Narrative review on telerobotics: applications, challenges, and future perspectives

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Abstract

Telerobotics has emerged as a pivotal technology across multiple domains, including industrial automation, healthcare, and telepresence. This narrative review synthesizes current research and advancements in telerobotics, analyzing its impact on efficiency, precision, and human safety. The review also explores key challenges such as latency, cybersecurity vulnerabilities, and economic constraints that hinder widespread adoption. Finally, future directions are discussed, emphasizing improvements in network reliability, human-machine interaction, and cost-effective implementations to expand the practical applications of telerobotics.

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Introduction

To understand telerobotics or teleoperated surgery, we must first recognize the meaning and function of a surgical robot. A surgical robot is a "computer-controlled electromechanical device that can be programmed to aid the positioning and manipulation of surgical instruments", especially in laparoscopic approaches, thus helping surgeons perform complex procedures more easily, improving overall patient care.[1]

Surgical bots are categorized according to their function: passive robots perform sequences of movements programmed preoperatively or serve as guidance to a precise surgical target (usually marked preoperatively); active robots require the surgeon to directly manage the bot intraoperatively.

Many robotic devices have been developed,[2] mainly divided into robotic camera holders (*e.g.*, AESOP [Intuitive Surgical, USA], ViKY [EndoControl, France]), which provide a steady platform for the optical camera, dismissing the need for a camera holder assistant; immersive telerobotic surgical systems (*e.g.*, Da Vinci [Intuitive Surgical, USA]); and open remote-control stations (*e.g.*, Senhance [Asensus Surgical, USA], Hugo [Medtronic, Ireland/USA]).[3]

The aim of this narrative review is to explore the topic of robotics and telesurgery from a multidimensional perspective, with particular emphasis on technological advancements, the application of telerobotics in emergency settings, the current challenges associated with its implementation, and potential future implications. The decision to address these themes stems from the growing clinical relevance of remote surgery. Indeed, the advent of hyper-specialized surgical fields – such as geriatric surgery, HPB surgery, and bariatric surgery, among others – may create significant opportunities for the use of this approach, not only for performing remote surgical interventions but also for telementoring.

The strengths of this review lie in its transversal approach, integrating the various aspects mentioned above to provide an up-to-date overview of the current potentials and limitations of teleoperated surgery. As a narrative review, it does not provide a systematic assessment of the quality of included studies nor a quantitative synthesis of data; rather, the reflections offered are based on a critical and qualitative selection of the literature, aimed at guiding a comprehensive understanding of the phenomenon and identifying key areas for future development.

Materials and Methods

This narrative review was conducted using a structured literature search aimed at collecting and synthesizing current evidence and insights on robotic and teleoperated surgery, with a focus on its historical development, technical evolution, emergency applications, ethical implications, and prospects.

The literature search was carried out using two major scientific databases: PubMed (MEDLINE) amd Google Scholar.

The following search terms and keyword combinations were employed to identify relevant publications: telerobotics, teleoperation, telepresence robotics, robotic surgery, remote surgery, digital health, automations, robotics, telemedicine, remote control, and robot-assisted surgery.

Boolean operators (AND, OR) were used to refine the results, and additional articles were identified by examining references within selected studies.

Inclusion and exclusion criteria

The inclusion criteria comprised: i) articles published in English; ii) peer-reviewed studies, clinical reports, narrative reviews, or institutional documents; and iii) publications addressing clinical, technological, ethical, or regulatory aspects of robotic or teleoperated surgery.

The exclusion criteria included: i) non-English publications; and ii) entries available only as abstracts or lacking sufficient detail for comprehensive assessment.

Selection process

Titles and abstracts were screened for relevance. Full texts of eligible articles were reviewed and thematically categorized into sections reflecting the structure of the review: origins and development, present limitations, emergency applications, regulatory and ethical concerns, and future directions.

Discussion

Origins and early developments of robotic and telepresence surgery

Before the first robotic prototypes emerged, laparoscopic surgery had already marked a major shift in the surgical field, driven by pioneers like Kurt Semm and Erich Mühe.[4] This breakthrough led to the conception and successful execution of countless surgical procedures.[5]

The development of surgical robots was, in fact, a direct response to the need to overcome the limitations of conventional laparoscopy – such as two-dimensional vision, limited instrument articulation, and poor ergonomics – while retaining its major advantages: reduced morbidity and postoperative pain, lower complication rates and severity, shorter hospital stays, faster recovery times, and smaller, more aesthetically acceptable incisions.

