held by older surgeons (Luscan et al., 2023). But what if the wiser, older surgeon is not physically able to operate? Surgeries can often last hours and require a great deal of mental and physical stamina. As such, it is reasonable to conclude that younger surgeons may generally be better suited to the physical requirements of a surgery.

Robotic assistance may level the playing field by offloading the physical strain to a machine. A surgeon can control the machine remotely, where they can more comfortably view and operate on their patient. More surgeries can be safely performed with minimal invasion since instruments on a machine can move more precisely and are smaller than fingers and hands. Additionally, the use of sterile machinery may reduce the risk of contamination.

This raised many implications about how robots would affect surgery. Would the introduction of robotic assistance redefine what it means to be a surgeon? Could the importance of dexterity decline in favor of wisdom, academic knowledge, and other non-technical skills? Additionally, how would robotic surgery affect costs? How would patients feel about being operated from a distance?

Initial Surgical Robots

The first commercially available development in surgical robotics was produced by a company called Computer Motion. They created the Automated Endoscopic System for Optimal Positioning (AESOP), the first surgical robot to receive FDA clearance in 1994 (George et al., 2018). It was initially designed for laparoscopic surgery; that is, surgery that involves incision in the abdomen or pelvis ("Laparoscopy," 2023). Its development was made to cover two needs: instrument articulation and holding a stable laparoscope that could be controlled by a surgeon (George et al., 2018). Prior to this, an assistant would have to hold the laparoscope, so the surgeon would have to issue commands to the assistant in order to improve vision. The goal of AESOP was to return this control to the surgeon and decrease the number of personnel required for surgery (Pugin et al., 2011). AESOP featured a single robot arm which could mount an endoscope or laparoscope (Pugin et al., 2011). This arm could be controlled by a surgeon via

pedals on a console (Pugin et al., 2011). However, AESOP lacked the capabilities to perform any manipulation of instruments; it was purely a way to improve the use of imaging systems.

The same company which produced AESOP released a new robotic surgical system called ZEUS in 1998. This was the first robot aimed towards improving on surgeon dexterity for minimally invasive procedures (Pugin et al., 2011). Unlike the AESOP, which only had one arm and an imaging system, ZEUS featured control of three robotic arms. Essentially, it was an AESOP system with two additional arms for manipulating other instruments. These two arms had four degrees of freedom each and were controlled via joysticks from a console, and a computer system connecting the console to the arms was capable of filtering out tremors and scaling down movement (Pugin et al., 2011). It also had advanced viewport capabilities, so the surgeon always has a good visual of what the endoscope is seeing. With ZEUS, a surgery could be performed without the surgeon directly handling any tools besides the console. This robot was like a Swiss army knife, and it was used for a wide range of complex operations, such as cardiovascular surgery and gynecologic surgery on top of the previously established laparoscopic surgeries (Pugin et al., 2011). Additionally, this was the first surgical robot that was able to perform long distance surgery. In 2001, A surgeon located in Manhattan, New York, was able to perform a cholecystectomy in Strasbourg, France, without any complications and no technical difficulties (Pugin et al., 2011). This proved that the long distance surgery (i.e. telesurgery) first envisioned for frontline soldiers during wartime was now possible.

The Development of da Vinci

However, another company was also innovating with surgical robots concurrently with Computer Motion. In 1995, Intuitive Surgical was founded in California. Their first iteration of surgical robots was called Lenny (short for Leonardo) (Morrell et al., 2021). Similar to the

ZEUS, it also featured three robot arms: two for holding instruments, and one for imaging. However, it was not approved for use with humans. Intuitive Surgical's second iteration was the MONA. It had all the abilities of ZEUS, but MONA's arms had seven degrees of freedom and a force feedback system, making it far more immersive to use than the ZEUS. MONA also proved its ability to perform telesurgery, and set the stage for the production of the da Vinci in 1998.

The da Vinci improved on the MONA with better ergonomics and software that allowed the surgeon to seamlessly switch between different control modes. Additionally, it beat out its main competitor, ZEUS, in modularity because of the way it was set up. The da Vinci was composed of three separate parts: a patient cart, a surgeon console, and image system. The patient cart held the robot arms and all the instruments necessary for procedures. The surgeon console contained a 3D imaging system and control features for the surgeon. The image system displayed a 2D visual of what was being seen by the surgeon. On the other hand, the main disadvantage of the ZEUS was that its three arms were mounted directly to an operating table, and that its arms only had four degrees of freedom. The da Vinci's seven degrees of freedom were able to fully mimic the movement of a human wrist. Additionally, the da Vinci's patient cart was not fixed to a single operating table, so it could be transported and reused much more easily. In fact, in 2003, Intuitive Surgical and Computer Motion merged into a single company and combined their surgical robot technologies.

The da Vinci proved its effectiveness when surgeons used it to perform procedures with minimal invasiveness. Its first usage was in 1998 at the Leipzig Heart Center in Germany, where surgeons used it to perform a cardiac valve repair and coronary artery bypass with significantly less invasiveness than standard procedures. The da Vinci got FDA approval in 2000, and was officially the first operative surgical robot in the United States.

