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Team 31

THE DA VINCI SURGICAL SYSTEM: A MODERN ALTERNATIVE TO TRADITIONAL PANCREATIC CANCER TREATMENTS

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Abstract*—Tumor removal surgeries can be absolutely devastating for cancer patients. Many cancer patients have extended recovery times, increased risk of infection due to fatigue, and a weakened immune system. Fortunately, modern engineering technology has paved the way for increased surgical precision through computer assisted surgical devices such as Intuitive Surgical Incorporated's da Vinci Surgical System. The device was designed to create a surgeon-controlled, minimally invasive procedure that gives the surgeon the ideal stable hand for the most precise incisions and maneuvers within the body.*

Tumor removal is an integral purpose for the da Vinci System. This paper will research the viability, efficiency, and safety of treating pancreatic cancers with a da Vinci Surgical System procedure. The two main surgeries to remove pancreatic tumors are a pancreatectomy and a pancreatoduodenectomy. Pancreatoduodenectomies (Whipple procedure) remove the tumor from the head of the pancreas, whereas pancreatectomies remove the pancreas.

When examining the effectiveness and safety of the da Vinci System in the removal of cancerous tumors in the pancreas, this paper will explore important safety statistics such as, but not limited to: blood loss, rate of complication, and time spent in the hospital. To further analyze effectiveness, the social (quality of life) and economic (cost efficiency) sustainability of the da Vinci System must also be examined through a multitude of statistics. The da Vinci System has begun and will continue to revolutionize surgery, which will improve the quality of life for cancer patients everywhere.

Key Words—da Vinci System, Pancreatectomy, Pancreatic cancer, Pancreatoduodenectomy, Robotic Surgery

WHAT IS ROBOTIC SURGERY?

Robotic surgery is just what it seems—surgery that involves an engineered robotic system. However, a common misconception is that the surgery is performed by the robot. Robotic surgery is how it is referenced, but the procedures are truly robotic-assisted surgeries; the surgeon performs the procedure by controlling the robot. The Mayo Clinic describes the robot as an advanced surgical tool that allows the surgeon to perform many complex procedures with increased precision, flexibility, and control [1]. According to Nanalyze's financial review, three of the biggest companies in robotic surgery are Mazor Robotics, Intuitive Surgical, and Medrobotics [2]. Nanalyze further explains that Mazor has focused its technologies on surgeries of the spinal region, Intuitive focuses on gastrointestinal procedures, and Medrobotics is the robotic leader in ear, nose, and throat procedures; however, all three are used for the same overarching purpose—increased surgical skills within their areas of usage [2].

This paper will focus on Intuitive Surgical's da Vinci Surgical System (DVSS) and, in particular, will look into the use of the DVSS as a treatment option for cancerous tumors within the pancreas. The DVSS is a minimally invasive robotic surgery device designed for increased surgical precision and optimal results. While the DVSS has enabled increased precision and positive results, its sustainability has brought into question whether robotic surgery is the next step for surgery. This paper will present findings on the safety, practicality, sustainability, and the significance of using the da Vinci Surgical System compared to a traditional open surgery to remove the tumors. We will explore if the da Vinci Surgical System has the ability to consistently save the lives of pancreatic patients, or if it adds an additional safety risk in an already dangerous procedure.

WHAT IS THE DA VINCI SURGICAL SYSTEM?

The da Vinci Surgical System is Intuitive Surgical's most well-known device. In 2000, the DVSS became the first FDA approved laparoscopic robotic surgical platform and has managed to remain the most common and well-known robotic-assisted surgery method [3]. UC Health describes the DVSS as a robotic-assisted surgical system that gives

surgeons the ability to be able to "perform complex minimally invasive surgical procedures with precision and accuracy" [3]. As explained by New York University's (NYU) Medical Center, the da Vinci Surgical System is a complex, multifaceted device that consists of two separate master devices as well as visual and movement aids within each master control and throughout the operating room (OR) [4]. Whilst Figure 1, from Unity Point Health, shows that the DVSS has the surgeon off patient, the overall staffing of the OR remains the same: a surgeon, physician assistant, nurse, and anesthesiologist [5].