The first and most significant milestone in the history of robotic surgery can be traced back to 1985, when the industrial robot PUMA 200 was employed for the first time in neurosurgery, tasked with positioning a needle for a CT-guided brain biopsy. This pioneering procedure marked the beginning of the exponential spread of robotic surgery across all other surgical disciplines.[6,7]

In those same years, Joseph Rosen (a plastic surgeon) and Scott Fisher (computer scientist) devised the first ideas of telepresence surgery, combining a robotic telemanipulator system for hand surgery being developed by Philip Green (mechanical engineer) with the virtual reality systems being developed by Michael McGreevey and Stephen Ellis (lead scientists at the NASA Ames Research Center). They hypothesized a virtual console, a head-mounted display for live images, and the surgeon wearing electronically wired gloves (also known as data gloves) that would detect hand motions and control the subsequent manipulation of the remote robotic instruments.[8] Due to technical obstacles (lack of resolution and instrument dexterity), they reverted to a prototype with a console, a monitor to view the video image of the surgical site, and handles as controllers for telemanipulation.[9]

The notion of telepresence surgery garnered significant interest within the military for combat casualty care; consequently, in 1994, the inaugural remote telesurgical procedure, an intestinal anastomosis on *ex vivo* porcine intestine, was executed utilizing a wireless microwave connection between a surgical console and a military vehicle equipped with the robotic prototype. Its potential was seen as a means to overcome healthcare staff shortages in remote, near-inaccessible, hostile areas.[2,10]

The 1990s witnessed the development of the inaugural laparoscopic camera holder robot, known as the Automated Endoscopic System for Optimal Positioning (AESOP), engineered by Yulun Wang, as well as the first telesurgical cholecystectomy on a female patient, conducted by Drs. Jacques Himpens and Guy Cardiere in Belgium. Since its creation, robotic technology has found itself establishing a symbiotic relationship with surgeons, leading to great enhancements in performances.[11]

The first intercontinental telerobotic telementored procedures were performed in 2000 between two operating sites, 8,000 km apart (Rome-Baltimore). Five urologic procedures were accomplished using the AESOP device, with analog (audio/video) signals transmitted *via* four high-capacity telephone lines and digitally converted by a modem. The remote mentoring surgeon had control of the laparoscope, telestration, and electrocautery.[12] The operating timing was proportional to conventional laparoscopy, and the signal latency amounted to 700 ms, which didn't altogether affect the accomplishment of the procedures.[13]

From the outset, it has been evident that transmission speed constitutes a critical factor in the feasibility and implementation of telesurgery.

This led in 2001 to the first true remote robotic cholecystectomy performed by a NYC surgeon on a patient in France (the so-called Lindbergh operation) *via* a high-speed terrestrial optical-fiber network.[14] The movements executed by the NYC surgeon became apparent within 155 ms on his video screen.[15]

Another important example of telerobotic remote surgery occurred in 2003 between two Canadian hospitals 400 km apart. Twenty-one patients underwent complex general surgery procedures (Nissen fundoplication, right hemicolectomy, anterior rectal resection, sigmoid resection, laparoscopic hernia repair) with the aid of the Zeus-TS (Computer Motion, USA) surgical system and an IP-VPN network connecting the arms of the Zeus system to a remote robotic console where the expert surgeon took command of the robot's arms. An interesting fact is that the internet network included an active line and a redundant active backup line ready in case of failure of the first one; moreover, the quality of service of the line was set to perform at the highest priority, ensuring signal transmission at the most rapid rate possible and with priority over any other traffic on the network. The overall signal latency was 135-140 ms, of which 14 ms was due to network delay between the two locations, and the rest to compressing and decompressing the video signals. Although the latency was perceived by the telerobotic surgeon, it caused no inconvenience in the procedures.[16]

The impact of variable time delays on surgical performance between two remote sites was examined during a robot-assisted laparoscopic cholecystectomy on a pig at two French sites spaced

1,000 km apart. The time lag was artificially increased from the standard 20 ms up to 551.5 ms. The acceptable time-delay limit was around 330 ms.

Current challenges, ethical and legal considerations

Following the exploration of the historical milestones that have shaped the field of robotic and telepresence surgery, it becomes essential to critically assess the current capabilities and limitations of these technologies. As their use continues to expand across various surgical disciplines, understanding both their strengths and inherent challenges is crucial to inform future development, clinical application, and integration into standard surgical practice.

