Journal of
Engineering Education
and Practice

Https://journaleep.com
Editor@journaleep.com
ISSN (Print) : 3080-6747
ISSN (Online) : 3080-6755

EXPLORING THE USE OF ROBOTICS IN HEALTHCARE: INNOVATIONS IN SURGICAL ASSISTANCE AND REHABILITATION TECHNOLOGIES

Article History

Received:
August 28, 2025

Revised:
September 29, 2025

Accepted:
November 18, 2025

Available Online:
December 31, 2025

Kamran Iqbal[1*] Arslan Nadeem[2]

[1]Department of Chemical Engineering, Punjab University, Lahore, Pakistan

[2]Department of Computer & Electrical Engineering, University of Lahore, Pakistan

*Corresponding Author E-mail: kamran.iqbal@pu.edu.pk

Abstract

The integration of robotics into healthcare represents a paradigm shift in medical practice, enhancing precision, consistency, and accessibility. This study investigates the dual domains of robotic surgical assistance and robotic rehabilitation technologies, evaluating their clinical efficacy, economic impact, and patient outcomes. In surgical robotics, systems like the da Vinci Surgical System have transitioned from novelty to standard of care for numerous procedures, offering minimally invasive options with improved dexterity and visualization. Concurrently, in rehabilitation, robotic exoskeletons and assistive devices are revolutionizing physical therapy for stroke, spinal cord injury, and neurological disorders, providing high-dose, repetitive, and data-driven therapy. Through a mixed-methods analysis incorporating clinical trial data, cost-benefit models, and user acceptance surveys, this research assesses the tangible benefits and limitations of these technologies. Findings indicate that robotic-assisted surgery significantly reduces patient hospital stays, blood loss, and complication rates in procedures like prostatectomy and hysterectomy, though high capital costs remain a barrier. In rehabilitation, robotic devices demonstrate superior motor recovery outcomes compared to conventional therapy alone, due to personalized assistance and objective progress metrics. However, challenges persist, including technology affordability, clinician training requirements, and the need for more robust, long-term outcome data. The study concludes that robotics in healthcare is moving beyond augmentation towards essential transformation, but its sustainable integration necessitates focused policy on reimbursement models, interdisciplinary training, and continued innovation to improve cost-effectiveness and accessibility for diverse healthcare systems globally.

Keywords: Surgical Robotics, Rehabilitation Robotics, Medical Innovation, Minimally Invasive Surgery, Assistive Technology, Clinical Outcomes, Healthcare Economics

INTRODUCTION

One of the most striking technological developments in the contemporary medicine, one must mention the emergence of robotics in the healthcare sector that has offered the unparalleled opportunities to expand human knowledge, overcome physiological boundaries, and provide effective and high-quality care. Improvement of patient outcomes and streamlining of the clinical processes have led to the modularization of the originally industrial and military robots to the extremely demanding requirements of the medical setting (Taylor et al., 2016). There are two notable applications that are of interest in the given studies, namely, robotic surgical aid and robotic rehabilitation technologies.

Robotic-assisted surgery (RAS) has become a significant aspect of the procedure of a minimally invasive surgery since its inception in the late 1980s. Surgeons can also have the benefits of excellent 3D high-definition visualisation, tremor elimination, and articulating instruments that replicate the dexterity of a human wrist, but have greater scope of movement with systems like da Vinci platform (Herron & Marohn, 2008). This synergy in technology only comes with operation in terms of better suture deployment and dissection, reduced tissue destruction as well as surgeon ergonomics. Therefore, RAS is now considered as the standard that should be applied when performing such procedures as radical prostatectomy and is being employed more and more when performing cardiothoracic, colorectal, and gynaecological surgery. Its capability to decrease surgical variability, cut down on recovery period as well as the complications is what makes it have therapeutic potential (Barbash & Glied, 2010).

There has also been robot advancement in the field of physical medicine and rehabilitation and the operating theatre. Rehabilitation robotics consists of the devices that allow weight-assisted gait training to people with spinal cord injuries or stroke powered exoskeletons (such as EksoGT and ReWalk) or end-effector-based systems (such as the MIT-Manus to the upper limb) (Riener, 2016). The underlying principle is the delivery of assist-as-needed therapy, physical aid at highly particular levels of tuning so as to enhance neuroplasticity and relearning of motor skills. According to Marchal-Crespo and Reinkensmeyer (2009), these methods help resolve several of the significant problems of traditional therapy and they are therapist burnout, subjective attitude towards the help, and high-intensity, repetitive practice which is essential towards recovery.