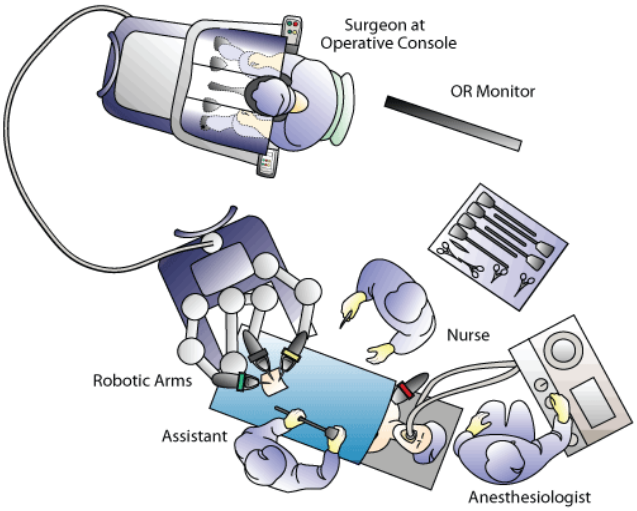

FIGURE 1 [5]
Overhead view of the OR for a da Vinci System surgery

The Console

Depicted in Figure 1, the surgeon is positioned at one of the master devices, traditionally referred to by NYU Med as the operative console [4]. As Figure 2 shows, the console consists of two handheld controls that provide "fingertip precision of movement," a footswitch that can redirect energy supplies within the OR, touchpads that can adjust visual and audio settings of the console, and a "stereoscopic monitor that provides a magnified, high definition 3-D view of the surgical site" [4], [6]. The monitor is within the console and provides the surgeon with a constant view of the surgical site, allowing the surgeon to watch exactly what he or she is doing while he or she is doing it—not looking away from his/her hands to watch a bedside monitor like traditional laparoscopic surgeries [3]. The surgeon places their head into the padded monitor as if he/she was wearing a helmet with maximum, customizable comfort. The two handheld controls are positioned directly below the monitor, where the surgeon can rest his/her arms on an ergonomically engineered padded armbar that is designed to keep the surgeon in a "relaxed and focused position at all times" [4]. The surgeon held devices consist of rings for the surgeon to insert his/her fingers into. Roswell Park Cancer Center describes how each ring allows the surgeon to control a very specific portions of the robotic arms (shown in Figure 3) [7], [8]. UC Health highlights how the design of the console gives the surgeon optimal comfort, and the controls give him/her the dexterity and precision to execute 1-2 cm incisions [3].

FIGURE 2 [6]
Visual of the DVSS's operative console

The Tower

The other master device is the robot itself. This device is referred to as the tower and is positioned directly over the patient during surgery [4]. The tower is what the surgeon controls and is what maneuvers within the patient to perform the surgery. It consists of four robotic arms that all mimic the exact motions of the operating surgeon at the console; three of the four arms can hold "a multitude of different surgical instruments" while the fourth arm is equipped with the 3-D camera that displays the image to the console's monitor [4]. Unity Point Health continues to explain that the attachable surgical instruments, shown in Figure 4, are "dime sized" and enter the body through incisions of equivalent sizes [5], [9]. A study published in the Journal of Hepato-Biliary-Pancreatic Science details that a typical da Vinci System surgery consists of five of such incisions (Figure 8) [10].

The arms may be the most intricate aspect of the da Vinci Surgical System. Just like a human arm, they have elbows and wrists; however, both have a range of motion much greater than the human surgeon [7]. The wrists are an Intuitive Surgical patented device—EndoWrists [3]. The EndoWrists bend in all directions similar to, but farther than, a human wrist and are able to do this within the patient's body [7]. As shown in Figure 4, these wrists are applied to the arms right where the attachable instruments connect for optimal precision [9]. Also equipped within the fourth arm of the DVSS is the high-performance vision system—the laparoscope [7]. The cameras that make up the DVSS's laparoscope are equipped with 3-D lenses that are able to

provide the surgeon with ten times magnification of the surgical field and are controlled by the foot pedals of the operative console, which adjust the focus and can reposition each camera [7]. The 3-D visual is displayed within the console's monitor as well as on the main OR monitor (Figure 1) [5]. These displays give the surgeon and the rest of the OR staff an advantage in maneuvers within the body as well as an increased ability to recognize internal issues before complications arise [7].

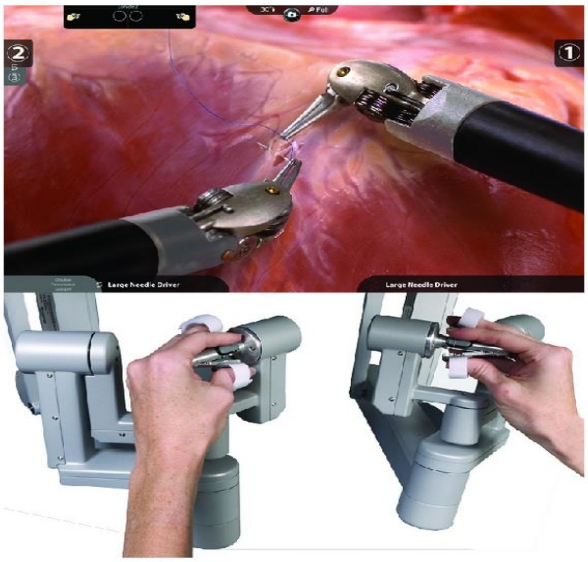

FIGURE 3 [8]
Representation of the ring-shaped finger controls of the console maneuvering the attachments on the robotic arms

FIGURE 4 [9]
Assortment of attachable devices onto the DVSS's Endowrists

Da Vinci Surgical System by the Numbers

The da Vinci Surgical System has been making new innovations in the field of robotic surgery since its debut in 2000. There are currently over 1,700 DVSS installed worldwide and are more than 775,000 DVSS surgeries performed annually [3]. It has statistically become the preferred method of prostate cancer treatment as well as hysterectomies [3]. In addition to prostate cancer, every gynecologic oncology fellowship program in the United States incorporates the da Vinci Surgical System [3]. Because the DVSS is becoming increasingly popular for cancerous tumor removal surgeries, we researched whether pancreatic cancer can become the next oncological specialty for the da Vinci Surgical System to revolutionize.