Intuitive Surgical continued to improve on the Da Vinci's design in order to make it more adaptable. In 2002, an upgraded da Vinci with four total arms was released to accommodate extra instruments that needed to be held or provide another way to hold anatomical structures. Furthermore, in 2006, Intuitive released the da Vinci S, which featured HD imaging systems and touch screen user interfaces. In 2009, another upgrade called the da Vinci Si was released which featured dual console surgery. The primary use of this was to train novice surgeons. Using the second console, novice surgeons could observe and perform tasks under the supervision of the expert surgeon. The da Vinci Si also received upgrades to its imaging system which made minimally invasive procedures easier to perform (Morrell et al., 2021).

The most recent and fully featured da Vinci was released in 2014, and is called the da Vinci Xi. The da Vinci Xi overcame the main limitations of the previous models. With the da Vinci Si and prior, all arms were mounted on a single column and were all parallel to each other. They were cumbersome to work around for surgical assistants, and the robot had to be moved around the patient frequently to get adequate access to parts of the body. This decreased operation time greatly, as the process of undocking, moving, and redocking the robot was very inconvenient and time consuming. The da Vinci Xi redesigned its patient cart, and maximized arm flexibility and mobility by mounting its arms on a structure similar to a boom-arm, so that the base of the arms is directly above the patient and not off to the side. Additionally, its arms were now much more compact and multiple tools can fit in one operating site. This prevents many collisions and requires docking to happen from any angle and only once. However, should the robot need to be repositioned, its docking and undocking process has also been streamlined to make the whole process faster. Additionally, its ergonomics, imaging systems, and interface continue to be improved on (Ngu et al., 2017).

Analysis of Social Determinism in Surgical Robots

The theory of social determinism proposes that the development of technology is the result of social factors (Gil-Garcia J. Ramon et al., 2014). Society's needs and wants are the cause, and the development of certain technologies is an effect (Gil-Garcia J. Ramon et al., 2014). If society finds that it no longer has any need for a certain product or technology, then its development will slow and possibly cease.

Now that I have a good idea of the da Vinci, its history, and its capabilities, I can now analyze its stakeholders and to determine what parts of its development were critical in ensuring its success. The da Vinci has been the most frequently used surgical robot, having performed over 11 million surgeries and having over 7,500 units installed worldwide (Marchegiani et al., 2023). As of now, it is dominating the market and has no serious competition. There are some new platforms being introduced, such as the Versius Minimally Invasive Robot System which was released in 2014 and the Hugo RAS Robotic System released in 2021 (Rivero-Moreno et al., 2023). However, these systems have not gained as much traction as the da Vinci due to being relatively new and having to fight an uphill battle with infrastructure that already benefits setups with the da Vinci.

First, I analyze the experiences that medical professionals have with the da Vinci system. In particular, the analysis focuses on the time during which the ZEUS and the da Vinci existed at the same time, i.e. 1998 to 2003. This is because this is the time frame where robotic surgery had not yet taken hold in the medical community, and the da Vinci system would have had real competition.

Sung and Gill performed a comparison of the performances of a da Vinci and a ZEUS during a urologic laparoscopy on swines. They found that the da Vinci had significantly less total operating time, surgery time, and had a shorter learning curve. With both robots, surgery was successful in all cases and blood loss was not significantly different (Sung & Gill, 2001). As such, robotic surgery had proven itself to be very effective at what it was made to do. Data showed that it shortened hospital stays, reduced blood loss, transfusion rates, and postoperative complications. This aligns with the main goal of providing a method of surgery that is minimally invasive. However, its main disadvantage was that it usually took longer to do than open surgery (Ho et al., 2011).

However, at the time of release, ZEUS had a lower cost than the da Vinci, primarily because the technology used in the da Vinci was more advanced and adaptable to different operations (Rivero-Moreno et al., 2023). Each of the da Vinci systems cost around 2 million dollars (Leung & Vyas, 2014). On the other hand, the ZEUS systems were marketed for $795,000 (“Minimal Access Robotic Surgery,” n.d.). At under half the price, the ZEUS was performing comparably with the da Vinci. To quantify, based on the swine operations that both systems were tested on, the ZEUS had a total operation time of 83.4 minutes on average, while the da Vinci had a total operation time of 61.4 minutes on average. As such, the ZEUS operations took 35.8% longer than the da Vinci operations. While this is only a 22 minute difference, it is unclear whether this 22 minute difference would increase or stay the same with longer operations.

It was clear that the medical community chose to use the da Vinci over the ZEUS, despite this large cost difference. By 2001, Intuitive Surgical managed to have over 100 da Vinci’s installed in hospitals around the world and even more were being shipped (“Intuitive Surgical

and Computer Motion Announce Merger Agreement," 2003). On the other hand, ZEUS never gained anywhere near that much traction and was only used in 12 centers around the world (University of PIttsburgh Medical Center, 2001). This is a prime example of social determinism, as the needs of the medical community had a strong influence on the development and design priorities of robotic surgery. Since both robots exhibited equal efficacy when it came to performing surgeries, the medical community chose the option with better nice-to-have features, such as more immersivity, decreased surgery time, ease of learning, and ease of use for the surgeon over qualities such as cost. This is further exhibited by the future iterations of the da Vinci being focused around decreasing surgery time with the Xi model's new structure and minimizing the required number of personnel with the added fourth arm in the S model and onwards. These features were prioritized over improvements in cost-effectiveness, since medical professionals appear to care more about having the best equipment to save lives in the most effective and efficient way possible.