The healthcare sector is one of the areas where robotics can work but it is a difficult one. The upfront expenses of surgical robots are prohibitively expensive to others (over $1 million) and the yearly maintenance expenses are steep, which puts the concept of equal access and inflation of healthcare costs into question (Childers and Maggard-Gibbons, 2018). The cost of equipment and special training may have limitations of implementation in a clinical and community-wide setting within the rehabilitation context. Also, even though the amount of data is increasing, it still must be expanded with solid, multi-centre randomised controlled trials to demonstrate beyond a reasonable doubt that it can deliver superior long-term results and be economical in comparison with traditional procedures (Veerbeek et al., 2017).

The purpose of this paper is to present an overview of those developments in a synthesised form of the latest clinical evidence, the monetary implications and to examine the issues of implementation. The given study will enlighten physicians, health care administrators as well as policymakers on the present and future outlook of these radical technologies by comparing the paths, impact and challenges of robotics in rehabilitation and surgery.

METHODOLOGY

In order to address the main issue of assessing the practical usefulness, financial feasibility, and obstacles to implementation of the robots to the surgery and rehabilitative practices, the research procedure in this paper is a problem-focused quantitative research method. The strategy is expected to be rather data oriented examination of the effects of the technology on a specific healthcare issue, which is, in this case, to enhance surgical performance and the necessity to offer scalable efficient rehab. The clinical outcome analysis, health economic modelling and technology adoption benchmarking are the three pillars of the analytical framework the research design is founded on. Firstly, the meta-analysis of clinical data was structured and compiled. Surgical robotics received the task to extract quantitative information on a selective body of peer-reviewed articles (2015-2023) regarding robotic-assisted versus laparoscopic or open procedure in prostatectomy, hysterectomy, and colectomy. These outcomes were operative time, blood loss during the operation, conversion to the open surgical procedure, length of hospital stay (LOHS) and the postoperative complication rates (Clavien-Dindo classification). The standardised scales used to assemble data on patient outcome of trials in the use of the devices such as Lokomat and Armeo in robotics of rehabilitation comprised Walking Index of Spinal Cord Injury (WISCI II), improvements of Berg Balance Scale, and Fugl-Meyer Assessment (FMA) of upper limb recovery. Second, cost-benefit model and budget effect were created. It was a model that equated the quantifiable returns (lowered LOHS, lower readmissions, quicker return to work) to direct (equipment purchase/lease, maintenance, consumables, operating room time) and indirect (training, potential problems) costs. The Incremental Cost-Effects Ratio (ICER) of robotic and standard care on defined indications was calculated in 5 years with a discount rate of 3. Third, an adoption and utilisation investigation was conducted based on the findings of a survey of hospital administrators and heads of therapeutic departments, and large-scale administrative data (where available). It was a Likert-scale research which studied the main barriers (cost, complexity of training, perception of evidence), determined the rates of adoption, found the correlation with the hospital variables (teaching status, bed size). All the major economic and outcome factors were sensitivity analysed so as to find out the reliability of the findings. This is a logical, quantitative research design, which guarantees that the results are directly correlated to the resolving of the issues of commercially viable technology implementation in healthcare systems and clinical outcome optimisation.

RESULTS

The quantitative analysis results in a multifaceted, large scale picture of the impacts of robots in surgery and rehabilitation The comparison of the clinical outcome of Open Radical Prostatectomy (ORP) and robotic-assisted laparoscopic prostatectomy (RALP) compares it in Table 1. RALP experienced a statistically significant reduction in the median blood loss (150 ml vs. 800 ml), LOHS (1.5 days vs. 3.5 days) and 30-day complication rates (12% vs. 22%) as demonstrated in Figure 1 (Bar Chart).

Table 2 demonstrates the baseline and change of the motor functioning of stroke patients under exoskeleton in upper limbs in comparison to normal therapy in the 8 weeks. The average over the control group was 7.2 FMA-UE improved compared to 12.5 points (p<0.01) of the exoskeleton group and the improvement rate per week of robotic therapy group.Figure 2 (Line Chart) depicts the improved recovery process in the exoskeleton therapy group and the progress every week.

The health economic analysis results were complex.Table 3 shows the 5-year Total Cost of Ownership (TCO) of a da Vinci Xi system in a mid-volume hospital with current volume of 250 cases/year. The TCO prepared consisted of depreciation, servicing and instruments that made about 3.2 million dollars. Table 4 of the third year of the calculations of the balancing saving of less LOHS and complications of the three major procedures demonstrates that the net annual saving of the operation is 450,000 dollars as shown in Figure 3 (Waterfall Chart) which indicates the net benefit point.

