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Review Article on Future Status of Robotic Assisted Surgeries in Developing Countries

Abstract:

Robotic-assisted surgery has transformed modern operative care by enhancing precision, dexterity, visualization, and minimally invasive capabilities. This review explores the evolution of robotic surgery and examines its future prospects in developing countries. Beginning with early computer-assisted surgical systems and progressing through telesurgery innovations, robotic platforms—particularly the da Vinci system—have demonstrated improved surgical accuracy, reduced complications, and faster patient recovery in selected procedures.

Despite these advantages, adoption 6 in low- and middle-income countries remains limited due to high acquisition and maintenance costs, infrastructure constraints, limited technical expertise, and disparities in healthcare access. Challenges such as inadequate training programs, unreliable power supply, insufficient digital connectivity, and lack of policy support further restrict widespread implementation. However, emerging developments in telecommunication technologies, virtual reality integration, and telesurgery offer promising solutions to bridge geographic and resource gaps.

The future of robotic-assisted surgery in developing regions depends on strategic investment, cost-reduction initiatives, international collaboration, and capacity-building in surgical education. Public–private partnerships, locally adapted robotic platforms, and tele-mentoring models may facilitate equitable access and strengthen surgical systems. Robotic surgery has 3 the potential to improve surgical outcomes and expand advanced care delivery in resource-limited settings. With appropriate planning and sustainable integration, robotic-assisted technologies could become an important component of modern healthcare in developing countries.

Key Words: Robotic assisted surgery, Developing countries, Future status.

INTRODUCTION

Even though the concept and presence of "robots" are relatively modern, the notion of machines operating independently dates back centuries.1 The word "robot" was introduced by Josef Čapek in 1921 in the play Rossum's Universal Robots, derived from the Czech term robota, meaning "labor." Over time, the term came to be associated with machines designed to perform repetitive, task-oriented work. Technologies such as computer assistance, robotics, automation, and virtual reality are comparatively recent developments and have only more recently been integrated into healthcare.1 In recent decades, medical technology has advanced at an exponential pace, with the introduction of robotic platforms in surgery representing one of its most significant milestones. Although robots were first used in surgery over 30 years ago, they have since become an established standard of care and have produced noteworthy outcomes.

BACKGROUND

The concept of building automated machines capable of performing tasks traditionally done by human hands has existed for a long time. In surgery, its earliest applications emerged more than six decades ago within the military. Combat situations often occur in hazardous environments that are difficult—or even unsafe—to access, where adequate medical care is frequently unavailable. The areas nearest to the point of injury are often those with the fewest resources and personnel. Because hemorrhagic shock and polytrauma are leading causes of early death in combat, the military recognized the urgent need to deliver specialized surgical treatment based on damage control principles immediately after severe trauma. This led to a shift from the traditional "Golden Hour" model—transporting injured soldiers to distant hospitals—toward bringing surgical capability closer to the battlefield, enabling rapid intervention within a "Golden Minute" framework.

Virtual reality pioneer Scott Fisher created the first head-mounted display (HMD), allowing users to experience a fully immersive three-dimensional environment, while engineer Phil Green developed a robotic telemanipulation system for microsurgery at the

Stanford Research Institute. Together, the concepts of telepresence and robotic telemanipulation laid the foundation for the development of telesurgery.

SUMMARY OF ROBOTIC SURGERY DEVELOPMENT

The journey of robotic surgery began in 1985 with the Programmable Universal Machine for Assembly 200 (PUMA), which was the first robotic platform used on human patients for neurosurgical biopsies.3 This technology was subsequently adapted for urologic procedures by The Robotics Centre at Imperial College. By 1992, the Robodoc® Surgical System was developed for prosthetic hip replacements, becoming the first robotic system approved by the FDA for orthopedic surgery.

In the 1990s, significant advancements were made with the introduction of the master-slave concept, allowing remote control of robotic movements.4 The company Computed Motion, founded in 1990 by Yulun Wang and supported by DARPA, created the AESOP® (Automated Endoscopic System for Optimal Positioning), a voice-controlled robotic arm for endoscopic procedures.5 The first model, AESOP 1000, was approved in 1994, and its successor, AESOP 2000, introduced voice control, reducing the need for an assistant to hold the endoscope. The AESOP platform continued to evolve, culminating in AESOP HR, which integrated various operating room functions, enhancing surgical efficiency.6

Despite these advancements, surgeons still required enhanced control over their movements. In 1998, Computer Motion introduced the ZEUS system, which allowed surgeons to manipulate surgical instruments from a distance. The ZEUS robot featured three arms, one for the endoscope and two for surgical instruments, and was first used at the Cleveland Clinic for uterine tube anastomosis surgery. This system also enabled remote surgeries, exemplified by Operation Lindberg, where a surgeon in New York controlled a robotic arm in France to perform a cholecystectomy.7