However, this brings us to our second stakeholder: the patients. Although the medical community may not value cost as much, the patients certainly will, since they are the one paying for the operation. I investigate two things: how robots affect the cost of surgery, how willing patients are to pay for the extra cost, and how trusting the patient is of surgery. In other words, given the choice between robot-assisted surgery and open surgery, what would the patient choose and why?

In 2023, Ng et al. gathered data from over a million patients showed that on average, robotic-assisted laparoscopic surgery cost about 18.3 thousand dollars, while typical open surgery cost about 16 thousand dollars. Even for procedures that were not laparoscopic, robot assisted surgery had a higher cost. The data also showed trends that the difference in cost was

increasing over time, as in 2012 the cost disparity was 1.6 thousand dollars while in 2019 the disparity was 2.6 thousand. Furthermore, this study also showed that robotic surgery only decreased complication rate by 2.2% and hospital stay duration by 0.7 days (Ng et al., 2023). Wilensky wrote an article in 2016 that criticized the use of robot-assisted surgery, claiming that the increased costs are not justified for all types of surgery. For example, Wilensky argues that for gynecologic operations, the robot-assisted surgery was no more effective than open surgery, but costs $2000 more. Furthermore, there is a lack of evidence that robot-assisted surgery will become more cost-effective over time, so there is controversy around whether this technology is worth supporting from a patient standpoint (Wilensky, 2016). The conclusion of the article is that robot-assisted surgery should only be used in certain types of operations where it has been shown to be significantly more effective. In the future, if this cost disparity becomes too large, the influence of the patients as a stakeholder in the use of da Vinci may be strong enough to warrant investment in cost-saving features.

In terms of overall trust in robot-assisted surgery, Torrent-Sellens et al. conducted a survey in Europe concluded that the only two factors which indicated trust towards robot-assisted surgery was having previous experience with robot use and having a preconceived notion about the ease of use of robots. All other variables that the study tested, such as attitude towards robots, perception of robots, and information about robots, all showed a general trend of mistrust and negative perception towards robot-assisted surgery (Torrent-Sellens et al., 2021). There are many criticisms of the use of robot-assisted surgery from the patient side. Higher costs and general mistrust for the technology have caused controversy that questions whether the technology is worth developing.

With this evidence, I can characterize the qualities that each stakeholder values when it comes to new technology. The medical community tends to look for performance features. They value improvements in qualities such as efficiency, ease of use, ease of learning, and effectiveness compared to previous methods. On the other hand, patients tend to highly value cost. It is important to them that whatever new medical technology is used should be enough of an improvement that it warrants the extra cost; if it is not, then it should either not be used or should not cost more. Additionally, preconceived notions and prior experience towards robotic technology and general helps build trust with patients and can build a positive perception with robot-assisted surgery.

The priorities of these stakeholders demonstrate the social determinism involved in robotic surgery. Robotic surgery is still a relatively new technology as it is barely three decades old. Much of its early development has been determined by the needs and preferences of the medical community. However, the development of robotic surgery may become more influenced by the needs of the patient in the near future. If the distrust and controversy behind the costs of robotic surgery continue to fester, then the demand for robotic surgery will decline. This will force the hand of the developers to invest in other features for robotic surgery which may not have been as strongly considered by the medical community. If not, robotic surgery will either die or find another purpose.

Conclusion

Robot-assisted surgery was a technology meant to be pursued for wartime applications. However, this initial motivation was eventually replaced by the need for more minimally invasive and safer surgery. It began with the PUMA, and then the AESOP, then the ZEUS, and finally the da Vinci. While the technology has proven itself to be capable of performing long

distance surgery as intended b the military, these surgery robots have found more applications within hospitals and improving the quality of surgical procedures for both the patient and surgeon. In particular, the da Vinci has managed to be the most successful and widely used surgical robot in modern times.

I analyzed two stakeholders to determine what it was that made the da Vinci so successful: the medical community who uses the da Vinci, and the patient who is operated on by the da Vinci. I found that the medical community found value in da Vinci's features which improved operating table efficiency and performance compared to other alternatives for surgical robots. On the other hand, patients are unhappy with the increased costs associated with the use of robots in surgery and tend to experience distrust towards such robots.

I argue that when it comes to medical devices, efficacy and cost effectiveness are the two most important factors when designing a new product or technology. With current trends, it is clear that the development of surgical robots are moving in the direction of performance improvements rather than cost effectiveness. The increasing price disparity between typical open surgery and robot-assisted surgery has caused patients to be increrasingly uncomfortable with choosing robotic assisted surgery. This is further exacerbated by evidence showing that the benefits of robot-assisted surgery are only significant for specific types of procedures. Finding a balance between these two qualities will be the best way to achieve a positive response with the product's audience.

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