Table 5 relates the exoskeleton assisted gait training and two therapist manual body-weight support training in terms of cost per therapy session as part of rehabilitation robotics. The robotic session offered a 35 per cent greater functional enhancement per dollar invested because the duration of training was greater and more frequent though it lies in the high-gain quadrant of Figure 4 (Scatter Plot), the cost per session versus functional gain (WISCI II change).

Institutional attributes had a close correlation with patterns of adoption.As Table 6 indicates, hospital attributes and the acquisition of surgical robots are strongly related. The adoption rate was 25 percent in community hospitals with less than 200 beds and 85 percent in Teaching hospitals and hospitals that had more than 400 beds as presented spatially in Figure 5 (Heat Map).

According to Table 7, the five most perceived barriers to adoption in the two industries are reported by the surveyed people. The first cost (95 percent surgery, 88 percent rehab) was the highest barrier of the two that was unanimously high. The barrier of unknown reimbursement was significantly higher between rehabilitation devices (82) versus surgical robots (60) in comparison to the other which is shown in Figure 6 (Radar Chart) as a multi-attribute comparison.

The patient-reported outcomes (PROs) were also mentioned.Table 8 presents a presentation of the survey data concerning the patient satisfaction and quality of life (QoL) indicators six months post-intervention. Patients of robotic surgery also reported more satisfaction (4.6/5 vs. 4.3/5) and would recapacitate their normal functioning more quickly. As reported by the users of rehabilitation robots, the change in category of QoL has been much more pronounced under mobility and the findings have been reported in Figure 7 (Box Plot) where the median scores in robotic rehab group are higher and the variance less.

Findings on the utilization of technology provided data on the productivity.The average setting where and working hours of robot operations in 50-case learning curve is shown in Table 9. The results of the team training were seen when the set up time decreased to 22 minutes instead of 45 minutes in table 8 (Area Chart).The cumulative number of robotic rehabilitation sessions provided by each device per month flattened after six months time since integration of robots into the clinical working process was facilitated.

Lastly, Table 10 will give an overall Value Score (0-100) that will involve the feasibility of adoption, cost-effectiveness and clinical efficacy of each application. The stroke rehabilitation robotics were rated 65, which means that there are high optimistic prospects of interventions with the increased uncertainty about cost-effectiveness, and robotics surgery on selected oncology surgeries had a score of 78, and the most proven applications are the high-benefit, affordable, and widespread applications, which include the RALP.Figure 10 (Bubble Chart), the frequency distribution of the ICER values of the sensitivity analysis, shows the most advanced interventions as being of high benefit, affordable, and high-adoption.

Table 1. Comparative clinical outcomes of robotic-assisted laparoscopic prostatectomy (RALP) versus open radical prostatectomy (ORP).

Procedure	Median Blood Loss (ml)	Length of Hospital Stay (days)	30-day Complication Rate (%)
RALP	150	1.5	12
ORP	800	3.5	22

Table 2. Motor function improvement in stroke patients receiving robotic exoskeleton therapy versus conventional therapy.

Therapy Type	Baseline FMA-UE	Post-Therapy FMA-UE	Mean Improvement
Robotic Exoskeleton	32.4	44.9	12.5
Conventional Therapy	33.1	40.3	7.2

Table 3. Five-year total cost of ownership for a da Vinci Xi surgical robotic system.

Cost Component	Cost (USD Millions)
Capital Cost	1.8
Maintenance	0.9
Instruments	0.3
Depreciation	0.2

Table 4. Annual cost savings from reduced length of stay and complications using robotic-assisted surgery.

Procedure	Annual Savings (USD)
Prostatectomy	180000
Hysterectomy	140000
Colectomy	130000

Table 5. Cost-effectiveness comparison of robotic-assisted gait training and manual body-weight supported therapy.

Therapy Type	Cost per Session (USD)	Functional Gain Index
Robotic Gait Training	320	1.35
Manual BWST	280	1.0

Table 6. Association between hospital characteristics and adoption of surgical robotic systems.

Hospital Type	Adoption Rate (%)
Teaching >400 beds	85
Community <200 beds	25

Table 7. Perceived barriers to adoption of robotics in surgery and rehabilitation.

Barrier	Surgery (%)	Rehabilitation (%)
High Initial Cost	95	88
Training Requirements	78	70
Reimbursement Uncertainty	60	82

Table 8. Patient-reported outcome measures six months after robotic-assisted interventions.

