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ROBOTICS: A NEW MIRACLE IN LIVER TRANSPLANT

Nyla Ajaz[1], Fauzia Rehman[1], Noreen Aslam[2], Alishbah Roobi[2], Ayesha Waris[2], Aqsa Shahid[2], Hina Pervaiz[2], Rida Sarwar[2], Asma Imdad[2], Muhammad Ahmad Sharif [3]

[1]Department of Phramacy, The University of Faisalabad.
[2]Department of Physiology, Faculty of Sciences, The University of Faisalabad.
[3]Department of Physical therapy, Superior University Lahore

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Corresponding Author:
Nyla Ajaz,
Department of Phramacy,
The University of Faisalabad

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ABSTRACT

In the treatment of liver tumors, minimally invasive surgery (MIS) is used widely these days. The robotic technology is used in MIS these days. This study examines the current position robotic donor hepatectomy and MIS in literature and assess any future potential ramifications during transplant sector which is usually done by robots. Nevertheless, although living donors have emerged to supplement deceased donors as a source of organs, supply has fallen well short of need. Therefore, in recent decades, rationing has been a negative focus. The fundamental idea of organ shortage may soon be in jeopardy due to recent changes in the epidemiology of liver illness and groundbreaking advancements in liver preservation. The emphasis will shift to enhancing fair access while removing barriers related to infrastructure, workforce development for organ recovery and rehabilitation, and related expenses. Liver preservation research is enhancing transplantation conditions. Several benefits of robotic surgery have been cited, such as three-dimensional (3-D) imaging that produces a constant, high-definition image, the absence of hand tremors, mobility; compare to laproscopic surgery the shorter learning curve and the lack of hand tremors.

INTRODUCTION

Most of the robotic surgeries, like three dimensional surgeries which produces high image definition (Murphy & Atala, 2014).Minimally invasive surgery is widely used these days. It determines the current position of robotic hepatectomy (Finotti, D'Amico, & Testa, 2022). The use of robot-assisted major hepatectomy has quickly gained popularity around the globe, largely due to the established da Vinci surgical system(Marubashi & Nagano, 2021). Thomas Starzl received his first liver transplant about 60 years ago. Throughout this time, improvements in medical technology have gradually made it possible to implement novel transplantation techniques. Both living donors and recipients can benefit greatly from robotic surgery's accuracy and less intrusive nature. Traditionally performed as an open surgery, liver transplantation poses significant pitfalls due to the intricate deconstruction of the liver, which include thick vascular and biliary networks. complications similar as inordinate blood loss, infections, and dragged recovery have driven the hunt for advancements in surgical ways(K. Labadie, K. M. Sullivan, & J. O. Park, 2018).

Minimally Invasive surgery of liver is developing, robotic surgery expertise is growing in the United States, and Europe is catching up to Middle Eastern and Asian experience. Minimally invasive liver surgery has well-established benefits over the traditional "open" technique, including the potential for better abdominal access in the event of a future liver transplant. The technique led to the use of robotic surgery for both minor liver resections and large hepatotectomies. Giulianotti et al. first discuss the use of robotic-assisted surgery in radical major liver resection for hilus cholangio-carcinoma between the years 2002 and 2010(Giulianotti et al., 2011).

Since the year 2002, usage of Robotically-assisted surgery (RAS) has been gradually adding in the surgery for transplantation. Tsung et aI. conducted an 11-match comparison of open liver and robotic surgery. There was less blood loss in robotic group and sanitarium stay in contrast to the open surgery, which has comparable mortality and morbidity rates(Ocuin & Tsung, 2016).

The comparison between 14 and 20 situations when a right hepatectomy was completing successfully on their own using a laproscopic or robotic technique. To preserve the function of liver malignant and benign excrescences were treated especially in the colorectal metastases. Minimally invasive surgery (MIS) was deemed contraindicated in cases where the diaphragm or major hepatic vessels (inferior vena cava, portal tone branches and hepatic tone) were involved(Marino, Glagolieva, & Guarrasi, 2018).