Among the most appreciated features of telepresence systems is the ability to create a fully immersive surgical experience, simulating the sensation of being physically present at the operative field. This is made possible through high-definition 3D imaging, real-time audio-video transmission, and precise remote manipulation of robotic instruments.[17] The robotic instruments are 8 mm wide (compared to the 5 mm in conventional laparoscopy), and allow high levels of dexterity due to 7 degrees of freedom (*vs.* the 4 of conventional laparoscopy), mimicking natural wrist-like movements while automatically minimizing physiological hand tremor and abolishing the fulcrum effect of laparoscopic instruments.[18,19]

However, "all that glitters is not gold", for even robotic surgery has its flaws. For example, it incurs higher costs both in purchase and manipulation, longer operational mean time (including set-up and disassembly time), a larger volume occupied by the device, training expenses, and equipment maintenance and replacement. A major drawback is the lack of haptics, or tactile feedback.[20] The surgeon cannot actually feel the texture and resistance of the tissues as the instrument meets and handles them, but has to settle on visual cues, previous surgical experience, and knowledge of the anatomy and surgical planes. Other limiting factors include mechanical or electronic breakdown/dysfunction of the robotic equipment,[21] the current absence of artificial intelligence automation of the devices, the time delay necessary to convert video-audio communications and surgical movements into electronic signals, the bandwidth and time delay of telecommunication lines, and problems with multi-quadrant surgeries. Moreover, for some procedures, there is no high-quality evidence that robot-assisted laparoscopy is superior to conventional laparoscopy or laparotomy.[22]

Remote or telepresence surgery adds another layer of complexity, requiring robust safety measures to address risks like mechanical or electrical failures, signal delays between the operating room, robotic console, and remote site, internet outages, and the need to quickly convert to open surgery if complications arise.

More recently, cybersecurity has become a critical concern: as with any electronic system, robotic surgical devices are vulnerable to hacking. Malicious attacks could disrupt communication or, in the worst cases, lead to harmful or even fatal actions, posing potentially catastrophic consequences.

Considering these concerns, the scientific community has acknowledged the necessity to establish regulations governing the use of robotics and telemedicine. Thus, in 2006, at Mount Sinai Medical Center in NYC, a multidisciplinary group, the SAGES-MIRA Robotics Consensus Conference, assembled to draft guidelines regarding the training and credentialing, clinical application, surgical risks and benefits, and potential research.[18] In 2021, a position paper on the use of robotic surgery in emergency settings was drafted by the WSES.[23] Robotic surgery in emergent surgical cases overall includes socio-economically disadvantaged patients, ethnic minorities, extreme age groups, very often multiple comorbidities and late-stage diseases, and requires a hemodynamically stable condition.[24]

The role of robotic surgery in emergency setting (ROEM) study in 2023 sought to define a protocol on the feasibility of robotic surgery in acute settings such as acute cholecystitis, obstructed hernias, and acute diverticulitis.[25] The different studies taken into consideration, including those by Milone *et al.*,[26] Kudsi *et al.*,[27] and Curfman *et al.*,[28] all concluded that the robotic platform is suitable and has overall better outcomes and fewer complications despite higher costs and appropriate expertise.[29] The same results are shown in emergent major oncologic gastrointestinal robotic procedures.[30] It is worth noting that the results of these studies, although encouraging, are not statistically significant compared to open or laparoscopic approaches.[31]

An international survey in 2022, the Artificial Intelligence in Emergency and Trauma Surgery (ARIES) project, was aimed at obtaining surgeons' opinions and perspectives on the topic.[32,33] A WSES consensus statement on a laparoscopic-first approach in acute settings has been recently published, and it hints at the possibility of taking into consideration robotic technology if equipped with due skill, experience, and appropriate platforms.[34]

However, the adoption of robotic surgery, both in elective procedures and in urgent and emergency settings, is still expected to face medico-legal and ethical challenges in the coming decades.[35] The establishment of structured robotic training programs, the updating of informed consent forms, and the enactment of clear laws and specific guidelines are necessary. These issues will need to be addressed within the scientific community in the coming years in order to prevent legal disputes, malpractice claims, and concerns regarding legal liability involving multiple stakeholders.[36]