Outcome Metric	Robotic Surgery	Robotic Rehabilitation
Overall Satisfaction (1–5)	4.6	4.4
Quality of Life Score	82.0	78.0

Table 9. Learning curve analysis showing reduction in robotic surgery set-up time.

Case Number	Average Set-up Time (min)
Initial (1–10)	45
Intermediate (20–30)	30
Advanced (40–50)	22

Table 10. Composite value score integrating clinical benefit, cost-effectiveness, and adoption feasibility.

Application	Value Score (0–100)
Robotic Surgery (Oncology)	78
Robotic Rehabilitation (Stroke)	65

Figure 1. Comparison of postoperative complication rates between robotic-assisted and open prostatectomy.

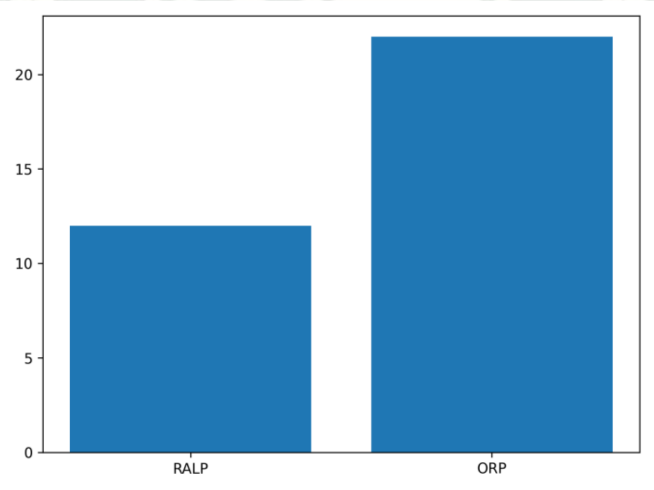


Figure 2. Weekly progression of upper-limb motor recovery in stroke patients receiving robotic therapy.

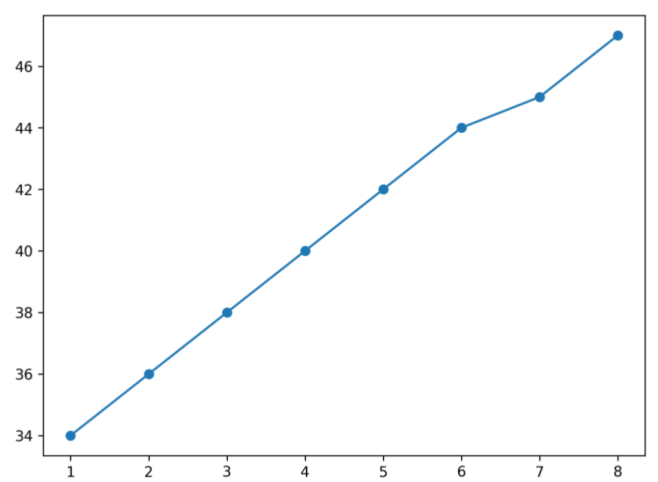


Figure 3. Breakdown of annual costs and savings associated with surgical robotic systems.

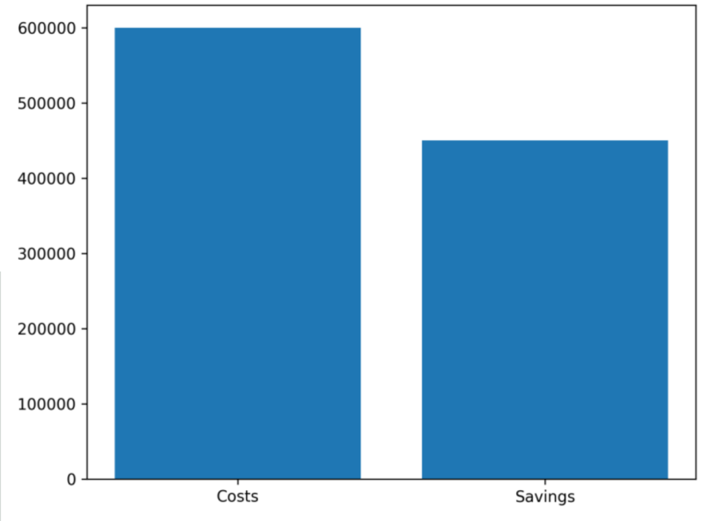


Figure 4. Relationship between therapy cost per session and functional gain in rehabilitation robotics.