In 1995, Intuitive Surgical was founded by Frederick H. Moll and Robert Younge, developing the first robotic surgical prototype known as Lenny, which featured three robotic arms.8 The second generation, named Mona, was used in human trials for procedures including cholecystectomy and gastric banding. Intuitive Surgical's major breakthrough came in 1998 with the introduction of the da Vinci Surgical System, which became the most successful robotic surgery platform. The da Vinci system received FDA approval for general laparoscopic procedures in 2000 and was instrumental in significantly less invasive cardiac surgeries.9,10

In 2003, following a legal merger, Intuitive Surgical absorbed Computer Motion, discontinuing the ZEUS system but integrating its technologies into future projects. This merger marked a pivotal moment in robotic surgery, combining strengths to develop more advanced surgical technologies.11

Overall, 2 the evolution of robotic surgery reflects a continuous effort to enhance precision, minimize invasiveness, and improve patient outcomes through technological innovation.

1 THE DA VINCI ERA: ADVANCEMENTS IN ROBOTIC SURGERY

The Da Vinci Era marks a significant chapter in the evolution of robotic surgery, culminating from around 35 years of technological advancements. While Intuitive Surgical Inc. has been operational for over 20 years, 2 the Da Vinci system represents a major leap forward in surgical technology.12

Key Developments

 Telepresence Surgery Concept: Inspired by the work of Phil Green, Richard Satava, 1 and the Stanford Research Institute (SRI), telepresence surgery aimed to allow surgeons to operate remotely. This concept led to the development of the Medical Forward Area Surgical Team (MEDFAST), a prototype robotic system that could be used in battlefield conditions.

 Inspiration for Intuitive Surgical: The first successful remote surgical procedure involved an intestinal anastomosis on an ex-vivo pig, which motivated Frederick H. Moll to establish Intuitive Surgical and further develop the telepresence concept.12

Da Vinci System Features

- Three Components: The Da Vinci system consists of a patient cart, a surgeon console, and an advanced imaging system. All robotic arms originate from a single patient cart, solving positioning issues associated with earlier systems.
- Enhanced Surgical Instruments: The system has seven degrees of freedom and two axial rotations, mimicking human wrist movements. The surgeon console features a stereoscopic viewer, providing high-focus and reducing fatigue.
- 3D Visualization: Utilizing a new 3D endoscope, the Da Vinci system projects images onto two synchronized screens, creating a realistic 3D view without the need for special goggles.
- FDA Approval: The initial Da Vinci robot received FDA approval in 2000, and a four-arm version was launched in 2002 to enhance surgical capabilities.12

Subsequent Improvements

- Da Vinci S Platform (2006): This version introduced 3D high-definition camera technology along with an interactive touch-screen display, streamlining the surgical setup.
- Da Vinci Si Model (2009): Became widely popular and introduced dual-console surgery for improved training and collaboration. It also featured advanced imaging options with Tile-Pro software and Firefly technology for real-time fluorescence imaging.
- Da Vinci Xi System (2014): The most advanced model to date, the Xi system redesigned the patient cart for enhanced mobility and flexibility. Its new architecture allows for docking from any angle, improving access around the patient.13

Technological Innovations

- Improved Arm Design: The Xi model features compact arms that minimize external collisions and enhance the range of motion.
- Integrated Table Motion (ITM): This technology allows dynamic repositioning of the patient during surgery without removing instruments, making multi-quadrant procedures more efficient.
- Advanced Instruments: The Xi system includes redesigned robotic ports and enhanced

Endowrist technology for better maneuverability. New energy devices improve performance and efficiency in sealing and cutting vessels.

 Single-Site Technology: Improvements in single-site access instruments have enhanced 1 range of motion and reduced bulkiness, allowing for more complex minimally invasive procedures.

Impact on 2 Surgery

The Da Vinci robotic platform has revolutionized minimally invasive surgery, offering numerous benefits such as:14

 High-definition, three-dimensional visualization

 Surgeon-guided, stable camera operation

 Improved ergonomics and motion scaling

 Enhanced dexterity in suturing and other tasks

Recent studies have highlighted the advantages of robotic-assisted surgery in various fields, including 1 visceral surgery, urology, and colorectal procedures. Positive outcomes have been reported in complex abdominal wall reconstructions using robotic platforms.15-16

In summary, the Da Vinci Era represents a transformative phase in robotic surgery, addressing the limitations of traditional laparoscopic methods and 3 paving the way for more efficient, minimally invasive surgical techniques.

