International Surgery Journal
Balasubramanian S et al. Int Surg J. 2020 Apr;7(4):1317-1323
http://www.ijsurgery.com
pISSN 2349-3305 | eISSN 2349-2902

DOI: http://dx.doi.org/10.18203/2349-2902.isj20201057

Review Article

The era of robotics: dexterity for surgery and medical care: narrative review

Shivaramakrishnan Balasubramanian[1]*, Jayakumar Chenniah[2], Gurumurthy Balasubramanian[3], Venkataram Vellaipandi[4]

[1]Department of Pharmacology, [2]Department of Pharmacy Practice, JSS College of Pharmacy, JSS Academy of Higher Education and Research, Ooty, Nilgiris, Tamil Nadu, India
[3]Department of Radio diagnosis, JJM Medical College and Hospital, Davangere, Karnataka, India
[4]Department of Orthopedics, Mahatma Gandhi Medical College and Research Institute, Puducherry, India

Received: 08 January 2020
Revised: 04 March 2020
Accepted: 05 March 2020

***Correspondence:**
Dr. Shivaramakrishnan Balasubramanian,
E-mail: shivaram.krishna@jssuni.edu.in

ABSTRACT

Robots are man-made machines; created to increase the performance of an action. They are either autonomous or semi-autonomous in the hands of the user. The medical field has evolved and revolutionized over the decades. It is the hour of the robot-assisted medical care to successfully change the clinical scenario of patient care. Employment of robotics in diverse fields of medical care has increased the effectiveness of the treatment and in return the effectiveness of the healthcare professionals. Our aim is to emphasize the advances in robot-assisted procedures over their comparable facets and highlight the unresolved challenges of robotics in medical care for the near future.

Keywords: Robotics, Surgical care, Medical care, da Vinci surgical system, Challenges, Future

INTRODUCTION

Robots are man-made devices that brought about a revolution in various fields of science and commerce. It came into existence to ease the human burden and its prominence is seen in everyday life. The designing of the robot is quite an exhaustive process. Once the design is perfected, they become as exceptional creative gadget by humankind and its evolution in medical care is astounding. Robots hasten the process of human thought into action, hence the meticulousness brought up the innovation of robotics into medical care. The comfort design of robots has intensified a surgeon's haptic capabilities, ingenuity, and perception. This advancement of technology has resulted in quicker health responses and improved quality of life of patients.

Current modern robotic surgical technology has progressed with the miniature portable robotic system, live stream video-assisted monitoring, and robot-assisted surgery. With the incorporation of this cutting-edge technology, robotics has paved the way for different uses of health care of patients. In this paper, we review and summarize such application of robotics in various disciplines of medical care and further future directions are discussed.

ROBOTICS: A HISTORICAL TIMELINE IN MEDICAL CARE

Robotics was not yet a part of science fiction until 1917 when Joseph Capek wrote a story 'Opilec' depicting automats.[1] Later in 1921, his brother Kard Capek wrote 'Rossum's Universal Robots'.[2] The word robot has its

root from the Czech word *robota*, meaning serf or laborer. The features of first robot used in live surgical applications were inbuilt pre-programmed data and computer-generated algorithm functioning without real-time operator units.

It was in the year 1985; an industrial robotic arm has been developed to perform a stereotactic brain biopsy which received US FDA approval in 1999.[3] In 1992, ROBODOC (CUREXO Technology Corporation, California, USA) was introduced to be used in hip replacements but it is not yet approved by US FDA due to its concerns regarding complication rates.[4] Other similar devices which have been used for knee and temporal bone surgery are ACROBOT (The Acrobot Company Ltd, London, UK) and RX-30 robot (StaubliUnimation Inc, Faverges, France) but these devices have neither completed clinical testing nor have obtained FDA approval.[5,6]

Scott Fisher and Joe Rosen foresaw the virtual insertion of the surgeon in telepresence surgery with the manipulation of remote robotic arms. By the beginning of the 20th century there was betterment in the tele-robotic field and the idea of integrating this technology in the budding field of laparoscopic surgery was attained.[7] Subsequently, it had been familiarized in the Defense Advanced Research Projects Agency (DRAPA) with the objective of letting a surgeon to treat a wounded soldier on the battlefield from a remote safe area. Later on, automated endoscopic system for optimal positioning (AESOP) was designed to replace a surgical assistant, which got US FDA approval in 1994.[8]

In 1999, Zeus surgical system (Computer Motion, Goleta, CA, USA) was introduced but it is no longer commercially available. Its operative procedural enabled a surgeon to sit in a console wearing polarized goggles to view the operative field in 3D. The Intuitive Surgical, Inc., USA developed da Vinci surgical system (DVS) in 1997 which consisted of a remote surgical console and three arms. It was employed initially to perform laparoscopic surgeries with the key of minimally invasive technique. As of today, there are several add-on features to the DVS, the fourth arm with features to function by switching between the other three arms[9].