Since the 2010s, the use of robotic devices has expanded the reach and significance of liver transplantation, greatly improving results for both donors and recipients. the notable developments in robotic surgery, the enduring difficulties including expense and training requirements, and the prospects for worldwide standardization and AI integration. 52 robotically assisted minimally invasive liver resection surgeries were among the 56 robotic hepatobiliary procedures we carried out in 2012. Compared to our laparoscopic group, it raised the percentage of patients with new hepatocellular carcinoma undergoing minimally invasive surgery by 15% and the number of patients undergoing minimally invasive liver resection by more than double. A recent study presented the first report of purely laparoscopic patron hepatotomies (PLDH) for the right lobe in 2013. In France, Rotellar and associates. Han et al. in Spain. For left lobe benefactors, Troisi et al. in Belgium and Korea. PLDH for full lobe patrons is now only available at a few select Indian institutes and high volume centers in Korea.

In the year of 2014, it is reported that first big match comparison in between the 114 laproscopic and 57 robotic (21 major liver resections) hepatectomies. This shows that minimally invasive surgery is very safe and achievable method in its operative and postoperative issues, and nothing has changed in the achievements of R0 status of periphery between the (2) two groups. The 69 resections of liver, consisting of 54 hepatectomies which are major in the terms of viability and safety of excellent results. The part of robotics in liver transplantation primarily focuses on two crucial areas donor hepatectomy in livings patron transplantation (LDLT) and donors surgery for graft implantation. In LDLT, robotic assisted ways allow surgeons to perform minimally invasive hepatectomies, reducing physical trauma and expediting recovery for living donors. These guidelines are provided to ensure the safe implementation and development of MIDH in LDLT Centers, aiming to enhance donor safety, donor care, and recipient outcomes(Cherqui et al., 2021). For donors robots aid in intricate procedure similar as vascular anastomosis and biliary reconstruction, icing better issues(Troisi, Patriti, Montalti, & Casciola, 2013). Also, the integration of robotics with imaging technologies like CT reviews, MRI, and AI-grounded planning tools has further enhanced surgical delicacy and opinions – timber. These advancements enable preoperative simulation, furnishing surgeons, thereby minimizing intraoperative pitfalls and perfecting effectiveness. While the implicit benefits of robotics in liver transplantation are apparent, their wide relinquishment faces challenges. High costs, a steep literacy wind, and limited availability to robotic systems have braked their integration into routine practice. Nevertheless, the growing body of substantiation supporting bettered patient issues, reduced complications, and short recovery times underscores the transformative impact of robotics in liver transplantation. As technology continues to evolve, robotic- supported surgery is poised to come to the keystones of ultramodern liver transplantation, reshaping the field and perfecting the quality of care for about benefactors and donors.

IMPACT OF ROBOTIC TECHNOLOGY

The use of robotic technology in the constantly changing healthcare industry has had a big impact on a number of surgical operations, including liver transplants. With improvements in surgical techniques, immunosuppression, organ preservation strategies, leading to liver transplantation has become the gold standard treatment for end-stage liver diseases and fulminant hepatic failure due to improved long-term graft and patient survival(Briceno & Ciria, 2010; Kemmer, Secic, Zacharias, Kaiser, & Neff, 2007).Nevertheless, the increasing need for liver transplants has surpassed supply to donor organs. The use of robotics in liver transplant operations is one exciting field of study. Robotic systems have the potential to enhance surgical precision, reduce surgical complications, and improve patient outcomes.

For example, irrefusable vasculature may be able to alleviate the lack of donor organs and offer patients with end-stage liver disease an alternate option(Kim et al., 2021).Moreover, normo-thermic machine perfusion may lessen the effects of early graft malfunction and enhance transplant results by enabling the ex vivo preservation and evaluation of donor livers(Li et al., 2022).