POTENTIAL BENEFITS OF ROBOTIC SURGERY INTEGRATION IN DEVELOPING COUNTRIES

Integrating robotic surgery into healthcare systems 5 in Low- and Middle-Income Countries (LMICs) offers several distinct advantages beyond the commonly recognized benefits. Here are some key potential benefits:

1. Reduction 4 of Surgical Site Infections (SSI)

 Lower Infection Rates: Robotic surgery typically involves smaller incisions compared to open surgery, which significantly reduces the risk of SSIs. This is particularly crucial in

LMICs, where SSIs are more prevalent and antibiotic resistance is a growing concern.17-18

- Shorter Hospital Stays: By minimizing SSIs, robotic surgery can lead to quicker recoveries, allowing patients to be discharged sooner. This helps [4] reduce the risk of nosocomial infections and conserves hospital resources, which is vital in overcrowded tertiary hospitals.19

2. Enhanced Safety and Hygiene

- Physical Separation: Robotic systems allow surgeons to operate from a console away from the patient, decreasing direct contact and the risk of infectious disease transmission, especially important during the COVID-19 era.20

3. Increased Surgical Capacity

- Addressing Surgeon Shortages: LMICs represent nearly half of the global population but host only 19% of the world's surgeons. While training more surgeons is essential, robotic surgery can help bridge this gap by enabling telementoring and telesurgery.21
- Remote Operations: Telesurgery allows experienced surgeons to operate remotely or guide less-experienced surgeons in real-time, overcoming geographical barriers and increasing surgical output.21

4. Educational and Research Opportunities22

- Local Hubs for Innovation: Institutions equipped with robotic surgical systems could serve as educational centers, offering training and research opportunities to improve surgical practices across LMICs.
- Tailored Solutions: Researchers in LMICs can adapt robotic systems to better fit local healthcare needs, potentially leading to innovations that address specific challenges faced in these settings.

5. Cost-Effectiveness23

- Healthcare Cost Reduction: While the initial costs of robotic-assisted surgeries may be higher, studies suggest that overall healthcare costs can be lower due to reduced post-discharge healthcare needs. This can offset the initial expenditure and make robotic surgery a financially viable option in the long run.

- Local Manufacturing: LMICs could consider developing their own robotic instruments to enhance affordability and accessibility, helping to close the surgical access gap with High-Income Countries (HICs).

POTENTIAL CHALLENGES TO ROBOTIC SURGERY INTEGRATION IN THE DEVELOPING COUNTRIES

While the integration of robotic surgery in the developing countries holds significant promise, several challenges hinder its implementation. Here are some key obstacles:

1. Financial Constraints

- High Initial Costs: The implementation of a robotic surgical platform can exceed $1 million, with additional costs of $3,000 to $5,000 per procedure. This financial burden is often untenable for healthcare systems in LMICs.24-25
- Transport and Insurance Issues: Many patients face financial barriers related to transportation and a lack of insurance coverage. For instance, studies in Colombia showed that robotic cardiac surgeries can cost significantly more than traditional procedures, creating further disparities in access to care.26

2. Socioeconomic Inequality

- Limited Accessibility: Robotic surgery is primarily available in wealthier communities, perpetuating socioeconomic inequities. Underserved populations often lack access to such advanced medical technologies, exacerbating existing disparities in healthcare.27

3. Shortage of Trained Surgeons

- Insufficient Training: There is a significant shortage of surgeons skilled in robotic techniques, and training programs are often not standardized. This inconsistency increases the risk of medical errors, jeopardizing patient safety in regions lacking proper training infrastructure.21
- Limited Simulation Resources: While simulation training with 3D models could enhance skills, such technologies may not be accessible in underserved communities.

4. Network and Connectivity Issues28

- Challenges with Remote Telesurgery: Although remote telesurgery offers a potential solution to bridge the gap in access, it requires reliable network connectivity. A delay of 300 ms is the maximum compatible with safe robotic surgery, which poses challenges in areas with poor internet infrastructure.
- Future Connectivity Solutions: While advancements like 5G technology could improve network reliability, the implementation timeline extends to 3–5 years in many LMICs, delaying access to these technologies.

5. Lack of Data

- Cost Transparency: There is a scarcity of comprehensive data detailing the costs associated with robotic platforms and their maintenance, making it difficult for healthcare providers to plan budgets effectively.[29]

Conclusion

Socioeconomic barriers remain a major obstacle to broader access. Expanding universal licensing for robotic technologies could increase market competition and product availability, which may help lower acquisition and installation costs. Additional strategies to ease this burden include promoting resource and equipment sharing among high-income countries (HICs), developing multinational cloud-based systems, and providing targeted subsidies to support implementation in hospitals located in remote regions. Strengthening transportation networks and logistical infrastructure could further improve access for underserved areas.

Effective use of surgical robots requires comprehensive training, including simulation-based practice in dry and wet laboratories, structured console training, and opportunities for independent experience—resources that are often limited in developing countries. Collaborative “twinning” partnerships between institutions in high-income countries and facilities in low- and middle-income countries (LMICs) can expand access to training, research, and clinical expertise, thereby supporting the growth of robotic surgery programs. Overall, robotic surgery offers significant potential advantages for developing countries. However, further research focused on regional challenges and context-specific improvements is essential to support broader adoption and to enhance the quality of surgical care in these settings.

Conflict of interest: No conflict of interest was declared by any of the co-authors.

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