PANCREATIC CANCER: TREATMENTS

The da Vinci System is able to assist the surgeons with many different surgeries, including the removal of pancreatic tumors. University of Wisconsin Health (UW) lists that the two major types of pancreatic tumor removal procedures are pancreatectomies and pancreatoduodenectomies [11]. UW declares if the cancer has not spread throughout the pancreas, a surgeon would prefer to perform a pancreatoduodenectomy to remove the tumor(s) [11]. This surgery is commonly known as the Whipple procedure and its goal is to remove the duodenum, the head of the pancreas [11]. On the other hand, if the cancer has spread throughout the pancreas, the surgeon would resort to a pancreatectomy, which removes the entire pancreas [11]. Both procedures are complex and require surgeons with years of experience in the field.

The Whipple Procedure

The Whipple procedure, performed strictly by a surgeon or with the assistance of a da Vinci System, involves the same steps; however, the da Vinci System enables better precision and is less invasive to the patient [11]. In a description of the Whipple procedure from the American Cancer Society, a traditional pancreatoduodenectomy requires one large incision down the middle of the abdomen, as well as multiple small incisions on the side [12]. Moffitt Cancer Center follows up by declaring, once the incision is made, the surgeon will carefully remove the head of the pancreas, and in some cases, the neck of the pancreas and nearby organs will be removed if the cancer has affected them [13]. The organs that could be removed include the gallbladder, bile duct, and the small intestine [13].

The major difference between the surgery being performed by a surgeon or with the assistance of the da Vinci System is that the da Vinci System allows the surgeon to perform the surgery through only five quarter sized incisions [10]. By minimizing the size of the incisions, the DVSS displays social sustainability through improving quality of life after surgery. Social sustainability is the overall impact of a new innovation on people.

The American Cancer Society warns the pancreatoduodenectomy is a highly complex procedure and requires a doctor with experience [12]. When the procedure is performed by a surgeon in a smaller hospital, or with less experience, 15% of patients die from complications; however, the casualty rate is reduced to less than 5% when the surgery

is performed in cancer centers by experienced surgeons with top-notch technology [12]. It is important to note that no matter how the procedure is performed, there are still many complications that could arise. Possible complications include the following: infections, bleeding, weight loss, change in bowel habits, diabetes, and the leaking of organs due to loose stitches after reconnection of the organs [12]. All in all, the Whipple procedure is extremely complex and has many opportunities for complications to arise, which can be minimized by the da Vinci System.

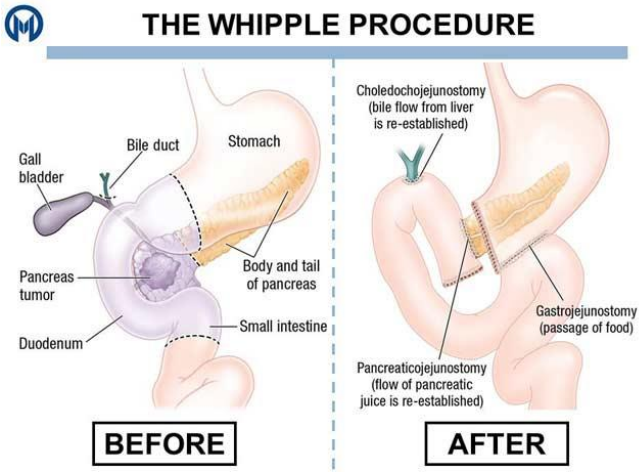

FIGURE 5 [13]
Before and after of one's pancreatic region for a pancreatoduodenectomy

Pancreatectomies

In comparison to the Whipple procedure, pancreatectomies are a simpler procedure performed less frequently due to there being considerably more side effects. The pancreatectomy procedure performed by the Medical University of South Carolina (similar to all pancreatectomies nationally) involves the end of the stomach becoming detached [14]. Then, the pancreas is removed along with a portion of the small intestine to which the pancreas is attached [14]. The gallbladder and spleen are also removed because they are connected to the pancreas [14]. To complete the procedure, the intestinal tract, stomach, and bile duct are reattached to the small intestine [14].

Like the Whipple procedure, the only difference in the procedure performed by hand or with the assistance of the da Vinci System is that the DVSS offers the surgeon more precision and uses less incisions [8]. A pancreatectomy does not come with a higher complication rate than the Whipple procedure; however, a complete removal of the pancreas will result in the patient displaying diabetic symptoms for the remainder of his/her life [12]. Without the pancreas, the body will be unable to break down glucose within the patient's bloodstream; this will cause the patient to become insulin dependent and be forced with taking insulin shots for the rest of his/her life [12]. Both procedures to remove pancreatic tumors are dangerous and complicated, and the da Vinci System enables more precision and less invasion compared to a surgeon alone.