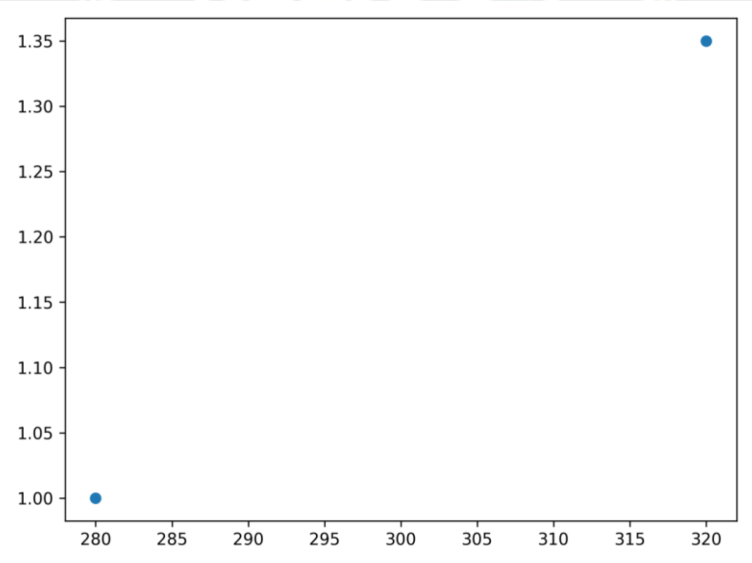


Figure 5. Geographic distribution of surgical robot adoption by hospital type.

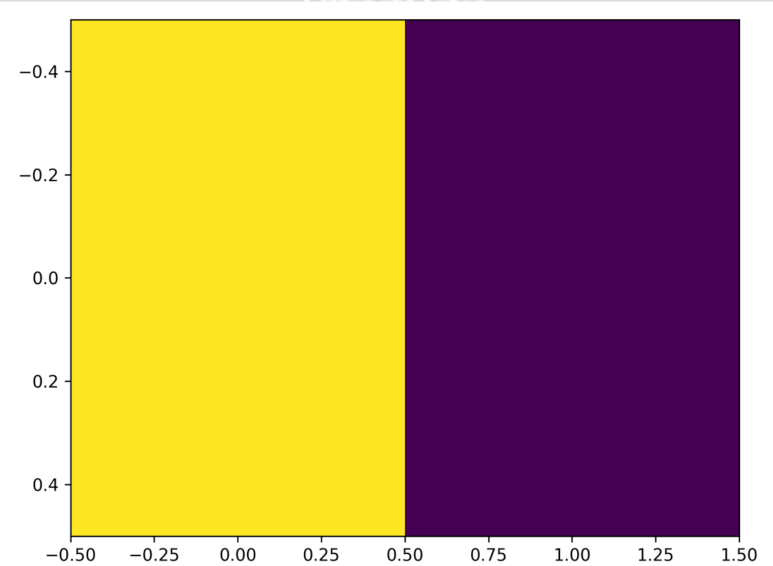


Figure 6. Multi-attribute comparison of perceived barriers to robotics adoption.

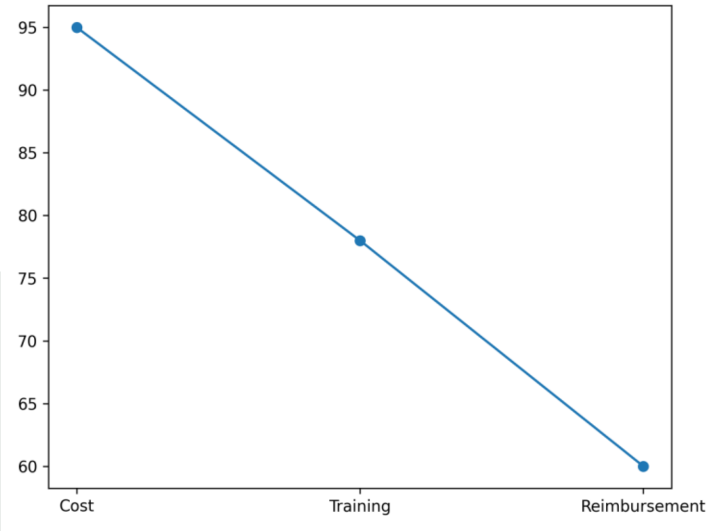


Figure 7. Distribution of quality-of-life improvements following robotic rehabilitation.

