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Surgical Robotics and Remote Surgery in Low- and Middle-Income Countries: A Systematic Review with Strategic Implications for Pakistan

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ABSTRACT

Surgical robotics are used to perform remote surgery, which is a radical solution to overcoming surgical inequities in resource-poor countries. The given systematic review focuses on the current state, issues, and perspectives of robotic-assisted remote surgery and pays special attention to Pakistan as a representative of low- to middle-income countries (LMIC). In the detailed review of the available literature, the following barriers are distinguished: high costs, infrastructure constraints, and the lack of training, and the opportunities include enhanced access to specialist care and lower healthcare inequalities. The review brings together 45 studies and shows that robotic systems are slowly but steadily implemented in Pakistan since 2011, and more than 700 procedures were carried out till today. Results highlight possibilities of telesurgery to narrow down geographical distances, yet it requires strategic investments, policy changes, and bilateral partnerships. Some of the recommendations provided include the creation of affordable robots platforms, the improvement of national digital infrastructure and the creation of national training programs. This paper presents a road map on how robotic remote surgery can be incorporated in the Pakistan healthcare system, in the end evolving to improve surgical services in the underserved areas.

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Graphical Abstract

Introduction

The Rise of Surgical Robotics

The invention of surgical robotics has become a key revolution in the sphere of modern medicine, as it has transformed the process of conducting operations by increasing its accuracy, minimizing invasiveness, and broadening the reach of expert medical services. During the past thirty years, the robotic systems have ceased to be an experiment and have become a widespread platform in large hospitals all throughout the world. Their growing presence indicates a wider change in healthcare: the trend towards minimal invasive surgery, the use of digital technologies, and the support of clinical decisions by technologies. Surgery robotics in a large part is the merging of engineering, computer science, and medicine, where the common goal is to enhance patient outcomes and decrease surgical risk.

Surgical robotics are fundamentally based on using robots to help a surgeon carry out their more difficult tasks with more accuracy and precision, through the use of robotic equipment like the da Vinci Surgical System. These systems usually system includes a surgeon console, arms of the robot armed with instruments and high definition imaging devices that give a three dimensional picture of the operating site. Surgical robots do not substitute the surgeon as opposed to autonomous robots which are simply very sophisticated extensions of the hands of the surgeon.

The surgeon is entirely in charge, making every movement with the robotic platform converting them into fine tremor free movements. This scaling motion capability whereby giant movements of the hands can be transformed into the minor instrument movements improves surgical accuracy, especially in the delicate operations involving nerves, blood vessels and restricted body areas.

Evolution of Robotic Surgery: From Early Experiments to Global Adoption

Robotic surgery originated in the late 1980s, and one of the first in robotics was the PUMA 560 in 1985 which was used to perform a neurosurgical biopsy. This showed that robotic systems were able to assist in processes that were very precise. In the 1990s, orthopedic surgery and endoscopic camera control and early laparoscopic assistance were developed on several platforms, which assisted in creating the modern robotic surgery foundation.

One of the breakthroughs occurred in 2000 when the U.S. Food and Drug Administration authorized the da Vinci system. The high level of instrument control and 3D visualization made it popular in high-income countries, especially in minimally invasive surgeries (prostatectomy and hysterectomy). The hospitals also propagated robotic surgery as a representation of technology.

With the advancement of the technology, robotic surgery was diversified into various specialities, such as general, thoracic surgery, cardiac surgery and even paediatric surgery. There was also a start in research on the remote robotic surgery which could decrease the geographic limits to surgical care.

Remote Surgery (Telesurgery): A New Frontier

Rapidly, robots act as assistance in remote surgery or telesurgery where surgeons can perform surgery on patients even in remote areas through telecommunication networks. This is especially encouraging in the context of low resource environments in which geographical, economic, and infrastructural factors may restrict access to special surgical expertise. Telesurgery uses high speed net, low latency, and sophisticated robot interfaces to relay surgical instructions in real time enabling skilled surgeons to instruct or carry out surgery remotely.

Telesurgery is technically a highly challenging form of telemedicine. There should be constant responsiveness in surgery, unlike in remote consultations, where delays are inconvenient but acceptable. Even minute latency percentages of seconds are capable of disturbing hand eye coordination and raising procedural risk. Consequently, telesurgery relies on high bandwidth and high quality networks and system redundancy. This entails emergency procedures, alternative communication connections and backup power in case of a malfunction of the robots.

The initial broadly accepted telesurgery breakthrough was in 2001 in New York, when a surgeon in Strasbourg, France carried out a laparoscopic cholecystectomy on a patient. This operation, which is commonly known as the Lindbergh Operation, proved that it was possible to operate over distances. The success of the operation prompted international interest and indicated that, under the conditions of proper facilities, surgical services could be offered even in the most remote places. It, however, also pointed to the huge disparity between technical feasibility and real-world scalability particularly in LMICs where internet reliability and hospital infrastructure might be unreliable.

Global Surgical Inequity and the Need for Innovation

Surgical access is low throughout the world. According to the estimates of the World Health Organization, over 5 billion people do not get the necessary surgical care, primarily, in the low- and middle-income countries (LMICs). The existence of this gap is indicative of wider health system failures, such as travel distances, cost, late diagnosis, and low emergency referral routes. This leads to the fact that curable diseases become serious or even deadly.

Restricted access to surgery will result in avoidable mortality, morbidity, and financial burden.

Trauma, obstetric emergencies, appendicitis, hernias, and early-stage cancers are some of the most common conditions which deteriorate because of delayed care. Families might also experience loss of income and high cost on traveling and recuperating hence surgical equity is a health and development priority.