OVERVIEW OF LIVER TRANSPLANTS AND THE NECESSITY OF CUTTING-EDGE SURGICAL METHODS

For patients with end-stage liver disease, liver transplantation has become the only viable treatment option, with advancements in immunosuppression and surgical techniques contributing to enhanced outcomes and survival rates. However, despite these improvements, the demand for donor organs continues to outpace supply, thereby necessitating innovative surgical approaches to optimize existing resources. The inherent complexities of liver anatomy and the meticulous nature of transplantation surgery illustrate the need for refinement in procedural accuracy and efficiency. Recent developments in robotic-assisted technology represent a transformative direction in this field, offering precise instrumentation and improved visualization that may reduce operative trauma and enhance recovery times. The potential of these cutting-edge surgical methods to overcome the drawbacks of conventional methods, especially when combined with 3D printing for preoperative planning, highlights their crucial role in the future of liver transplantation(Di Benedetto, Ballarin, & Tarantino, 2016). Laparoscopic hepatectomy has gained significant popularity due to its numerous advantages, including reduced postoperative pain, shorter hospital stays, and quicker recovery times, allowing patients to return to their normal lives sooner. This minimally invasive surgical technique is especially appealing as it offers better cosmetic outcomes, with smaller scars compared to traditional methods. Moreover, established comparative studies have consistently demonstrated that laparoscopic approaches are not only feasible but also effective for procedures like left donor hepatectomy. As healthcare continues to prioritize patient comfort and efficiency, laparoscopic hepatectomy stands out as an innovative solution for liver surgery, making it a preferred choice for both surgeons and patients alike(Park et al., 2019).Innovations in technology could improve safety, lessen the physical and functional demands on patients, increase survival rates, and lessen the negative side effects of immunosuppressive medications in liver transplantation. Although surgical robotics has advanced significantly, the application of robots in liver transplantation, especially after surgery, is still a major area of study. This review will provide an update on the prospects of liver transplantation robots. Among the primary illnesses that qualify people for liver transplants are alcoholic, cholestatic disorders, liver disease, viral hepatitis, liver cirrhosis and acute liver failure(Broering, Sturdevant, & Zidan, 2022).

APPLICATIONS OF ROBOTICS IN LIVER TRANSPLANTATION

Partially removing the liver from a live donor now requires surgery. The donor has numerous benefits over open surgery or even standard laparoscopic procedures with robotic liver transplantation, a significant advancement in medical technique. Among the principal advantages of robotic liver transplantation are the following.(Marubashi & Nagano, 2021)

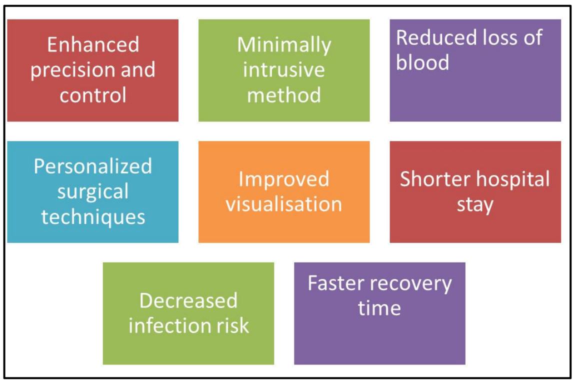

Figure No 1: Application of Robotics in Liver Transplantation

ADVANCEMENTS IN ROBOTIC SURGICAL SYSTEM

Surgical procedures have advanced significantly using robotic surgery devices in liver transplantation, improving patient outcomes and precision. Because of the delicate nature of liver anatomy, these systems use minimally invasive techniques and modern imaging technologies to help surgeons navigate complex anatomical regions more accurately. When compared to open operations, robotic-assisted surgeries have shown significant benefits, including decreased postoperative discomfort, shortened recovery times, and fewer problems(A.Y. Kshirsagar & et al., 2023).Robotic platforms have the potential to revolutionize surgical procedures and boost therapeutic effectiveness in liver transplantation as they develop further, integrating artificial intelligence and improved imaging techniques. Additionally, the ability to execute complex movements with robotic tools greatly enhances the surgeon's control and dexterity during operations, which eventually helps in hepatocellular carcinoma patients achieve better oncologic results and surgical margins(K. Labadie, K. Sullivan, & J. Park, 2018). Due to the recent advancements in laparoscopic liver resection, its application has been extended to both donor and recipient surgeries in living donor liver transplantation. However, some recipients may also experience beneficial effects from laparoscopic procedures similar to those seen in living donors. The robotic surgical system offers an advantage over traditional laparoscopic surgery by enabling microsurgery in a stable surgical field (Lee et al., 2022).

By utilizing the benefits MIS (Minimally Invasive Surgery), the incorporation of robotic-assisted technologies into liver transplantation has transformed surgical methods. Surgeons may now undertake intricate liver surgeries with greater control and precision thanks to modern robotic instruments like da Vinci Surgical System, which solves the problems with laparoscopic procedures. With the help of articulated movements and high-definition 3D imaging, these robotic systems enable complex dissection and suturing in small anatomical regions. Additionally, there is mounting evidence that, in comparison to open procedures, the robotic technique promotes faster patient recovery while lowering postoperative consequences including pain and infection rates.

Table 1: Modern Robotic Liver Transplantation Technologies.