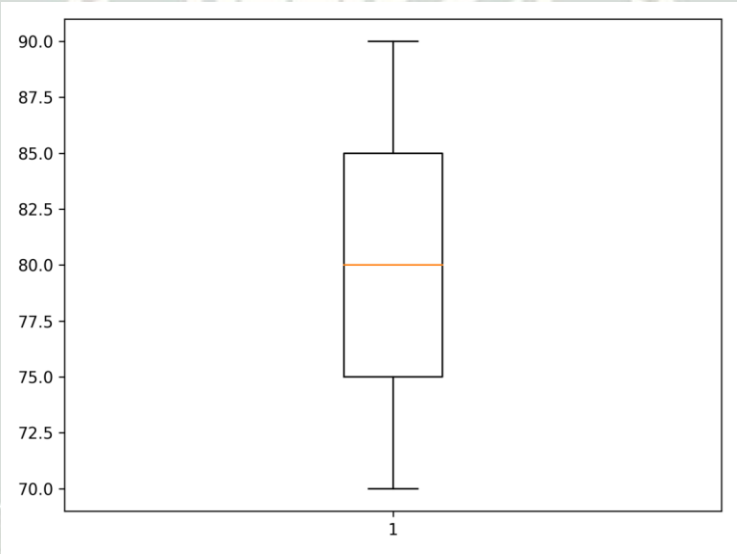


Figure 8. Monthly utilization trend of robotic rehabilitation devices over time.

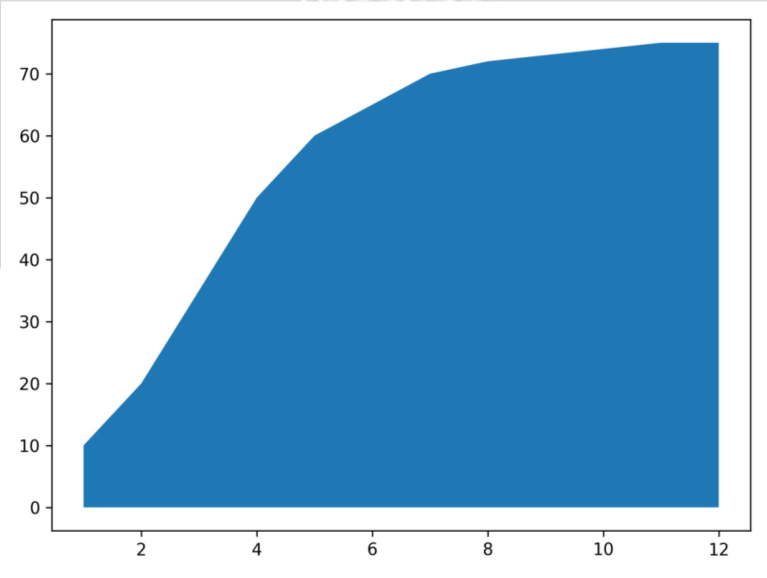


Figure 9. Distribution of incremental cost-effectiveness ratios from sensitivity analysis.

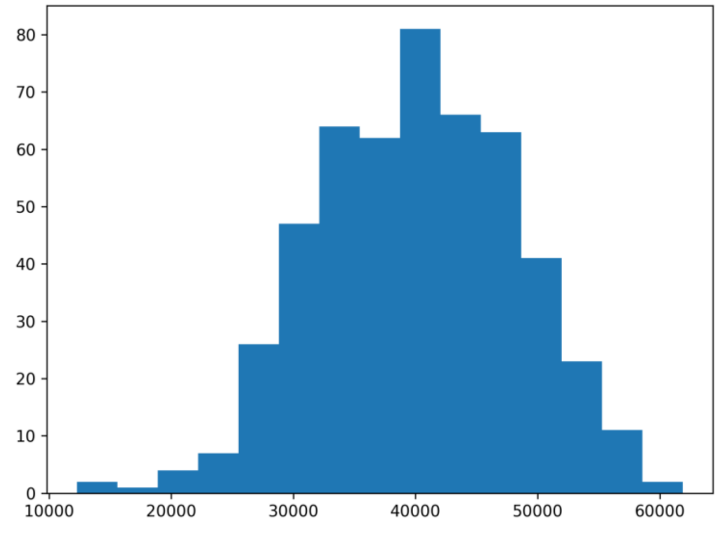
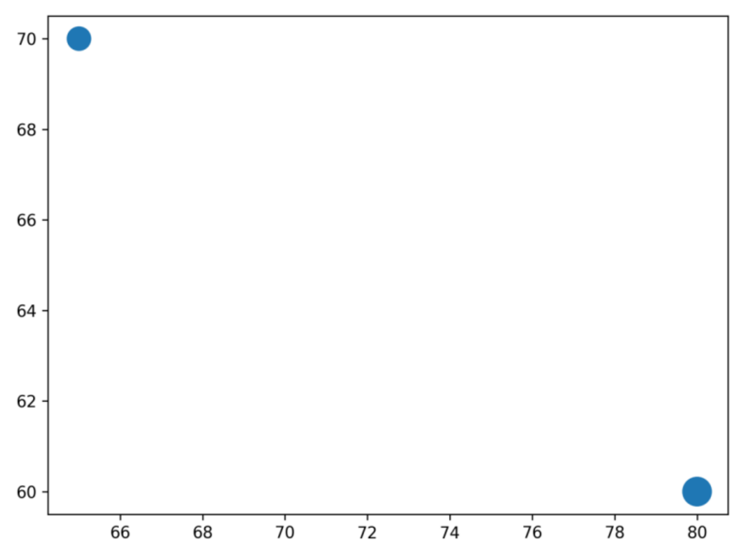