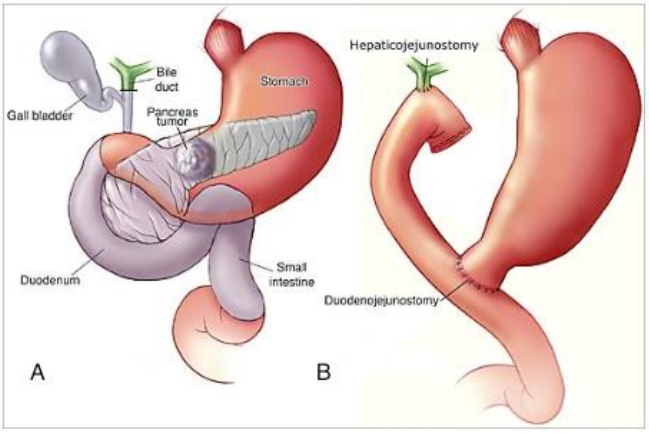

FIGURE 6 [15]
Shows the before (A) and after (B) of one's pancreatic region for a pancreatectomy

DA VINCI SYSTEM: SURGICAL ADVANTAGES

The da Vinci Surgical System has many advantages over traditional surgeries for pancreatic cancer. First, a study in journal of Oral Oncology describes how the DVSS provides a three-dimensional view of the patient that has different magnification settings [16]. This gives the surgeon a comprehensive view of the patient and lets him or her see closer up than he or she could when performing surgery without robotic assistance. The system also has three different arms for holding different instruments [16]. Since an unassisted surgeon can only hold two instruments at once, the da Vinci System offers a huge advantage allowing the surgeon to swiftly switch between more than two instruments. These instruments also have the same seven degrees of freedom of movement that a human hand possesses [16]. Because of this, there is no loss of freedom by using da Vinci over traditional surgery.

Most importantly, the device allows motion scaling of the surgeon's movement up to five times smaller than by hand [16]. This means that the surgeon can instantly change how precise his or her movements are and can reach incredible levels of precision that are not possible for an unassisted human. All of these advantages add up to create an incredibly precise system that lead to smaller incisions and very precise movement. These advantages can make surgeries much safer and easier for both the patient and surgeon. This increase in safety has led to real life improvements to patients of surgeries for both pancreatectomies and pancreatoduodenectomies.

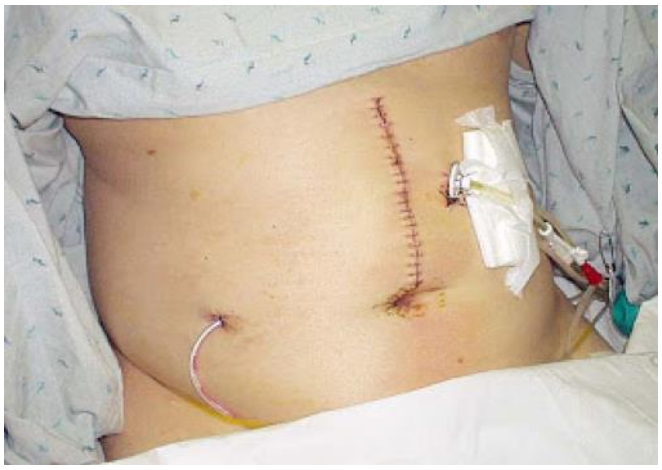

FIGURE 7 [17]
Incisions for a traditional pancreatic surgery

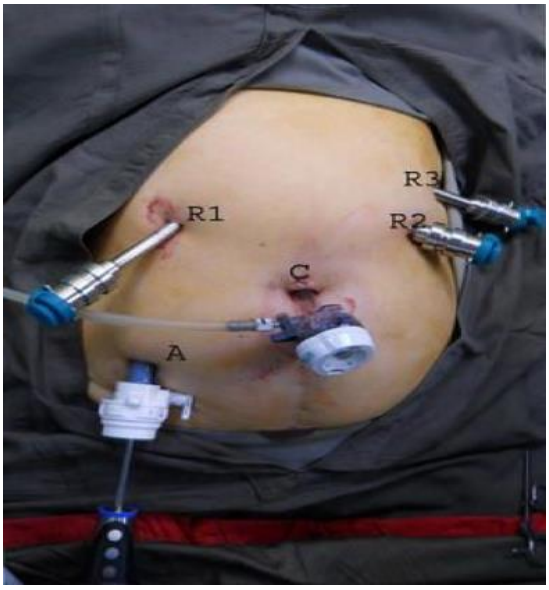

FIGURE 8 [10]
Incisions for a da Vinci System pancreatic procedure

Pancreatectomy Advantages

The da Vinci Surgical System has been shown to improve the results of pancreatectomies. A study performed at Yonsei University in Korea tested the benefits of the DVSS. The study stated that one of the biggest problems when it comes to pancreatectomies is that during the removal of the pancreas, it is difficult to preserve the spleen [18]. The Korean study discovered that during traditional pancreatectomies, the spleen is only preserved 40-80% of the time [18]. The spleen, while not essential for human life, helps decrease the risk of infections throughout a person's life. For those who have cancer, the spleen being damaged up to 60% of the time can cause a plethora of unneeded problems that can further reduce quality of life and life expectancy [18]. Surgeries using the da Vinci System, however, have a much better success rate; the spleen preservation rate observed with da Vinci surgery was a staggering 95% [18]. That is an almost 50% improvement on the average preservation rate obtained during traditional surgeries. This dramatic increase is most likely attributed to the increased precision that the da Vinci System offers. This data had a p value of 0.027, which supports the idea that the change is statistically significant [18]. By preserving the spleen at a greater rate, the da Vinci System shows a high social sustainability for pancreatectomies. Improving people's lives, like the da Vinci System has shown, is a characteristic of positive social sustainability.