Sr No	Name of Technology	Manufacturer's Name	Introduction Year	Key Features
1	da Vinci Surgical System	Intuitive Surgical	2000	Improved dexterity, 3D visualization, and minimally invasive equipment(Quirino Lai et al., 2012)
2	Versius Surgical System	CMR Surgical	2018	Flexible placement, modular design, and 3D HD vision(Quirino Lai et al., 2012)
3	Senhance Surgical System	TransEnterix	2016	Interfaces for augmented reality, eye tracking, and haptic feedback(Quirino Lai et al., 2012)
4	Robotic-assisted Laparoscopic Surgery	Various	Varies	Combining current laparoscopic methods with soft manipulation of tissues(Quirino Lai et al., 2012)
5	Robo-Arm Systems	Various	New technology	Accurate instruments for dissection and suturing, AI integration for support(Quirino Lai et al., 2012)

Moreover, robotic systems' versatility opens up possibilities for both intricate reconstructions and living donor liver transplants, highlighting their vital role in contemporary surgical practice and their potential to enhance patient outcomes in this challenging field of transplantation(Q. Lai et al., 2012).

ADVANTAGES

Robotic assistance in liver transplantation offers considerable improvements over conventional surgical methods, leading to better patient outcomes and increased operational efficiency(Works).Robotic technologies make minimally invasive procedures possible, resulting in smaller incisions. This reduces postoperative pain and speeds up patient recovery. Furthermore, the improved visualization and accuracy that robotic tools offer allow surgeons to execute intricate procedures with greater control and dexterity, which is crucial in delicate area of liver surgery. The usage of robots-assisted treatments can result in a more positive postoperative trajectory by reducing the incidence of problems such wound infections and excessive bleeding, as the field of laparoscopic surgery has already shown. When taken as a whole, these advantages highlight how revolutionary robotics can be in liver transplantation and strengthen their position as a vital development in surgical technique(Quirino Lai et al., 2012).The main benefit of robotic-assisted surgery is that it gives the "open surgeon" back control by simulating open surgery instead of laparoscopic surgery. Other benefits of the robotic platform include its capacity to overcome range of motion restrictions, a narrow field of view, and physiological tremor. The filter of tremors, supplementary instrument levels of freedom, and high resolution amplified 3D image enable precise dissection, easier suturing, and careful tissue handling. All of them are essential preconditions for a safe LD operation. RDH allows the hepatic duct stump to be sutured shut following the donor surgery, unlike CLDH. This suture ligation may reduce the risk of biliary morbidity in the donor and the development of several bile ducts in transplant which is graft by removing requirement for clipping and increasing the length of duct on both graft sides and donor by a few millimeters. Using visual guiding has helped in important surgical procedures. Using indocyanine green for real-time fluoroscopic guidance increases the safety and accuracy of the division of bile duct. Following a brief period of flow control, an indocyanine green injection enhances the visibility of the ischemia delineation line, and allows a precise dissection to reduce the loss of blood and ischemic parenchyma in the graft and donor. Surgeons who do RDH report feeling more certain about the safety of their donors because to the previously mentioned dexterity and optics. Furthermore, teams contend that vascular structure recognition during parenchymal and hilus dissection transection is above than CLDH. These benefits together guarantee that the RDH learning curve makes up a small portion of the CLDH.

A Taiwanese sequence claims that RDH learning curve was only 15 instances, which is one-third of what CLDH calls for(4). More importantly, prior laparoscopic surgery experience was not always necessary to begin an RDH program. The distribution of MIDH to LT units worldwide is significantly impacted by this. Because the area is so specialized, most reputable LDLT hospitals likely have surgeons who only know the basics of laparoscopic procedures. Regarding these seasoned surgeons will get the most sophisticated laproscopic techniques will be like creating wheel(Di Benedetto, Tarantino, Guerrini, Ballarin, & Magistri, 2020).

EVALUATION OF BETTER PATIENT OUTCOMES AND SHORTER RECOVERY PERIODS

By drastically improving patient outcomes and shortening recovery periods, the use of robotic technology in liver transplantation has revolutionized conventional surgical techniques. With less damage to the surrounding tissues and more accuracy, surgeons can execute intricate liver resections with minimally invasive robotic-assisted operations. Reduced postoperative problems, such as bleeding and infections, have been linked to these developments and are important indicators of surgical success(A.Y. Kshirsagar & et al., 2023).Furthermore, the application of robotics enables improved dexterity and vision during complex operations, resulting in shorter hospital stays and speedier surgical completion. Patients' quality of life improves after surgery as a result of quicker recovery times and a quicker return to their regular activities. In addition to serving as an example of the trend toward less invasive procedures, the use of robotic systems in liver transplantation highlights the need for continued research into their effectiveness and patient-centered results.