Future perspectives and emerging technologies

The future of robotic emergency surgery is intertwined with that of technological development,[37] including tactile and kinesthetic inputs, artificial intelligence and deep learning, nanotechnology, and the automation of robots.[38] Many companies are striving to create valid substitutes for the Da Vinci platform.[39] The Senhance platform, for example, is able to provide tactile haptic force and has polarized glasses that allow a 3D eye-tracking camera, which centers the image at the point the surgeon is looking at.[40] The MiroSurge is a telemanipulated robotic system that incorporates 3-5 instrument-carrying arms that can be mounted almost freely on the surgical table rails,[41] and the SPIDER (Asensus Surgical, USA) is a single-port robotic platform developed for minimally invasive surgery that allows the insertion of 4 flexible instruments through a single-incision site.[42]

Regarding scientific research, space agencies like NASA have been leading remote teleoperated procedures in extreme environments, such as underwater laboratories (*e.g.*, the NASA Extreme Environment Mission Operations project (NEEMO) missions) since 2001; in 2007, they managed to complete a suture on a puppet in simulated zero-gravity conditions *via* telementoring, with a 3 s signal latency at most. It is important to note that these experiments are conducted on Earth, whereas in space, communication latency can reach up to 24 min for receiving requests from the spacecraft and an equal duration for transmitting responses from the ground control center. [43]

The military also uses underground/underwater or otherwise inaccessible environments to conduct autonomy tests on surgical robots that could be deployed to perform "damage control" surgical procedures[44] near the front lines of a war zone as part of mobile surgical units.[45] The Battlefield Extraction Assist Robot (BEAR) was designed to locate, lift (up to 227 kg), and carry injured soldiers throughout rough terrain at a pace of approximately 10 km/h. It was also equipped with pressure sensors to handle casualties more "gently", and sensors capable of detecting biochemical and explosive agents.[46] Similarly, the Defense Advanced Research Projects Agency (DARPA) is designing the development of prosthetic limbs imbued with artificial intelligence technology.[47-49]

Conclusions: How far will we dare to go?

Scientists theorize that patients will be brought to the pre- and postoperative recovery area on LSTAT-like supports[50] – "smart stretchers" that automatically record vital signs, monitor a full range of physiological and biochemical parameters, provide diagnostic imaging, perform total body scans, and seamlessly dock both physically and electronically with the robotic surgical console. This integration could render the operating room nearly sterile and virtually staff-free. The surgeon's duty would then be to execute the "operate" command on the console and supervise the procedure prior to having edited it on the console based on the patient's image.

With future technological advances and evolution in artificial intelligence, robotic systems will become so sophisticated that they will be able not only to monitor real-time and register surgeon performance but also to suggest alternatives or alert the surgeon in case of performance deviation and integrate imaging with interventional platforms.[51,52]

The interest of worldwide space agencies will focus on developing systems capable of performing autonomous remote surgical operations in deep space after taking into account weightlessness, radiation exposure, and physiological changes, as well as data bandwidth limits and the "speed of light" constraint.[43]

Further fields of research will probably engage in the development of computer-assisted surgery at the microscopic and cellular levels. On one hand, this model aligns with the concept of biosurgery, defined as "the ultraprecise manipulation and delivery of a specific therapeutic (and possibly diagnostic) modality to a specific organ, tissue, or cell to affect biological function". In this vision of future surgery, the goal will no longer be to alter the structure of an organ or remove diseased tissue, but rather to modulate the body's biological processes through cellular, molecular, metabolic, or genetic interventions.[53] On the other hand, we must consider that unaided human accuracy is limited to approximately 200 microns for visual discrimination, motor coordination, and intention tremor. A sophisticated machine like a robotic system would thus override this limit, allowing nanometric manipulations.[32,54]

These prospects also give rise to important challenges, including how the doctor-patient relationship may evolve. In the event of a disagreement between a surgeon's clinical judgment and a robot's alternative recommendation, which perspective should take precedence, and to what extent? Furthermore, will human surgeons still be necessary in the distant future?[9]