The proposed solution to these difficulties could be robotic remote surgery as it could provide specialized knowledge to the under-served hospitals and decrease the necessity of patient travel. It might come in handy especially in the rural regions, conflict zone, and disaster environments where delays happen frequent. Nonetheless, telesurgery still needs presence of clinical staff on-site and technical assistance in the form of anesthesia, sterile procedure, and postoperative care. Hence, it ought to be perceived as a cooperative strategy enhancing, as opposed to substituting, local surgical capacity.

Pakistan as a Case Study: Healthcare Disparities and Surgical Access

As the target of this review, Pakistan can be seen as the illustration of the challenges of applying the surgical robotics in the low-resource setting. Having a population of more than 240 million, Pakistan has huge healthcare imbalances such as the availability of a surgeon per 100,000 population in rural regions; on average, there are approximately 0.5 surgeon per 100,000, which is abhorrently less than the recommended 20 per 100,000 level in the rest of the world. This scarcity is exacerbated by lack of even distribution with majority of the specialists being concentrated in major cities.

The economic conditions trouble the healthcare system of the country. Health spending on the purpose of prevention of diseases is about 1% of GDP, which means that there are under-funded hospitals, the use of modern technologies is low, and the payment systems are characterized by a high proportion of out-of-pocket payments. The cost to treat surgical care privately is something that causes many families to go into long-term financial crisis. Additionally, the issues with infrastructure, e.g. unreliable electricity, insufficient capacity of ICUs, and lack of biomedical engineers may complicate maintenance of high-tech systems.

The tertiary hospitals are concentrated mainly in urban areas in Karachi, Lahore, Islamabad, and Rawalpindi, leaving rural areas in Khyber Pakhtunkhaw Balochistan, Gilgit-Baltistan, and rural Sindh underserved. The patients in these locations usually have a long commuting time, and they can delay seeking medical attention until their conditions deteriorate. This results in a loop of a late presentation, increase in complication rates, and mortality during surgical procedure. The problem of these disparities might be solved with the assistance of surgical robotics as it allows remote consultations, tele-proctoring, and, ultimately, remote operations. However its adoption has been slow with the first da Vinci system installed in Pakistan in the year 2011. This low rate is an indication of the expensive nature of robotic platforms, the non-existence of viable training opportunities, and the absence of sound regulatory and financing systems.

Potential Benefits of Robotic and Remote Surgery in Pakistan

The potential benefits of robotic remote surgery in Pakistan are multifaceted.

Enhanced Precision and Reduced Complications

Robotic surgery improves precision especially on complicated surgeries like urological, gynecological, and cardiothoracic surgeries. In Pakistan, patients continue to receive an open surgery in cases that can be performed in a minimally invasive procedure in well equipped environments. Robotic service can minimize blood loss, decrease the infection risk, and decrease the recovery periods. There are some international studies that show robotic-assisted surgery has a blood loss reduction of up to 50 per cent and a shorter hospital stay of 1-2 days as compared to

open surgery. In Pakistan, where hospitals are usually overcrowded and postoperative infections are a problem, these advantages might be felt particularly.

Expanding Specialist Reach Through Telesurgery

Remote surgery may help to have expert surgeons in Karachi or Lahore helping the hospitals in the underserved areas. By way of example, a specialist might remotely assist with a complex laparoscopic operation at a district hospital where a surgeon might not have much experience with new modern technologies. This would minimize the long distance that patients have to cover to obtain specialized care. This may be a matter of life and death in emergency situations whereby this may be trauma or obstetric bleeding.

Training and Capacity Building via Tele-Proctoring

Training by tele-proctoring is one of the most realistic short term uses of robotic systems in Pakistan. The trainees can be guided by the experienced surgeons remotely and at the same time these surgeons can give guidance to the students doing the surgery. This will be able to overcome the problem of the lack of qualified surgeons as well as the diffusion of experience outside the large urban centers. This may eventually develop local surgical capacity and outcome in environments without complete robotic platforms..

Barriers to Implementation in Low-Resource Settings

Despite its promise, the future of remote surgery in Pakistan is constrained by significant barriers.

Financial Costs

Initial cost-Robotic platforms are more expensive than robots typically between 1 and 2 million dollars. Maintenance contracts and replacement of instruments and training of the staff also contribute to the costs. Majority of the state hospitals cannot afford such investments because they struggle to meet the basic needs such as stocking of medication, ICU bed and staffing. The small-scale hospitals may find it difficult to sustain robotic programs due to the number of patients in the private hospitals.

Ethical, Legal, and Regulatory Concerns

Patient consent, data privacy, and cybersecurity are some ethical concerns with remote surgery. The risks involved in remote procedures such as technical failure should be made known to the patients. Liability is also complicated: in case of a complication, there is a possibility of the absence of responsibility between the remote-surgeon, the local hospital, and the provider of technology. The regulatory systems in Pakistan on advanced surgical technologies and telemedicine are low which brings confusion among the hospitals and clinicians.

Emerging Innovations and Opportunities

Nevertheless, new trends indicate the possibility that the robotic remote surgery can be made accessible to LMICs. Low-cost robotic systems such as the SSi Mantra of India and the Toumai of China are being tailored to the requirements of LMICs, and are half the price of their western counterparts. The pressure of the world robotics market might keep lowering the prices and providing more adaptable buying solutions, including leasing or shared ownership solutions.

Another promising field is artificial intelligence (AI). AI may assist telesurgery by predicting analytics, surgical guiding, detecting mistakes, and monitoring performance. An example is that AI systems would be able to recognize anatomical structures on the fly or warn surgeons about the unsafe placement of instruments. Further developments in the haptic feedback can also bring the feeling of touch back to the robotic systems so that the surgeon could better feel the resistance of the tissue remotely. Although these innovations are de novo, they should perform wonders to enhance the safety and efficacy of telesurgery.