IS A LIVER TRANSPLANT WITH ROBOTIC ASSISTANCE SAFE AND SUCCESSFUL?

Indeed, multiple trials have demonstrated the safety and efficacy of robotic-assisted liver transplantation. Surgeons can now execute intricate surgeries with more control and precision thanks to technology, which eventually improves patient outcomes. Furthermore, robotic surgery's minimally invasive technique causes less bodily stress, less discomfort, and quicker recovery periods. All things considered, robotic-assisted liver transplantation has revolutionized the area of transplant medicine.

THE CURRENT AND FUTURE ROLES OF ROBOTS

Many authors point out a few noteworthy benefits that support the robotic approach. Despite taking longer than open surgical procedure, the donor who has their liver removed under robotic surgery needed less patient-controlled analgesia following the procedure and was able to return to their normal activities more quickly. These benefits are mainly due to th access locations for the abdomen that are minimally invasive and cutting as opposed to conventional midline incision(Rammohan & Rela, 2021).The robotic approach is very good at identifying the correct plane of transection because of the 3-D and magnified vision. Additionally, robotic-assisted surgery allows for correct biliary and arterial dissection, specifically during isolation of inferior vena cava. The improved capacity of robotic arms to sew, especially in retro-hepatic region, allows for better management of unexpected bleeding.
According to the curve of learning for robot-assisted surgery seems to be significantly lower than that for laparoscopy, which is very essential for the upcoming application and development of robotic techniques. The proper hepatic plane of resection and hemorrhage control are two crucial elements of the safety of donor. The slight loss of blood seen in majority of donor robotic series may be outlined by the harmonic scalpel's improved suturing and sealing capabilities(Chen et al., 2016).Moreover, the approach to robotic surgery allows surgeon to do a liver resection with a faster learning curve and increased relative complexity. The requirements for donor surgery inclusion changed over time. At first, robotic surgery was advised for transplants weighing less than 800 grams. The right lobes with bile duct trifurcations, or portal vein trifurcations and inferior right hepatic veins were previously present from the tenth instance, and larger resections were subsequently performed(Pinto-Marques et al., 2024).

CONTROVERSY FOR THE USE OF ROBOTICS

Warm ischemia time (WIT) during graft removal, vascular bleeding management safety, biliary transection safety, and cost of all these procedures are the primary concerns with the robotic method. The majority of data indicates that WIT is frequently longer than laparoscopic or CODRH treatments. The lengthier operating time, which involves additional manipulation time and docking, particularly in mobilization hepatic lobe of the right side, may account for the longest WIT when compared to laparoscopic surgery or

CODRH. There is currently no evidence linking higher liver enzymes to recipient issues. However, the experts say further research is needed to understand the ramifications of an extended ischemia time. When compared to traditional open donor right hepatectomy (CODRH), pure laparoscopic donor right hepatectomy (PLDRH) provides better surgical results for donors. However, especially in low-volume transplant institutions, the complexity of the surgery frequently discourages transplant teams from performing it. To demonstrate the feasibility of PLDRH in a low-volume transplant program, we compared the results of PLDRH with CODRH (Lapisatepun et al., 2022). The accurate identification of the hepatic duct anatomy is another issue with the robotic technique. Following a fully laparoscopic right hepatectomy, biliary problems accounted for the bulk of sequelae. Donor biliary issues (stenosis or biliary fistula) increased as a result of the first series' usage of the Hem-o-loc or clip to close the hepatic duct. It is best to divide the hepatic duct as cleanly as possible because cutting it can shorten it by changing the length of the stump. The donor's biliary stump should ideally be sealed with flowing suture(Magistri, Tarantino, Ballarin, Coratti, & Di Benedetto, 2017).

DRAWBACKS

The lack of an ultrasonic aspirator (UA) for parenchymal transection is a common drawback in robotic liver surgery. The primary obstacle to a more seamless transition from open laparoscopic to robotic liver surgery is most likely this limitation. In order to accomplish safe parenchymal transection, surgeons must develop intermediate new methods.