Another problem with surgeries in general is complications after surgery and the need for a second operation to fix a problem. Pancreatectomies are not immune to such problems. Both of the listed problems were improved upon by using the da Vinci System for pancreatectomies. Complications after surgery can make patients' lives significantly worse; they can cause major problems to the patients that can last a lifetime. A Beijing study, published in the Annals of Surgical Oncology, combined the data from several previously conducted, peer edited studies from across the world; they deduced that the complication rate during traditional pancreatectomy procedures ranged from 18-75% [19]. With up to a 75% complication rate, traditional surgery creates complications for a lot of patients. This is significantly decreased by using the da Vinci System. The complication rate in the same conglomeration of studies was 1-36.4% [19]. With such a lower rate, the da Vinci System has assisted saved many patients from having to deal with complications after they had their surgery, which is another example of this device showing high social sustainability.

A further problem with pancreatectomies is the reoperation rate. This is costly to patients, both in money and health. The same Beijing study showed that compared to a traditional pancreatectomy, the da Vinci Surgical System had a reoperation risk difference of -12% [19]. This means there is a 12% lower risk of having to call a patient back in for a second operation when performing the procedure with the da Vinci Surgical System. This is not as big of a change as some of the other improvements that the da Vinci System has made, but it still has helped many patients from having to undergo the risks of a second surgery. Overall, the da Vinci System improves the results of the pancreatectomy procedure as well as the quality of life of the patients.

Pancreatoduodenectomy Advantages

In addition to pancreatectomies, pancreatoduodenectomies (PD) have also been made safer by the da Vinci Surgical System. The PD, or removal of the head of the pancreas, can lead to many problems just like any other surgery. These problems include, but are not limited to, blood loss during surgery, subsequent hospital stay, and complication rate after surgery; all of these problems are lessened when surgeons use the da Vinci System. First, the blood loss during surgery is much less when using the da

Vinci System over traditional surgery. Blood loss can be especially bad for patients who have rare blood types. These types might not be immediately available for use which can cause delays to the surgery and increase many other risks. The less blood loss can mitigate these risks by requiring less blood for transfusion. In an International Journal of Medical Robotics and Computer Assisted Surgery study on PDs, surgeries with the da Vinci System result in 30% less blood loss than the by hand equivalent surgery [20]. This decrease in blood loss makes PDs safer for the patient. Another problem with PDs is the subsequent hospital stay after the surgery. While this problem is not medically problematic, it still has a negative impact on the patient. The longer the hospital stay the higher the bill. Plus, one could be doing other activities if they did not have to be in the hospital for so long. On average the hospital stay is 50% longer for patients of traditional surgery than those who underwent a DVSS procedure [20]. The decrease in hospital stay from the da Vinci System can get people back on their feet and back to their regular routine much quicker.

Perhaps the most important problem from pancreatoduodenectomies is the complications from surgery. Just like pancreatectomies, these complications can be devastating for patients' health. The postoperative complication rate is about 50% lower for patients of the da Vinci System [20]. The most harmful of problem from PDs is halved when surgeons use the da Vinci System. This statistic alone can give patients a peace of mind entering a very dangerous and risk filled surgery.

The da Vinci Surgical System overall has been shown to improve the lives of pancreatic cancer patients undergoing both pancreatectomies and pancreatoduodenectomies. This improvement of the lives of cancer patients shows a positive impact on people. The positive impact supports that the da Vinci System has high social sustainability.

DA VINCI SYSTEM: HURDLES

Economic Sustainability

Even though the da Vinci Surgical System has led to surgical patients having a better quality of life, it has struggled to become an overall replacement to traditional surgeries. One factor that has contributed to its struggles is the lack of economic sustainability. Economic sustainability is the ability for a product to be economically feasible for both producers and consumers. A Health Line report on the economic feasibility of the DVSS lists the cost of a single DVSS robot at approximately two million dollars, as well as multiple hundreds of thousands in additional attachments [21]. While many large hospitals have no issue paying two million dollars for this equipment, smaller practices cannot afford this equipment. This has led to an underwhelming production since the da Vinci system was released in 2000. Overall, there are just over 1,700 da Vinci systems installed in hospitals around the world [3]. This level of production hints that this system has been economically unsustainable in its current form.