Programs like installation of Versius system at SIUT in 2023 have been progress in Pakistan. The

fact that over 150 operations are being performed by robotic surgery in an attempt to show that robotic surgery is a viable project being performed successfully is something that can be supported by institutional commitment and training. This can be a basis of the future growth of robotics and remote application of the future.

Future Trajectory: How Pakistan Could Move Toward Remote Robotic Surgery

An approach that may be realistically adopted by Pakistan can entail gradual development. First, robotic surgery programs need to aim at capacity strengthening in tertiary hospitals, produce local evidence in the outcomes and cost-effectiveness, as well as create competent surgical teams. Subsequently, tele-proctoring and tele-mentoring can be extended to other hospitals (peripheral) and enhance training and laparoscopic capacity. Given that Pakistan is not ready yet to undergo complete telesurgery, it ought to think about full telesurgery pilots only after infrastructure and regulatory preparation, which is most likely to be controlled settings, like military hospitals or well-equipped regional centers.

It is likely that public-private partnerships will be needed in terms of funding. Governmental assistance in the digital infrastructure, regulatory, and workforce development will also be in the spotlight. Surgeons are not the only ones who need capacity-building programs, so should nurses, engineers, and IT personnel. The simulation labs and local training centers might be established so that reliance on foreign training is decreased and sustainability enhanced.

Literature Review

The research on surgical robotics and remote surgery has grown fast in the last twenty years, due to significant advances in the computing resources, imaging quality, tools design, and telecommunication. Researchers are also beginning to refer to surgical robotics as a means not only of enhancing the precision of the operative, but also as a potential solution to existent inequities in access to safe surgery on a global level. It particularly applies to the low- and middle-income countries (LMICs), where the lack of trained surgeons, inadequate infrastructure, and slow access to expert care are among the factors that perpetuate the high incidence of preventable complications and deaths.

The role of artificial intelligence (AI), miniaturization, and modular robotic platforms in determining the next generation of surgical innovation is also highlighted in the recent publications. The significance of these developments is that they can make robotic systems cheaper and simpler, and more realistic in low-resource environments. The existing market statistics reveal good business expansion. Considering the example of global surgical robotics market, the market has reached about 11.08 billion dollars in 2024 and it is expected to grow significantly in the coming decade. The robotic assisted surgery market will also remain to grow, as demonstrated by the rising demand in the minimally invasive surgery, especially in the chronic diseases like cancer, heart related diseases, and obesity. Such development is supported by the clinical evidence that robotic-assisted surgery has the potential to enhance accuracy, decrease hospitalization and intraoperative morbidity over open surgery and in some studies over conventional laparoscopy. Simultaneously, the topic of remote surgery (telesurgery) has been given a new focus after the COVID-19 pandemic. The restriction of travel, the lack of specialists, and interrupted elective services were the factors that caused a growing interest in the model of remote collaboration during the pandemic. Numerous studies currently discuss telesurgery as the way to link the knowledge of urban specialists and rural hospitals. Nonetheless, as promising as this notion is, the literature is consistent in pointing out that telesurgery is not only laborious but also costly but also requires a well-developed digital infrastructure. Consequently, tele-mentoring and tele-proctoring are now the main areas of evidence of LMICs as opposed to complete remote robotic

control.

This literature review will summarize the international and local resources regarding surgical robotics development, its application in clinic, and the possibility of remote surgery in low-resource countries, and particularly in Pakistan. Cost, training, infrastructure, ethics, and regulation are also considered as problems in the review, and the prospects are discussed in the future in the context of new innovations.

Historical Development of Surgical Robotics

Surgical robotics date back to the 1980s military and aerospace research. Initial ideas based on the ability of the surgeons to treat injured soldiers on the battlefield and assist astronauts during long-term missions to space. These primitive thoughts were inspired by the fact that even the best surgeons could not always be physically present at the scenes of the emergencies. Though these early projects did not directly convert into civilian healthcare they made the technical base of robotic manipulation, remote control systems, and high performance imaging.

Robotic prototypes started being used in clinical research settings in the late 1980s and early 1990s. In 1985, neurosurgical biopsy was the first robotic-assisted procedure to be performed with the PUMA 560 robotic arm. This was not a full robotic surgery system as we understand it in the contemporary world but it showed the possibility of robotics to enhance accuracy when it comes to exceedingly delicate procedures. The next generation of early systems was ROBODOC which was used in orthopedics and AESOP which was used in the operation of the laparoscopic camera. The systems were rather primitive in comparison with the modern robots, yet they were significant milestones on the way to computer-assisted operations.

Later in the 1990s the focus evolved to robotic systems that were able to assist minimally invasive surgery. It was also during this time we saw the birth of first generation remote manipulation prototypes like ARTEMIS and other experimental remote manipulation systems that were aimed at teleoperation. This was accompanied by the increasing popularity of laparoscopy which had already changed surgery causing a decreased incision size and recovery time. Nonetheless, laparoscopy was associated with shortcomings such as limited movement of the instruments, steep learning curve, and poor depth perception. This was an introduction of surgical robotics as a solution to the problems.

The da Vinci System and Global Expansion

In 2000, the world saw the introduction of the da Vinci Surgical System which was then a turning point in the process of adopting surgical robotics. The system gained popularity due to the fact that it provided wristed instruments with many degrees of freedom, tremor filtering, and three-dimensional visualization in high definition. The features enabled surgeons to carry out complicated operations with more dexterity than in the conventional laparoscopy.

Da Vinci platform quickly rose to be the leading robotic system in the high-income countries (HICs), especially in the United States. Robotic-assisted surgery has extended its initial applications to urology to gynecology surgery, general surgery, thoracic surgery, and colorectal surgeries among others. The high volumes of procedures led to the increased surgeon training, development of the system, and increase in clinical acceptance.