There is currently no evidence of notable clinical breakthroughs, despite the specific benefits that robotic setups can offer minimally invasive surgeons. A robotic laparoscopic procedure can cost up to 5000 US dollars more than its conventional counterpart, and a single da Vinci SP system costs over US$ 1.5 million. Additionally, robotic technology is still very valuable(Lapisatepun et al., 2022). The intricacy of the technology, together with problems with biocompatibility, conservation, and sterilization, are the causes of the high costs. Therefore, it is delicate to defend equivalent fees for a technology that, while implicitly improving surgical skill, has not yet been shown to produce clinically significant benefits for the cases. This is also due to a number of ethical issues that surround the use of robots in medicine, including the possibility of malfunctions and system failures that could harm the patient and the lack of clear guidelines for determining legal responsibility in the event that these things occur in In addition to maintaining robotic systems safer and investigating ways to make the technology more accessible and inexpensive, efforts should be directed on bridging the legal gaps. An FDA study on the topic outlines the difficulties and nonsupervisory routes for include robotically assisted surgical bias in the request.

The primary problems currently impeding the benefits of new RASDs are inadequate stakeholder collaboration, a lack of a public registry, a formal framework to describe their developmental stages, uncertainty regarding their actual clinical potential, and an inability to evaluate and compare training and simulation technologies to induce and collect clinical data. Surgical robots are essential for assisting surgeons in more sophisticated and technically challenging minimally invasive operations, which helps to establish and increase the prevalence of MIS.

CHALLENGES AND LIMITATIONS

One common limitation of robotic liver surgery is the absence of an ultrasonic aspirator (UA) for parenchymal transection. A more smooth transition from open laparoscopic to robotic liver surgery is probably hampered by this limitation. Surgeons must create novel intermediate techniques to achieve safe parenchymal transection. Robotic technology is still very beneficial, even if there is little evidence of major clinical breakthroughs despite the particular benefits that robotic setups can give minimally invasive surgeons. For instance, a robotic laparoscopic treatment can cost up to $5,000 more than its traditional counterpart, and a single da Vinci SP system costs over US$1.5 million. The intricacy of the technology, together with problems with biocompatibility, conservation, and sterilization, are the causes of the high costs. Therefore, it is delicate to defend equivalent fees for a technology that, despite its implicit ability to improve surgical performance has not yet been shown to produce clinically significant benefits for the cases. This is also because of a variety of ethical concerns that surround the use of robots in medicine, such as the potential for system failures and malfunctions that could damage the case and the absence of precise methods for defining legal culpability in the event that these things happen. up addition to continuing to improve the safety of robotic systems and researching ways to lower the cost and increase accessibility of the technology, efforts should be directed toward filling up the legal gaps. Regarding this subject, the FDA has released a paper detailing the difficulties and unsupervised routes for adding robotically assisted surgical bias to the request. The main factors currently slowing down the adoption of new RASDs are the absence of a public registry, the absence of a formal framework to characterize their developmental stages, the ambiguity surrounding their actual clinical possibility, the inability to evaluate and compare training and simulation technologies, and the lack of cooperation amongst stakeholders to induce and gather clinical data. Surgical robots are essential for assisting surgeons in more sophisticated and technically challenging minimally invasive operations, which helps to establish and increase the prevalence of MIS(Marubashi & Nagano, 2021).

CONCLUSION

The superiority of the robotic approach over laparoscopic or open methods in living donor hepatectomy is not entirely supported by the literature currently in publication. It is safe and possible to execute robotic donor hepatectomy on carefully chosen living donors by highly skilled teams. Over the past few decades, technological developments have contributed to the growth and prevalence of MIS. Some of the most recent advancements in imaging, robotics, instrumentation, and vision have been demonstrated, highlighting the shortcomings of current practice and highlighting important areas for improvement that require future attention. Modern cameras can compensate for the loss of stereovision and provide a view of the operating field comparable to open surgery, providing 3D images in high definition. This is a clear improvement over fiber optics. Robotic approaches need to be compared to traditional procedures and evaluated for performance in terms of improving surgical technique and lowering morbidity. In order to speed up the learning curve and cut down on operating times and expenses, to close the distance between surgeons and machines, progress must be made. To enable the field of MIS to develop and thrive, future studies should concentrate on haptic feedback, loss of eye-hand coordination, and lack of depth perception all significant problems that have not yet been adequately addressed.

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