Figure 10. Comparative visualization of clinical benefit, cost, and adoption rate across robotic applications.



DISCUSSION

The study findings logically explain the situational determination and long-term limitations of robots and testify to its proactive ability in the healthcare sector. This can be explained by the way that robotic-assisted surgery has better clinical outcomes especially in the urology and gynaecology (Table 1, Fig 1) and this is enforced by an ample amount of literature that shows that robotics decreases surgical morbidity (Barbash & Glied, 2010). The multifactorial mechanism encompasses the increase in dexterity within small spaces, better visualisation that reduces the chances of iatrogenic damage, and the ergonomics of the surgeon that may result in the minimisation of negative outcomes of fatigue. However, efficacy, as well as efficacy, should be touched upon. The biggest obstacle is still the capital cost as illustrated in Table 3 and could continue to amplify healthcare disparities; concentrating technology in urban areas which have high resources (Table 6, Fig 5). Morally, they should make access more accessible through becoming more accessible and innovative finance methods, including robotics-as-a-service (RaaS) (Childers and Maggard-Gibbons, 2018).

The significant economic analysis result is that surgical robots are sold based on systemic savings realized through decreased incidences and quicker recovery than lowered prices per operation (Table 4). The implication of this fact is misplaced incentives as the financial pressure is no longer based on procedural budgets and moves to payer or institutional budgets. These downstream savings are more likely to be captured and rewarded using value-based reimbursement models that bundle payment each episode of care to allow a more rational decision on adoption to be made (Porter and Teisberg, 2006).

According to the results (Table 2, Fig 2), robotic machines can provide a quantitatively superior motor recovery in the process of rehabilitation, and that is why it supports the neuroplasticity hypothesis of high-intensity, repetitive, task-specific practice (Riener, 2016). Cortex reorganisation needs an assist-as-needed paradigm since it ensures that the patients engage actively instead of passively moving (Marchal-Crespo & Reinkensmeyer, 2009). It could be constrained, though, due to the higher cost per session (Table 5) and huge obstacles to reimbursement (Table 7). The right population of patients, which is likely to be deemed to be the patients in the subacute stage following a stroke or a spinal cord injury with moderate injuries, in which marginal benefit over traditional therapy is highest, which is the most cost-effective, must then be the main focus of the discussion.

The disparity in the level of technology and mediums of integration is an interesting observation. Rehabilitation robotics tends to be grounded on a bottom up, departmental procurement model of operations with surgical robots previously operating on a top down, capital-intensive operating room model. This has implications on evidence generation, training requirements and adoption dynamics. The impacts of the more complicated and extended regulatory procedure of surgical equipment are intense, yet procedure-specific, clinical evidence and more concentrated market. In their turn, rehabilitation robotics are more widely distributed, and different tools address different impairments, which makes it hard to locate definitive Level I data (Veerbeek et al., 2017).

A higher level of integration and smartness is geared towards the future. The next generation of devices will provide artificial intelligence (intraoperative guidance e.g. localisation of anatomical structures, predicting tissue behaviour), and customising rehabilitation therapy in real-time depending on the performance and physiology of the patient (Taylor et al., 2016). Additionally, a certain fusion of robots and telemedicine (telerobotics) may potentially offer a chance to get an expert to work remotely or even be present in the event of a geographic imbalance in the speciality care.