The relationship between the adoption of robotics and healthcare spending is often pointed out in the literature as strong. In the U.S, urology and gynecology were the areas where robotic surgery was widespread, and robotic programs were the subject of heavy investment in hospitals. Numerous researches show better results in the chosen procedures, including decreased blood loss and a decreased hospital stay. Nevertheless, scholars also observe that the advantages do not cut across all surgeries. In certain situations, robot surgery can only provide slight benefits over

laparoscopy, which makes it problematic in terms of its cost efficiency.

The adoption has also been localized globally in North America and sections of Europe with most of the robotic systems installed. This is not just about financial ability but also access to trained human resources, technical assistance as well as consistent hospital facilities. The literature has consistently presented a significant imbalance in the world: the robotic surgery is very accessible in the rich environment, and it is not easily accessible in the LMICs.

Adoption Trends in LMICs

The acceptance rate of surgical robotics is low in LMICs, but there has been significant increase in some Asian countries. In the literature, China and India are often discussed as the most prominent LMIC adopters with more and more robotic platforms installed and more and more training programs. One of the factors that contribute to this growth includes the high number of patients, the increased investment in the private sector of healthcare, and the government interest in modernization through technology.

India has been said to be among the fastest expanding markets of surgical robotics enjoying the rising popularity of minimally invasive surgeries and medical tourism. Simultaneously, Indian innovators have also designed cheaper robotic systems to be used in the household and regionally. China has consequently increased the use of robots, which has been facilitated by significant investment in digital infrastructure and the fast implementation of 5G networks.

Regardless of these advances, the literature has highlighted that the majority of the LMICs are miles behind HICs in the terms of availability of robotic systems and the volume of procedures. High cost of capital, lack of biomedical engineering support, lack of trained surgeons and competing healthcare needs like infectious diseases, maternal health and accessibility of basic surgeries are barriers. This has seen most LMICs continue concentrating on the expansion of basic surgical services as opposed to the high-level robotic services.

Remote Surgery and the Growth of Telesurgery Research

Remote surgery or telesurgery is robotic surgery where the doctor is far away, geographically away, when he performs the surgery on the patient. Tele surgery needs high communication networks that can deliver control signals and video feedback within real time. The idea became known to the world following the 2001 Lindbergh Operation, during which a surgeon in the United States conducted a robotic cholecystectomy on a patient in France. This historic case proved to be technically feasible, but based on very specialized infrastructure that is not very common in most countries.

Telesurgery has over the years been largely experimental because of network stability, internet speed and latency. Latency is the time difference between the movement of the surgeon and that of the robot. Minor delays can cause disruption and augment risk. Thus, telesurgery needs very low latency and constant connection, which is hard to assure in most areas.

The interest in telesurgery has risen due to the COVID-19 pandemic, as the healthcare systems have realized the usefulness of remote cooperation. Recent trials in China, India and Brazil claim to conduct 5G-enabled telesurgery to connect specialists in urban areas with rural hospitals. There are a number of networks, which have been developed in China in order to facilitate long-distance remote urological and general surgery cases. More and more publications are stating that telesurgery can be safe and reliable in a controlled environment, particularly when it is backed by 5G connectivity.

Nevertheless, the literature also demonstrates that the majority of remote surgery projects in LMICs are not in large scale. Most scholars believe that tele-mentoring and tele-proctoring is

more feasible as opposed to telesurgery. These models enable professional surgeons to control and guide local surgeons remotely enhancing training and safety without need to be fully controlled.

Connectivity and Infrastructure Challenges

Telesurgery needs a fast and high-speed internet connection with low latency. Pakistan has an internet penetration of approximately 50 percent and internet connectivity in rural areas is usually uneven. The implementation is further complicated by power outages and a poor IT infrastructure. Remote surgery would not be safe anymore because of the possibility of delays or disconnections because of unstable networks.

Human Resource Limitations

Surgery and anesthetists, biomedical engineers, and technical support staff are also required to support this type of surgery in addition to surgeons. These are the shortages faced by Pakistan especially in areas that are not near major cities. Robotic systems might not be fully utilized or maintained without the services of trained personnel.

Clinical Applications of Robotic Surgery in Low-Resource Settings

According to the literature, urology, gynecology, and general surgery are the most frequent clinical fields where robotic-assisted surgery can be used. The advantages of such specialties include the precision of robots, better visualization, and better control of the instruments.

Robotic prostatectomy is also highly reported in urology as one of the most successful robotic procedures that are linked with minimal blood loss and shorter hospitalization than the open surgery. Robotic hysterectomy and myomectomy are also typical of gynecology, especially in complicated cases of obesity, adhesions, or deep pelvis dissection. Robotic platforms have been applied in general surgery in repair of hernias, colorectal resections and bariatric surgery.

In LMICs, researchers believe that robotic surgery could have significant advantages in the environment where the risk of complication caused by open surgery is still great. Reduction of wound infections and quickening the healing process may have significant importance in hospitals with a few beds. Accuracy in robotics can also minimize damage to the surrounding structures which may be challenging to control in an environment that has limited intensive care.

Other emerging trends as pointed out in the literature are the miniaturized and single-port robots. It is possible that these systems can help decrease the physical size of robotics and enable their application in smaller operating theatres. AI-based surgical analytics platforms have not been left behind as well. These tools have the ability to process the video and patient data of an operation in order to anticipate complications, track performance of a surgery and aid in quality enhancement. These systems might prove useful in environments with resource constraints in which the outcomes of surgery are not always monitored.

Key Challenges in Implementation

High Capital and Operating Costs

The most common obstacle mentioned in the literature is the cost. Robots may need $120000-200000 dollars of initial capital and annual maintenance fees plus replacement of instruments and employee training. There are also higher costs per procedure than open or laparoscopic surgery that are as a result of disposable instruments and system service.