Paralleling the unsustainability of the cost for the hospitals, a DVSS surgery costs an average of three to six thousand dollars more than its traditional counterpart [21]. Many patients are not able to overcome the increased price for a less invasive and more precise procedure, and therefore the machine is not economically sustainable for some consumers of the device. The fact that not all people have access to this machine also plays a role in social sustainability. This lack of access to a potentially lifesaving machine means the da Vinci System, because of its economic unsustainability, fails to increase the quality of life for some of the people who need it. The lack of economic sustainability has hindered the da Vinci System's progress towards replacing traditional surgery. In addition to the price, learning something as detailed and revolutionary as robotic surgery takes a significant amount of time for surgeons, requiring them to take additional time out of their personal lives.

Training

The time commitment and training needed for a surgeon to be comfortable operating a DVSS is another hurdle for the growth of the device. For example, Doctor Kevin Roggin from the University of Chicago School of Medicine is one of many doctors that made the switch to performing the Whipple procedure with the da Vinci system [22]. Learning the new system took hours of extensive training and analysis. Doctor Roggin explains his training began at a medical center where he spent over 100 hours learning the basics of the equipment [22]. After learning the basics and practicing on simulations, he was able to be certified by Intuitive Surgical. Even once certified, his training did not end there [22]. He traveled to the University of Pittsburgh Medical Center (UPMC) to watch known experts perform the Whipple procedure with the da Vinci System [22]. He ended his training by being videotaped while performing 20 da Vinci pancreatoduodenectomies on life-like models; from these videotaped training he was able to analyze his technique and receive feedback from UPMC experts [22]. After all his extra training, Dr. Roggin was ready to perform the surgeries with the da Vinci System back in Chicago [22]. Dr. Roggin's training is typical of that required for a surgeon to become an expert at controlling the DVSS; a survey of da Vinci certified surgeons showed that on average it takes 80 practice procedures to become confident behind the console [22]. With surgeons already spending years in residency, the extensive training the da Vinci system requires makes it difficult to easily migrate into modern day surgery. It also brings up a minor negative social sustainability for the surgeon; the additional time out of the surgeon's daily life. The lengthy training comes with a learning curve and a hefty price for the experience and still does not leave surgeons and the da Vinci system immune to mistakes.

Legal Issues

The last main barrier the da Vinci system has struggled to overcome has been lawsuits. The Drug Dangers database lists that there have been over 10,000 reported "injuries or adverse events associated with da Vinci" from 2000-2013 [23]. Of these reports, over 8000 of them were from the robot malfunctioning, 1300 were injuries and, 144 were deaths associated with the device [23]. The most common injuries from the robot include the following: organ burns, tears in organs, punctured ureters, and bowel injuries [23]. While this large of a number may be alarming, over 1.5 million surgeries were performed with the DVSS during this time—representing a 0.67% chance at a mishap, which is very low for surgery [23]. Despite this less than one percent mishap rate, Intuitive has paid over 97 million dollars in lawsuit settlements from these damages, significantly damaging the da Vinci System's integrity and opportunity to revolutionize surgical methods [23].

In most cases, the injuries resulting in settlements have come from lack of training or device malfunction. For example, the da Vinci EndoWrist Monopolar Curved scissors attachment had to be recalled because it developed small cracks that allowed electricity to flow and resulted in internal burns on patients [23]. Besides lawsuits attributed to this recall, the number of lawsuits seems to be high due to the fact that it is an unorthodox method; as in, people are more apt to attribute an error in a difficult surgery to the robot when it could simply be a result of malpractice on the surgeon themselves or an unavoidable complication. For example, in one lawsuit that went to court, a patient that had a prostatectomy died from complications after the surgery [23]. The trial was ruled in favor of Intuitive because the surgeon ignored guidelines regarding some of the patient's health concerns [23]. This confirms that the lawsuit totals of over 10,000 were not all genuinely due to errors in the DVSS. Unfortunately, with the number of lawsuits Intuitive has faced, it has been hard for the company to establish the DVSS as a sustainable surgical device.

While the high payouts (nearly 100 million dollars) may raise a red flag, it is important to remember medical lawsuits almost always end in high payouts, and it is much harder to defend an issue when the robot is involved—if the error occurred due to malpractice a surgeon would be quick to let the machine take the fall over themselves. Surgeries always come with a risk and patients/families seem to better understand errors made by surgeons without the assistance of technology because they understand humans are not perfect. People know the surgeon is doing his/her best job to make everything go smoothly—that is just human nature—but they are less inclined to experience such empathy for a machine. While some of the complications listed above have come as a direct result of the da Vinci System malfunctioning, there is nothing to support that the technology is any riskier than traditional surgery methods.

POTENTIAL ALTERNATIVE?

While the paper has focused on the practicality of using the da Vinci Surgical System as a replacement for traditional pancreatic cancer procedures, this section will put the da Vinci's technologies up against other leading robotic surgery devices. We exaimened how Intuitive's da Vinci Surgical System stacks up against Mazor Robotics' Mazor X and Medrobotics' FLEX Robotic System in surgical areas such as control, mobility, vision, flexibility, and haptic feedback. As well as device technologies, the consistency of the companies were also evaluated for reliability and safety purposes.