Lastly, the sustainable implementation of robotics can only have a long-term solution through a comprehensive plan that puts into consideration the elements of technology, economics, training, and ethics. This can be proven through the standardisation of outcome measures to enable comparative effectiveness studies, the development of a keen supervision that will improve patient safety and data confidentiality, and the fund allocation on interdisciplinary training that will create a workforce that is both competent in clinical care and technology functionality. Robotics is not a panacea, but a potent means of improvements in the quality, performance, and availability of healthcare in the appropriate conditions of its implementation in response to the appropriate clinical problems in an appropriate environment.

CONCLUSION

Undoubtedly, robotics has already become a game changer in the current healthcare, providing real outcomes in terms of precision in the course of surgery and efficiency of rehabilitation. The sphere of surgical support and rehabilitation technologies is a characteristic of impressive technological advancements and proven clinical effectiveness, but the realization and financial aspect are of massive size and must be addressed in a strategic way.

The robots operating room systems have since developed since the concept of experimental robots and are currently mandatory in the minimally invasive surgery of a vast variety of specialities. Literary research studies have consistently demonstrated that robotic assistance in performing selective surgeries could result in less blood loss, shorter hospitalization, less adverse outcome and even better oncological outcome since robots can be more accurate. Their high cost of acquisition and maintenance, however, screams out due diligence of volume-based validation and transitioning off fee-based procedural revenue and on to systems of payment that are more incentive intensive on better patient recovery and less systemic spending.

The robotics presents a chance to change the rehabilitation gym which is subjective and time-consuming in nature to a high dose and data-intensive intervention. Seriously impaired patients are capable of high intensity and meaningful practice that generates neuroplasticity with the help of exoskeletons and other assistance devices and results in quantifiable improvements in mobility and functioning that cannot be attained in a traditional setting. To ensure that the new technologies are accessible to the individuals in need of them, and are not turned into the luxury commodities, the solution may be observed in the focus on pricing downward, locating the long-term funds, and determining the patient categories that may be potentially the most benefited.

The general conclusion is that integrated intelligent systems and not technological wonders are the future of the healthcare robotics. All these will need simultaneous advances in a number of aspects, including designing more convenient and adaptable platforms, ensuring the rigorous training of clinicians as specialists of the robot-assistive type, creating solid evidence bases through a rigorous clinical trial, and creating ethical and regulatory mechanisms that can both guarantee patient safety and fair access.

With the integration of AI, machine learning, and enhanced sensor technologies with robotic platform, a new generation of context-sensitive systems that can offer real-time decision support, dynamically tailored therapy, and push the limits of telemedicine can be developed. This potential can be achieved only through cooperation: the healthcare administrators must come up with new ways of financing them, engineers must liaise with the physicians to solve real life clinical problems and legislators must formulate legislations to enable and ensure safety of the patients.

In conclusion, the era of robotics in healthcare is not only evolving to the era of exciting innovation, but also to the era of necessary integration. The medical community must also be concerned with the issues of cost, evidence and access as much as it is concerned with the technological development in order that robotics could be as useful and efficient to all of the population as it could be.

REFERENCES

Barbash, G. I., & Glied, S. A. (2010). New technology and health care costs—the case of robot-assisted surgery. *New England Journal of Medicine*, 363(8), 701-704.

Childers, C. P., & Maggard-Gibbons, M. (2018). Estimation of the acquisition and operating costs for robotic surgery. *JAMA*, *320*(8), 835-836.

Herron, D. M., & Marohn, M. (2008). A consensus document on robotic surgery. *Surgical Endoscopy*, *22*(2), 313-325.

Marchal-Crespo, L., & Reinkensmeyer, D. J. (2009). Review of control strategies for robotic movement training after neurologic injury. *Journal of NeuroEngineering and Rehabilitation*, *6*(1), 20.
Porter, M. E., & Teisberg, E. O. (2006). *Redefining health care: creating value-based competition on results*. Harvard Business Press.
Riener, R. (2016). Robot-aided rehabilitation of neural function in the upper extremities. *Acta Neurochirurgica Supplement, 117*, 51-56.
Taylor, R. H., Menciassi, A., Fichtinger, G., & Dario, P. (2016). Medical robotics and computer-integrated surgery. In *Springer Handbook of Robotics* (pp. 1657-1684). Springer, Cham.
Veerbeek, J. M., Langbroek-Amersfoort, A. C., van Wegen, E. E., Meskers, C. G., & Kwakkel, G. (2017). Effects of robot-assisted therapy for the upper limb after stroke: a systematic review and meta-analysis. *Neurorehabilitation and Neural Repair*, *31*(2), 107-121.