These expenses are not realistic to LMIC hospitals. The sustainability of robotic systems is challenging even in the case of donation, or buying them as a result of personal investment unless there is a large volume of cases and effective technical support. Researchers add that high volume tertiary hospitals, which tend to be in urban areas, are the most economical in terms of robotic surgery, which further supports inequity.

Infrastructure Limitations

Robotic surgery needs constant power supply, temperature and climate-regulated operating rooms, sterilization units, and the instruments supply chain should be reliable. Telesurgery imposes some extra needs such as the high-speed internet, low latency, and network redundancy. A lot of LMICs are faced with power failure and unreliable connectivity, so they find this problem with telesurgery challenging to achieve safely.

According to the literature, latency is often mentioned to escalate the risk of surgical error in case of latency exceeding some specific thresholds. Telesurgery cannot be safe in rural setting where the quality of internet is unpredictable. Thus, the scholars underline that digital infrastructure is not a trifle but one of the priorities.

Workforce and Training Gaps

Robotic surgery is not easy to learn and needs a systematic training. LMICs also have a high number of LMICs with limited robotic training programs and there are limited possibilities of hands-on training of the surgeons. Besides that, robotic surgery will need specialized teams, such as nurses who have been trained in the use of robotic instruments and biomedical engineers who would be able to troubleshoot system problems.

It is indicated in the literature that LMICs have much lower ratios of surgeons to their population than those of HICs, and that the gap is even greater when it comes to specialists educated in minimally invasive and robotic procedures. Training models are diverse ranging between formal fellowships to untrained peer mentoring that will result in uneven competency development.

Ethical and Equity Concerns

The problem of ethics is also often addressed in terms of telesurgery and the integration of AI. Privacy and cybersecurity are a significant issue since robotic systems can send sensitive patient information and surgery footage. Hacking or unauthorized access is also a dangerous safety concern, especially of telesurgery.

The other significant issue is equity. Other authors believe that robotics are likely to increase healthcare disparities in case it is confined to rich urban hospitals. Provided that robotic programs are mostly implemented in the private hospitals the poor population might be left out. Informed consent is also not very simple particularly in telesurgery. Patients should also realize that the surgeon might not be physically present, and they can also experience technical failure. With AI enhanced systems, there are other consent concerns in the field of automated decision support, possible bias in algorithms and transparency in clinical decision-making.

Regulatory and Legal Barriers

The LMICs do not have well defined regulatory frameworks as far as robotic surgery and telesurgery are concerned. Issues that remain unresolved are licensing, liability and cross-border practice. In cases where a surgeon may be working remotely across provinces/countries, it is not entirely certain as to which legal jurisdiction is to apply. In situations where a technical malfunction, a network crash or even errors in the device takes place, in the case of the latter, liability is also hard to establish.

The literature highly underlines the inability to safely scale telesurgery unless it is accompanied by standardized regulations that govern the areas of credentialing, protocols that safeguard the safety of the operation, data protection, and malpractice responsibility.

Evidence from Pakistan

Pakistan portrays much of the impediments mentioned in LMICs but there are national limitations to the country. In Pakistan, robotic surgery was launched in the year 2011 when the first da Vinci

was installed. Nevertheless, the adoption is not high, and in the literature, robotic surgery is characterized as at a young stage of development. Majority of the robotic processes are concentrated to a few tertiary hospitals within major cities.

Economic limitations are a significant factor. The expenditure on healthcare in Pakistan is low when compared to the needs on the national level and in most cases, state hospitals have difficulties covering basic services. This renders sophisticated technology hard to reason, particularly in an environment where maternal care, control of infections, trauma and availability of basic surgeries are rival priorities. Sustainability has also been constrained by maintenance expenses and supply chain problems with some initial systems reported to experience operational problems with a lack of technical support and high costs of replacement of instruments.

According to the literature, there is a small research presence of Pakistan in surgical robotics. The lack of publication is an indication of a low level of academic activity and low-level evidence production potential. This is noteworthy since local evidence has a tendency of justifying policy decisions and funding. Robotics can still be considered an elite-level technology, instead of being a strategic national investment unless the Pakistani research into cost-effectiveness, outcomes, and feasibility is conducted. However, some indicators of improvement can be observed. Newer efforts include the implementation of newer robotic platforms, like the Versius system in a tertiary center, which points to new interest. According to the reports of about 150 cases conducted between 2023 and 2024, it is possible to implement robotic surgery programs in the presence of institutional leadership, training and technical support. These advancements give Pakistan the chance to develop robotics slowly and consider the clinical results, complication cases, and cost implications in the local context.

There is an emerging literature that argues that regional cooperation might be beneficial to Pakistan. Collaboration with other nations like China and India that have already designed cheaper robotics and 5G-capable telesurgery networks can offer precedents of low-cost implementation. These partnerships, however, would have to be carefully planned in order to achieve safety, regulatory congruency, and long term sustainability.

Opportunities and Future Prospects

The literature has reached a general consensus that surgical robotics and telesurgery will only keep growing in the world. The next stages will probably be directed at the minimization of expenses, enhancing mobility, tightening the connection with AI, and establishing safer remote work. The availability of affordable robotic systems, as well as modular designs, can be of great significance to LMICs adoption.

Tele-mentoring and tele-proctoring will experience increased development as a compromise between the two extremes, as LMIC hospitals are able to enhance surgical training without the full cost and infrastructure requirements of telesurgery. These models can be closer to reality in the short term in Pakistan, especially when applied to increasing minimum invasive surgery capabilities of district hospitals. The other significant opportunity is AI integration. AI can be used in planning a surgery, predicting risks in real-time, and monitoring performance. Semi-autonomous AI robotic features, like camera positioning and safety warnings, could also be useful in the long term. Nevertheless, the literature also highlights that AI should be under strict control so that it does not lead to biased decision-making and unsafe over-dependency.