The Companies Behind the Products

From a production standpoint, Intuitive and the DVSS is the model company for laparoscopic robotic surgical devices. The da Vinci System was the first FDA approved device of its kind in 2000 [3]. It remained the only attention-grabbing device in the field of robotic surgery until 2004 when Mazor Robotics' also received FDA approval, followed by Medrobotics in 2005 [2]. Nanalyze's review shows that Medrobotics only managed to break into the mainstream within the past five years [2]. Additionally, despite reaching the milestone of becoming a 60-billion-dollar company through its now 19 years of production, Intuitive and the DVSS have had drastic positive surges of their stocks in the most recent two years; with jumps from just over 100% dividends at the beginning of 2017 all the way up to 386% at the mid-point of 2018 [2]. Mazor also followed the trend in the stock market, reaching returns of over 350% this past year [2]. As stated above, Intuitive has incurred 60 billion dollars in revenue, Mazor boasts a market cap of 1.65 billion, and Medrobotics sits at 181 million [2].

From an output standpoint, the da Vinci Surgical System towers in comparison to the Mazor X and the FLEX Robotic System. As of the 2018 mid-year report, the da Vinci Surgical System has been used in more than five million procedures worldwide while the Mazor X has only preformed 30,000 procedures and 200,000 implants and the FLEX Robotic System has an undocumented total (believed to be much lower due to the profit values) [2].

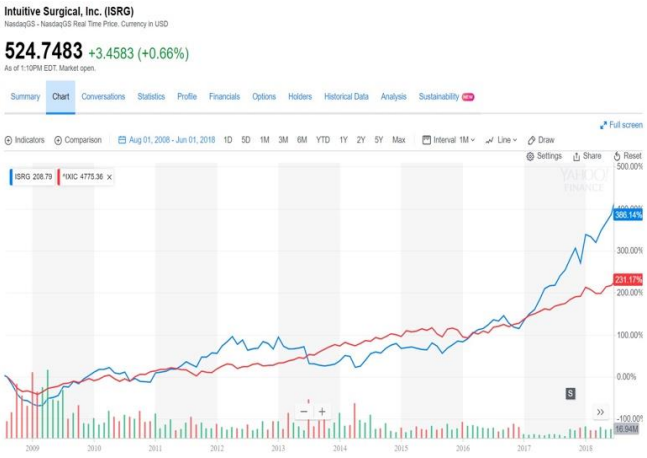

FIGURE 9 [2]
Snapshot of Intuitive Surgical's Stock

	Da Vinci Surgical System (Intuitive Surgical Inc)	FLEX Robotic System (Medrobotics Inc)
Master-slave control system	++	–
Mobile	+++	++
3D HD stereoscopic vision	+++	++
Haptic Feedback	–	++
Flexible	–	+++

Key: - represents standard condition
+ represents each stage of an advancement

FIGURE 10 [16]
Side by side comparison of DVSS and FLEX Robotic System

Surgical Performance

To avoid all chances of company names and past success causing a bias for present times, the technology of each company's device was also evaluated. From the company and revenue statistics, it would appear that Mazor X is the DVSS's biggest competition. However, both companies' stocks are rising; one's rise is not causing a fall in the other's stock. This can be attributed to the fact that the Mazor X has become almost exclusively used for spinal surgeries, an area that the da Vinci System does not tend to service [2]. With that being said, the Mazor X can be ruled out as an alternative option for pancreatic tumor removals.

While the FLEX Robotic System is primarily used for ear nose and throat procedures, Medrobotics has just been approved to use the FLEX for "scar-free colorectal surgeries" [2]. Colorectal surgeries fall under the large category of gastrointestinal surgeries with pancreatic procedures, which the da Vinci System Specializes in.

Figure 10 displays some of the results of a study, published in Oral Oncology, that focused on the comparison of the two systems (DVSS and FLEX) [16]. The results display an even distribution of advantages within the OR for each system. The da Vinci System was shown to provide better control/precision, provide a better visual of the operation site, and provide the surgeon with more mobility during the procedure [16]. On the other hand, FLEX displayed a much wider range of motion within its device (more flexibility than the EndoWrists) and provided the surgeon with better haptic feedback (touch sensitivity) [16].

These statistics suggest the FLEX is able to carefully maneuver a larger area within the patient and provide the surgeon with a better sense of pressure on the patient, allowing him/her to implement an increased degree of gentleness. However, the superior vison of the da Vinci's laparoscope allows the surgeon and staff to easily identify what is fat/muscle/tissue as well as more readily discover issues such as bleeding [7]. Additionally, the four arms of the DVSS, as well as advanced controls, give the surgeons increased control over what is being done and can do more at one time (multiple arms) [16].

IS DA VINCI THE BEST OPTION AVAILABLE?

Is da Vinci the Superior Robot?

The da Vinci Surgical System was not only the first of its kind, but it remains the most popular robotic assisted surgery device to this day. Performing over three times more surgeries per year (approximately 775,000) than the next most popular device (Mazor X) has performed in its 15-year existence (approximately 250,000), it is clear that the DVSS

is the preferred method of robotic assisted treatment by both professionals and patients [2],[3].