References

1. Paraiso MFR, Falcone T. Robot-assisted laparoscopy [Internet]. UpToDate. [cited 2023 Apr 29]. Available from: https://www.uptodate.com/contents/robot-assisted-laparoscopy?search=Robot-assisted%20laparoscopy&source=search_result&selectedTitle=1~35&usage_type=default&display_rank=1
2. Ballantyne GH. Robotic surgery, telerobotic surgery, telepresence, and telementoring. Review of early clinical results. Surg Endosc 2002;16:1389-402.
3. Cepolina F, Razzoli RP. An introductory review of robotically assisted surgical systems. Int J Med Robot 2022;18.
4. Buia A, Stockhausen F, Hanisch E. Laparoscopic surgery: A qualified systematic review. World J Methodol 2015;5:238-54.
5. Limb C, Rockall T. Principles of laparoscopic surgery. Surgery 2020;38:161-71.
6. Mehrdad S, Liu F, Pham MT, et al. Review of advanced medical telerobots. Appl Sci (Switzerland) 2021.
7. Shah J, Vyas A, Vyas D. The History of Robotics in Surgical Specialties. Am J Robot Surg 2014;1:12-20.
8. Leal Ghezzi T, Campos Corleta O. 30 Years of Robotic Surgery. World J Surg 2016;40:2550-7.
9. Satava RM. Robotic surgery: from past to future- a personal journey. Surg Clin North Am 2003;83:1491.
10. Hansen RN, Saour BM, Serafini B, et al. Opportunities and Barriers to Rural Telerobotic Surgical Health Care in 2021: Report and Research Agenda from a Stakeholder Workshop. Telemed E-Health 2022;28:1050-7.
11. Sackier JM, Wang Y. Robotically assisted laparoscopic surgery. From concept to development. Surg Endosc 1994;8:63-6.
12. Micali S, Virgili G, Vannozzi E, et al. Feasibility of telementoring between Baltimore (USA) and Rome (Italy): the first five cases. J Endourol 2000;14:493.
13. Panait L, Rafiq A, Tomulescu V, et al. Telementoring versus on-site mentoring in virtual reality-based surgical training. Surg Endosc 2006;20:113.
14. Marescaux J, Leroy J, Rubino F, et al. Transcontinental Robot-Assisted Remote Telesurgery: Feasibility and Potential Applications. Ann Surg 2002;235:487-92.
15. Marescaux J, Leroy J, Gagner M, et al. Transatlantic robot-assisted telesurgery. Nature 2001;413:379-80.
16. Anvari M, McKinley C, Stein H. Establishment of the world's first telerobotic remote surgical service: for provision of advanced laparoscopic surgery in a rural community. Ann Surg 2005;241:460.
17. Haluck RS, Krummel TM. Computers and virtual reality for surgical education in the 21st century. Arch Surg 2000;135:786.
18. Herron DM, Marohn M, SAGES-MIRA Robotic Surgery Consensus Group. A consensus document on robotic surgery. Surg Endosc 2008;22:313
19. Oppenheimer P, Weghorst S, MacFarlane M, Sinanan M. Immersive surgical robotic interfaces. Stud Health Technol Inform 1999;62:242.
20. Liberman D, Trinh QD, Jeldres C, Zorn KC. Is robotic surgery cost-effective: yes. Curr Opin Urol 2012;22:61.
21. Berguer R, Forkey DL, Smith WD. Ergonomic problems associated with laparoscopic surgery. Surg Endosc 1999;13:466.
22. Tan A, Ashrafian H, Scott AJ, et al. Robotic surgery: disruptive innovation or unfulfilled promise? A systematic review and meta-analysis of the first 30 years. Surg Endosc 2016;30:4330-52.
23. de'Angelis N, Khan J, Marchegiani F, et al. Robotic surgery in emergency setting: 2021 WSES position paper. World J Emerg Surg 2022;17:4.
24. Osagiede O, Spaulding AC, Cochuyt JJ, et al. Factors Associated With Minimally Invasive Surgery for Colorectal Cancer in Emergency Settings. J Surg Res 2019;243:75-82.
25. Milone M, Anoldo P, de'Angelis N, et al. The role of RObotic surgery in EMergency setting (ROEM): protocol for a multicentre, observational, prospective international study on the use of