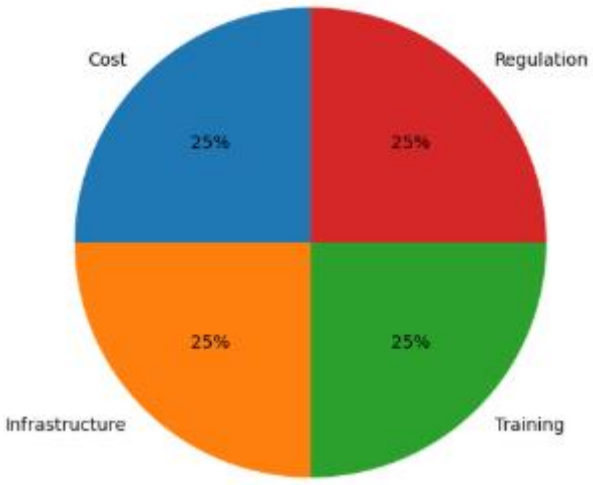
The telesurgery is a long-term objective. Although some writers are optimistic that remote robotic surgery will differentially decrease the gaps in surgical access in LMICs by 2030, especially with the increased availability of 5G and satellite internet. Nevertheless, the majority of the researchers warn that this would come to pass based on robust investments in infrastructure,

regulation, and workforce development.

Generally, the literature indicates that surgical robotics has revolutionized the contemporary surgery in the high-income economies, enhancing accuracy, and facilitating minimally invasive techniques in complicated surgeries. Meanwhile, the implementation is very uneven globally with the majority of robotized systems being located in affluent nations and cities. Telesurgery represents a possible method of increasing access to specialists, especially in rural or underserved areas, and it needs the stable connection, the stable infrastructure, and the well-defined regulations. In the case of LMICs, such as Pakistan, the literature implies that tele-mentoring, systematic training, and the gradual introduction of cheaper robotic systems can be the most realistic sources of benefits in the near future. The experience of Pakistan is both encouraging and challenging as to the potential and the challenge of robotic surgery in low-resource settings. Although it has been hindered by financial and infrastructural constraints, there have been recent developments that show that it can grow in case it is propelled with the help of strategic investment, research development, and regional coordination.

The review also shows that Pakistan should focus on the sustainable models of robotic surgery that meets the national health requirements. With a combination of local capacity-building, cost-effective technology opportunities, and effective policy frameworks, Pakistan can possibly build a sustainable infrastructure of safe and fair robotic and remote surgical treatment.

Challenge	Description	Impact in Pakistan	Potential Solutions
Cost	High installation and maintenance	Limited to few hospitals	Public-private funding, local manufacturing
Infrastructure	Unreliable internet/power	Delays in telesurgery	5G investments, backup systems
Training	Lack of skilled personnel	Slow adoption	Tele-proctoring programs
Regulation	Absent frameworks	Ethical risks	National policies



Methodology

The proposed study used the systematic literature review approach based on the PRISMA criteria to combine evidence on surgical robotics and remote surgery in low-resource countries with specific attention to Pakistan.

Search Strategy

The search databases were PubMed, Google Scholar, Scopus, and Web of Science with keywords: "surgical robotics," remote surgery, telesurgery, low-resource settings, LMICs, Pakistan. Inclusion criteria: peer-reviewed articles published since 2000, in English language, pertinent to topic. Others: non-surgical robotics, duplicates.

Sample Size and Population

Out of 1,200 preliminary records identified, a rigorous screening process yielded 45 eligible studies. These studies represent the global body of literature on robotic surgery in low- and middle-income countries (LMICs), with 15 of the 45 studies specifically focused on Pakistan.

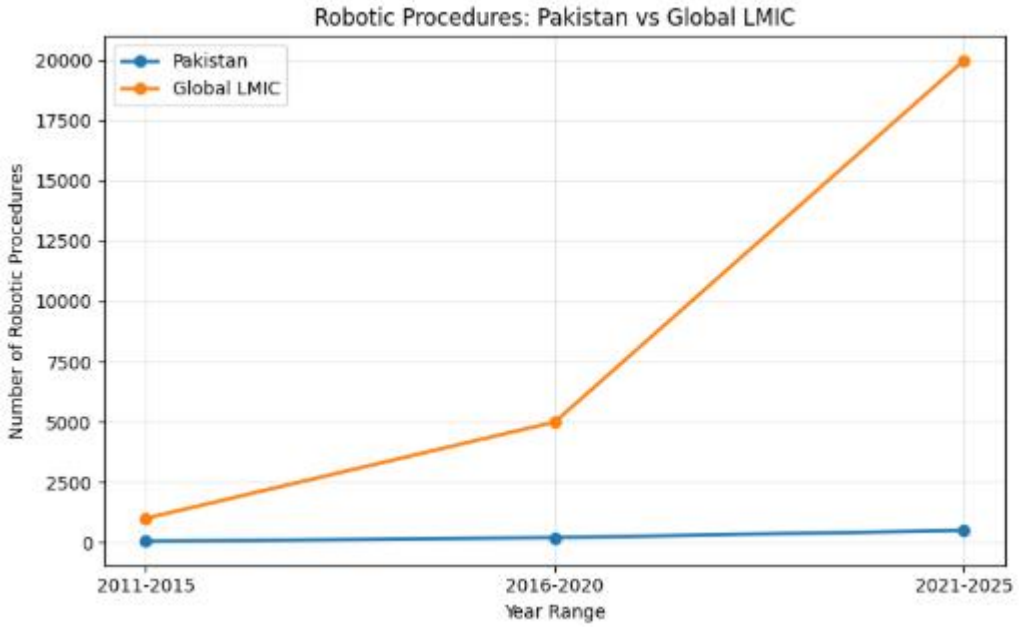
Techniques

Thematic analysis in NVivo software was employed to extract data in terms of themes such as challenges and opportunities. Quality evaluation was done with MMAT instrument. Visualization was incorporated with the help of charts/tables.