From a gastrointestinal procedure standpoint only, the DVSS remains the superior device. While the FLEX System has recently made technological advancements that outperform some aspects of the da Vinci System, wholistic aspects of the device, such as control, still lag behind [16]. However, the in depth procedural and comparative statistics of safety and results have not yet been thoroughly reported on due to recency.

With technological advancements and the statistics yet to be posted, it is possible for FLEX to become a better option than the da Vinci in the future; however, as of right now, the DVSS has proven itself as the superior robotic assisted surgery device.

Is da Vinci the Superior Method of Treatment?

The da Vinci Surgical System has proven itself among the robotic community, but we still must explore if it offers more benefits than a traditional pancreatectomy or pancreatoduodenectomy. The DVSS offers a postoperative quality of life that was previously impossible. It gives the surgeon up to five times more precision than the human hand, which has resulted in a 50% increase in the preservation of neighboring organs, such as the spleen [16], [18]. Spleen preservation has been proven to decrease risk of infection which could be life threatening to cancer patients who have a compromised immune system [18]. As well as organ preservation, the increased precision has led to a 12% lower reoperation rate and up to 75% less complication rate among these pancreatic procedures [19]. Finally, the precision has also led to a 30% decrease in blood loss and a 50% shorter postoperative hospital stay for patients [20]. These statistics have proven that the DVSS is socially sustainable for both the patient and the surgeon. With all the benefits the system creates for the patient, they are able to get back to their daily lives quicker and make a full recovery. Additionally, with a significantly lower complication rate, it provides the surgeon with a better reputation for success and less of a chance at a lawsuit do to malpractice. It is clear the DVSS offers many advantages to the patient over the traditional methods of cancerous tumor removals in the pancreas, but there are still disadvantages to be taken into account.

The da Vinci System's largest complaint is the issue of economic sustainability—not only for the patient but for the hospitals. With a two-million-dollar price, excluding attachments, the DVSS is a huge expense [21]. However, with an increased price of surgeries with the device (an average of three to six thousand dollars more than the traditional methods), the initial price tag pays itself off in the long run [21]. Plus, while a 2-million-dollar price tag may seem way too high, it turns out to be a very small cost for many hospitals that are multimillion-dollar facilities. The years of training needed may also seem like a large price tag for hospitals; however, they can wait to hire the surgeons until after they complete their training—hospitals are not forced to train all surgeons on this device. Therefore, the benefit of having a da Vinci System at their complex outweighs the costs for the hospitals and would potentially offset the initially negative social sustainability for the surgeons. There is no specific data on the average salaries of da Vinci certified surgeons; however, on average, surgeons who perform the highest priced surgeries (brain and orthopedic) have the highest average salaries. That would suggest that, due to the increased costs of da Vinci procedures, da Vinci certified surgeons are paid slightly higher. A higher salary would be well worth the time spent in training and could vastly increase the surgeon's home life.

For patients, an increased price tag can come across as an issue. However, in the reality of things, a three to six thousand dollar increase on a $100,000 or more procedure is so miniscule, it can almost be completely neglected in the minds of the patients [21]. Also, numbers do not lie; the DVSS offers a plethora of benefits over traditional surgeries that can be evaluated at much more than a six-thousand-dollar price tag. This can refute the earlier claim that an increased price per procedure would cause some patients to be unable to receive such a procedure—that is just not the case. Therefore, the cost for patients, while an inconvenience, is not detrimental compared to the advantages a DVSS procedure can provide them—allowing us to confidently classify the DVSS as socially and economically sustainable.

The last alarming con for the da Vinci System is a very high amount of lawsuit payouts. Totaling near 100 million dollars as of 2013, the DVSS has not been immune to mistakes [23]. Out of those settlement payouts, however, only 8,000 lawsuits were reported for machine malfunctions, which resulted in an attachment recall and have since been resolved [23]. Those 8,000 malfunctions represent 0.53% of the 1.5 million surgeries that were performed by the DVSS as of 2013 [23]. While lawsuits are never a good social aspect for a device and can be a result of life threatening or ending issues, the 0.67% overall lawsuit rate is extremely low for any surgery [23].

Questions of sustainability arise when injuries and lawsuits occur; however, the rate of mishap is so minute that this device cannot be deemed unsustainable from a social aspect. With only one documented recall, and a fraction of a percent error rate, the da Vinci Surgical System can be deemed a safe, socially sustainable surgical system. The high payouts from these lawsuits do not affect the hospitals or surgeons; they are payouts from Intuitive itself. The product has had a sustainability scare in the past for the producers; however, the recent stock market jump to an already 60-billion-dollar company has laid all those fears to rest [2]. The payouts themselves can be attributed to the fact that medical lawsuits generally end in multimillion-dollar settlements and that it is much harder to defend a robot in court against a human than simply a surgeon.

With all the pros and cons of the system taken into account, the da Vinci Surgical System appears to be a

sustainable surgical revolution, and it is only a matter of time before it becomes the go-to surgical method for the removal of cancerous tumors in the pancreas. If technology continues to evolve, it may even become the go-to for all surgeries. The DVSS is a safe, sustainable, practical, and advantageous surgical device that has the potential to change the future of surgery—only time will tell its success story.

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