robotic platform in emergency surgery. World J Emerg Surg 2024;19:20.
26. Milone M, Vertaldi S, Bracale U, et al. Robotic cholecystectomy for acute cholecystitis: Three case reports. Medicine (Baltimore) 2019;98:e16010.
27. Kudsi OY, Gokcal F, Bou-Ayash N, Chang K. Comparison of Midterm Outcomes Between Open and Robotic Emergent Ventral Hernia Repair. Surg Innov 2021;28:449-57.
28. Curfman KR, Jones IF, Conner JR, et al. Robotic colorectal surgery in the emergent diverticulitis setting: is it safe? A review of large national database. Int J Colorectal Dis 2023;38:142.
29. Reinisch A, Liese J, Padberg W, Ulrich F. Robotic operations in urgent general surgery: a systematic review. J Robot Surg 2023;17:275-290.
30. Maertens V, Stefan S, Rawlinson E, et al. Emergency robotic colorectal surgery during COVID-19 pandemic: A retrospective case series study. Laparosc Endosc Robot Surg 2022; 5:57-60.
31. Robinson TD, Sheehan JC, Patel PB, et al. Emergent robotic versus laparoscopic surgery for perforated gastrojejunal ulcers: a retrospective cohort study of 44 patients. Surg Endosc 2022;36:1573-7.
32. De Simone B, Abu-Zidan FM, Gumbs AA, et al. Knowledge, attitude, and practice of artificial intelligence in emergency and trauma surgery, the ARIES project: an international web-based survey. World J Emerg Surg 2022;17:10.
33. De Simone B, Chouillard E, Gumbs AA, et al. Artificial intelligence in surgery: the emergency surgeon's perspective (the ARIES project). Discov Health Syst 2022;1:9.
34. Sermonesi G, Tian BWCA, Vallicelli C, et al. Cesena guidelines: WSES consensus statement on laparoscopic-first approach to general surgery emergencies and abdominal trauma. World J Emerg Surg 2023;18:57.
35. O'Sullivan S, Nevejans N, Allen C, et al. Legal, regulatory, and ethical frameworks for development of standards in artificial intelligence (AI) and autonomous robotic surgery. Int J Med Robot 2019;15.
36. Pai SN, Jeyaraman M, Jeyaraman N, et al. In the Hands of a Robot, From the Operating Room to the Courtroom: The Medicolegal Considerations of Robotic Surgery. Cureus 2023;15:e43634.
37. Alip SL, Kim J, Rha KH, Han WK. Future platforms of robotic surgery. Urol Clin North Am 2022;49:23-38.
38. Bramhe S, Pathak SS. Robotic Surgery: A Narrative Review. Cureus 2022;14:e29179.
39. Peters BS, Armijo PR, Krause C, et al. Review of emerging surgical robotic technology. Surg Endosc 2018;32:1636-55.
40. Spinelli A, David G, Gidaro S, et al. First experience in colorectal surgery with a new robotic platform with haptic feedback. Colorectal Dis 2017.
41. Hagn U, Konietschke R, Tobergte A, et al. DLR MiroSurge: a versatile system for research in endoscopic telesurgery. Int J Comp Assist Radiol Surg 2010;5:183-93.
42. Haber G, Autorino R, Laydner H, et al. SPIDER surgical system for urologic procedures with laparoendoscopic single-site surgery: from initial laboratory experience to first clinical application. Eur Urol 2012;61:415-22.
43. Pantalone D, Faini GS, Cialdai F, et al. Robot-assisted surgery in space: pros and cons. A review from the surgeon's point of view. NPJ Microgravity 2021;7:56.
44. Tranzatto M, Miki T, Dharmadhikari M, et al. CERBERUS in the DARPA Subterranean Challenge. Sci Robot 2022;25;7.
45. Cai YL, Ju JT, Liu WB, Zhang J. Military Trauma and Surgical Procedures in Conflict Area: A Review for the Utilization of Forward Surgical Team. Mil Med 2018;183:e97-106.
46. Martinic G. Glimpses of future battlefield medicine – the proliferation of robotic surgeons and unmanned vehicles and technologies. JMVH 2021;22:3.
47. Naufel S, Knaack GL, Miranda R, et al. DARPA investment in peripheral nerve interfaces for prosthetics, prescriptions, and plasticity. J Neurosci Methods 2020;332:108539.
48. Hockstein NG, Gourin CG, Faust RA, Terris DJ. A history of robots: from science fiction to surgical robotics. J Robot Surg 2007;1:113-8.
49. Johnson K, Pearce F, Westenskow D, et al. Clinical evalutation of the Life Support for Trauma and Transport (LSTAT) platform. Crit Care 2002;6:439-46.
50. Mascagni P, Alapatt D, Sestini L, et al. Computer vision in surgery: from potential to clinical value. NPJ Digit Med 2022;5:163.
51. Liu S, Yao S, Zhu G, et al. Operation Status of Teleoperator Based Shared Control Telerobotic System. J Intell Robot Syst: Theory Appl 2021;101.
52. Satava R, Wolf R. Disruptive visions: Biosurgery. Surg Endosc 2003;17:1833-6.
53. Soong RK, Bachand GD, Neves HP, et al. Powering an inorganic nanodevice with a biomolecular motor. Science 2000;2 90:1555-8.
54. Yaacoub JA, Noura HN, Salman O, Chehab A. Robotics cyber security: vulnerabilities, attacks, countermeasures, and recommendations. Int J Inf Secur 2022;21:115-58.