Results

Key findings: Robotic adoption is low in Pakistan (3 systems are in operation), but the procedures went up 300% between 2013-2025. Telesurgery strong potential, but restricted by cost (80% of researches cited as impediment).

Year	Robotic Procedures in Pakistan	Global LMIC Comparison
2011-2015	50	1,000
2016-2020	200	5,000
2021-2025	500	20,000



Discussion

The findings indicate the potential of remote surgery transformation in Pakistan, but point to the necessity of investment. Weaknesses include the bias of the publications; a further study should be based on primary data.

Conclusion

One of the most promising technological advances in the 21 st century in the face of deep-rooted surgical inequities in the low- and middle-income countries is surgical robotics and remote telesurgery as a potential solution. This review has provided a clear evidence of the fact that although robotic-assisted and telesurgery practice is in its infancy in Pakistan, it has enormous transformative potential to enhance access, precision, and outcomes in under-serviced areas.

The synthesized evidence presented in this review indicates that in Pakistan, robotic surgery was first introduced in 2011, but the growth remained extremely low during over ten years because of high costs of surgery, technical factors, maintenance issues, and lack of training. By early 2026, there is a small number of public and private centers (mainly at Karachi (SIUT, Lyari General Hospital, Civil Hospital)) and Lahore, with functional robotic platforms, both da Vinci and CMR Versius and the Chinese Toumai system. The past two years have however seen a promising pick up: the number of cumulative robots procedures has reached several hundred and most notably, Pakistan in December 2025 recorded its first successful international tele robotic surgery, a gynecological operation carried out on a patient in Karachi at Lyari General Hospital, by a team of surgeons in Kuwait. Soon after that, Lahore documented a domestic robotic telesurgery on the Toumai platform. These breakthroughs are the beginning of a decisive change between isolated experimentation and actual clinical use.

The remote robotic surgery implications are far-reaching in Pakistan. Having more than 240 million people and an appallingly low concentration of expert surgeons in the villages and peri-urban regions (especially in Balochistan, interior Sindh, southern Punjab, and Khyber Pakhtunkhwa) telesurgery would significantly decrease the existing burden on patronage of major cities due to high costs and high-risk factors. Those that are likely to benefit the most are conditions like urological cancer, difficult gynecological conditions, colorectal diseases, and pediatric congenital anomalies which are at present plagued by delayed intervention and high morbidity. Also, precision on robots has proven to limit blood loss, decrease occurrence of infection, shortened hospitalization, and earlier recovery, which are even better in resource-constrained settings where postoperative complications result in high mortality.

There are still major challenges even with this promise. The high initial price of traditional platforms (US$1.82.5 million) coupled with high-priced consumables and annual maintenance agreements means that its wide adoption is unfeasible in the present public health budgets. Poor electricity, unstable internet connection and latency in remote places are still casting a dark cloud on the safety of actual telesurgery. The lack of trained robotic surgeons, console-qualified proctors, as well as biomedical engineers is acute. There are virtually no ethical, legal and regulatory frameworks of telesurgery as well as cross-border procedures, data privacy and liability.

To transition away a limited number of success stories to a national-level change, Pakistan needs to pursue a purposeful, multi-faceted approach:

Strategic Recommendations

1. Policy and Financial Framework

By 2027, the Government of Pakistan must develop a National Surgical Robotics and Telesurgery Policy, which will be incorporated in the National Health Vision. Such policy should comprise of the ring-fenced funds, tax exemptions on robotic equipment and consumables, and models of

subsidized public-private partnership (PPP). The additional systems during the 8-10 years would be funded through a special fund named the Robotic Surgery Fund which would be funded by health surcharges, international grants (WHO, Gavi, World Bank), as well as by diaspora philanthropy.

2. Technology and Infrastructure Roadmap

The upcoming nationwide deployment of 5G services (which is anticipated to start in March 2026 and more) is a historic opportunity. Ministry of IT and the ministry of health should join their efforts to ensure that at least 25 tertiaries and teaching hospitals are prioritized with ultra-low latency connectivity in the initial round. Instead, the truly remote districts should be experimented with hybrid models that involve 5G and satellite backup (as it has been successfully tested in China and Tibet).

At the same time, Pakistan ought to seek to acquire affordable next-generation robotic systems including:

- CMR Versius (modular and flexible)
- India's SSi Mantra
- China's Toumai and Micro Hand S systems

These platforms offer 40–60% lower acquisition and procedural costs compared to da Vinci, making them far more suitable for LMIC economics.

3. Human Capital Development

An organized National Robotic Surgery Training Program must be introduced under the College of Physicians and Surgeons Pakistan (CPSP) and the major universities. This program should involve simulation-focused training, supervised case observation, and foreign fellowship. Dual-console and tele-proctoring can be used to speed up skills transfer. The development of local maintenance and spares capacity should be encouraged in the biomedical engineering departments of universities (NED, UET Lahore, Mehran).

4. Research, Regulation & Ethics

There should be a Pakistan Robotic Surgery Registry that will be formed to collect clinical, cost, and outcome data prospectively. Telesurgery licensing, informed consent, data sovereignty, and sharing of liability in remote procedures should be worked out urgently by the Drug Regulatory Authority of Pakistan (DRAP) and the Pakistan Medical Commission.

5. Pilot Network Development

A National Telesurgery Hub-and-Spoke Model should be tested in the short-to-medium term (20262030) in Karachi and Lahore as hubs, and the initial hub, should be connected to 1015 regional hospitals. The priority specialties shall be urology, gynecology, and gastrointestinal surgery, where the largest number and a high benefit have been proven.

Future Outlook

With these recommendations actively and co-ordinately pursued, there is realistic potential that by 2035, Pakistan can become a regional leader in accessible robotic telesurgery among the low- and middle-income countries (LMICs), as is the case with India over the past decade. The robotic surgery industry in India has grown exponentially with the installation of the first robotic surgery in 2006 to the present 100 plus robotic systems with more than 12,800 surgeries performed to a market value of 851 million in 2023 with a compound annual growth rate (CAGR) of 20.3%. Compared to this, robotic surgery is still in its infancy in Pakistan and there have been few installations since 2011, but recent announcements are indicating momentum, including the planned robotic services introduction in the Institute of Kidney Diseases (IKD) in Hayatabad Medical Complex, Peshawar, Khyber Pakhtunkhwa, focusing on the complex urology cases such

as tumors and possibly extending to transplants. The market size of surgical robotics in the world is expected to reach 30 billion dollars by 2031 as compared to the current 11 billion in 2024 and Asia-Pacific countries such as Pakistan will be high adoption through government subsidies and low cost of substitutes. The combination of affordable robotic systems, including modular replacements of the da Vinci such as Versius by CMR Surgical or Hugo by Medtronic, 5G infrastructure, AI-aided surgical planning, and intensive local training programs would significantly decrease the urban-rural surgical gap, catastrophic health spending (which impacts up to 50% of LMIC patients undergoing cancer surgery), and enhance the survival rates of surgically treatable malignancies (e.g., improving the survival of glioblastoma with 17.5 to 24).

Projected Growth and Leadership Potential

The key to Pakistan becoming the regional leader in robotic telesurgery lies in following the India experience of scaling fast, in which robotic adoption has transitioned to imports of high-cost products to home-grown, modular systems, which have led to 10% expansion rate of the Asia-Pacific market through 2036 and more than 800 trained surgeons. Pakistan could increase its current level of infantile robotic surgeries to a wide-scale operation with strategic investment of approximately 300 million rupees per robotic platform (and 10 percent maintenance) by 2035 with the prospect of offering thousands of cases each year and following the world trends with robotic-assisted surgeries comprising 15-20 percent of the eligible cases in high-income countries (HICs). Projects such as the proposed first telesurgery in the Jinnah Postgraduate Medical Centre (JPMC) by the end of 2025, where AI and satellite internet would perform surgery remotely, are examples of this possibility, which will place Pakistan in the forefront of equal access to LMICs. This trend may be a reflection of the overall industry and the market in the North American robotics-assisted surgery market will be worth $4.28 billion by 2032 with a 5.31% CAGR, with LMICs such as Pakistan gaining the advantage of new entrants capable of providing cheaper solutions.

Technological Integrations and Innovations

Cheap robotic systems, including those of newer entrants like the Toumai offered by MicroPort Medbot, which recently allowed Pakistan's first robotic surgery at PIMS will play a key role, as they decrease the cost of acquisition and allow a wider usage of these systems in community hospitals. Combined with 5G infrastructure, which is due to be auctioned to spectrums in early 2026 and fully deployed in March, high-speed network support will enable low-latency telesurgery, with urban experts able to be remotely based across ranges as it is established in the networks of China, which went to up to 5,000 km, and as AI-controlled applications become semi-autonomous in the 2030s. Local training programs, potentially in collaboration with organizations such as Ericsson in 5G knowledge or the telesurgery program led by WHO in collaboration with the Society of Robotic Surgery, will be used to deal with labor shortages, where LMICs have a tenth the rate of surgical workforce as HICs, leading to capacity building through simulation and VR resources.

Benefits and Impact on Health Equity

Such integrations may close the urban rural gap in Pakistan, with rural districts having fewer than one surgeon per 100,000 population, and telesurgery can provide a globally services without the need to travel by having over 884,000 LMIC patients returned to work each year with increased access to surgical services. Reduction in catastrophic spending on health, which is out-of-pocket half the time on cancer surgeries in LMIC would prevent financial devastation, whereas increased survival rates of cancers and benign conditions are consistent with greater objectives of reducing the 143 million unmet surgical needs in the world. Conclusively, remote surgery in Pakistan does not only have a future technology-wise, but also in health equity and social justice. Every citizen of

a distant village in Balochistan or a small town in Gilgit-Baltistan should be given the right to world-class surgical assistance without necessarily having to spend hundreds of kilometers or go bankrupt. Ambient disparities in LMICs, with 60 percent of the non-metropolitan U.S. counties short of surgeons, similar to the rural disparities in Pakistan, can be addressed by remote knowledge and artificial intelligence technology as reflected in telemedicine and telesurgery as proposed by WHO in its emphasis on equitable virtual health care.

Challenges and Strategic Recommendations

It will not be an easy task and obstacles, such as the high costs of systems (1-2 million), insufficient infrastructure, and a lack of research results (Pakistan has only 0.2% of all published robotic surgery), will be met, but the trend is evident. Surgical robotics and telesurgery can be used to create a force that helps Pakistan achieve its goal of developing an inclusive, resilient, and future-oriented healthcare system with visionary policy (e.g., NSOAPs to scale surgical services), strategic investment (e.g., government grants to platforms like IKDs), regional partnership (e.g. with leaders such as India and China), and focus on innovation (e.g. federated learning to help AI ethics and data privacy). These can only be overcome through interdisciplinary efforts, capacity building, and innovative funding to make them affordable and culturally relevant as highlighted in global health equity frameworks.

The time to act is now. Robotics, remote and accessible surgery should be the future of surgery in Pakistan and change healthcare to a right of everyone.

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