DVS got approval for laparoscopic surgeries in 1997 based on the telesurgical principle. Nevertheless, US FDA approved DVS for extensive general, cardiac, gynecologic and Urologic procedures in the year 2000. Clinical study reports state that DVS being a superior user-friendly interface has unique abilities with respect to equal or improved surgical outcomes like lower blood loss in procedures, lesser hospital stay, and a favorable learning curve.[10] Researchers show that miniature implantable robots that are manipulated from outside with much less force and trauma to the tissues, helps in delicate handling of the surgical fields.[11] In the near future, robotic devices with remote telemonitoring, smaller instrumental dimensions and streamlined platforms for multipurpose usage may be expected.[12]

ROBOTICS IN CARDIOLOGY

Robotics has been introduced in the field of cardiology in the early 1980s, with the idea to overcome the clinical challenges associated with conventional procedures in cardiology. Robotics use in the field of cardiology started with the AESOP which is a simple, voice-activated, camera positioning robot. The first robotic system used was the Zeus robotic microsurgical system. However, only nonclinical trials had been done, using isolated porcine heart, calves for coronary artery bypass in early stages. After its US FDA (2000) clinical trials, its application has found to be limited pertaining to left internal thoracic artery - left anterior descending anastomosis.[13]

The robotic science has evolved to the sophisticated and successful DVS which can perform surgeries for coronary artery disease (CAD-single or multivessel), mitral valve repair, atrial septal defect, congenital heart disease.[14] DVS shows promising results on arrested or beating heart surgery.[15] Generally, we found that DVS has narrow application in the pediatric population (<30 kg). This may be due to its large instrumental dimension needed for entry port sites.[16] Robotics not only has its role in cardio-surgeries but acts as an upheaval for cardiologists to intervene in their clinical scenarios using Cor Path 200 robot system. It has a remote interventional cockpit and bedside disposable cassette for conducting percutaneous coronary intervention.[17]

The benefits of robotics in cardiology surgery in terms of clinical outcomes have been found to be as lesser tissue trauma, reduction in blood loss, hastened healing rate, shorter hospital stay, improved quality of life with few or no complications, and 100% success rate on scheduled frequent follow-ups. In the actual procedural point of view, robotics enables the surgeon with a better field of visualization, with high magnification, tremor free, precise micro-instrumentation, and ambidexterity. Cardiologists and technicians are in a great threat for orthopedic and radiation-related occupational hazards, often leading to missed work days. The hybrid revascularization procedures are an eye-catching innovation. Upon our review, we found the requisites for an additional degree of freedom inside the chest cavity, support for beating heart, attainability to different target vessels and vibrotactile sensation while grasping and suturing.

ROBOTICS IN OPHTHALMOLOGY

Since the invention of stereo-taxical micro-manipulator (SMOS) by Guerroued and Vidal in 1989 many robotic platforms in the field of robotic-assisted ocular surgery sprouted especially for vitreoretinal surgeries. Potential robotic applications in ophthalmology are in retinal

surgery, retinal vein cannulation, implant surgery and drug delivery. Ophthalmic robots are classified into assistive hand-held instruments like micron, co-manipulation platforms and telemanipulation systems.[18]

Any surgical procedure performed for the human eye needs precision and has to be quick. The influence of human error can further complicate the procedure. Hand tremors and lack of necessary skills can add to the existing critical scenario of an ophthalmic surgical procedure. Robotic systems have eliminated all the above demerits and have paved way to superior operability over manual procedure. It also provides the surgeon with a magnified view of the surgical site. Ida et al conducted a study with the procedure of microcannulation on pig's eye by using the microsurgical robot and this has successfully substantiated the superiority of robotics.[19]

Robotics aids in intraocular measurements and assists in reducing human errors. This enables the surgeons to execute surgical procedures like vitrectomy and retinal surgery. Steady hand robots, smart sensing tools like microforce sensor and optical coherence tomography has developed for assisting in intraocular measurements.[20-22] Taking into account of the fragile nature of the eye, adjustment of scaling of motion is a major hurdle in robotic-assisted surgery. In the near future, the robotics may provide the surgeon with a suitable tool to bio-print living cells into the retinal pigment epithelium and choriocapillaris and hence replace the damaged cells.

ROBOTICS IN OTORHINOLARYNGOLOGY

Otorhinolaryngology is a field which is unexplored. As of 2000, DVS is the only US FDA approved and actively marketed system for transoral robotic surgery (TORS) for head and neck injury.[23] Weinstein and O'Malley developed TORS and feasibility of this technique was estimated using DVS. Clinical applications of robotics in Otorhinolaryngology include head and neck tumor resection, thyroidectomy, parathyroidectomy, skull base surgeries and laryngeal surgeries. The first robotic TORS were for excision of the vallecular cyst as reported by Mcleod and Melder in 2005.[24] A study conducted on comparing robotic and conventional open thyroidectomy for papillary thyroid carcinoma stipulated robotic thyroidectomy via the bilateral axillo breast approach which is safe and acceptable. However, betterment in resolving the central node dissection issues is required.[25]

In a study by Ye et al to assess the patient outcomes with video-assisted and robotic-assisted thoracoscopic surgery (VATS and RATS) for Masaoka stage 1 thymoma was done. The results stated no significant difference between both groups with respect to the duration of surgery and blood loss. Even though the hospitalization cost was high in RATS it had less postoperative pleural drainage and short hospital stay. The analysis of the study report of short-term follow up showed promising results but long-term follow up is necessary to evaluate the survival and disease-free rate.[26]

Nevertheless, the major challenges faced by the surgeons are the ergonomics of the robot arms which are not coaxial within the laryngoscope. The whole set up process is lengthy. The absence of suction devices, instrument crowding and high cost associated with the installation were prominent concerns. Future prototypes have been expected to incorporate instrument miniaturization, the design of robot arms that function in the coaxial plane of the laryngoscope, integration of suction powered instruments into the robot's arms, and enhanced tooltip dexterity.

ROBOTICS IN HEPATOLOGY

Usage of robotics in liver surgery has so far been limited in over few past decades. But with the increasing experience pathologies dealt by robotics, surgeons have gradually reduced the intricacy of surgery, from initial classifying and removing cysts to liver resection and have evolved to major hepatectomies.[27] The applications of robotics in Hepatology are liver resection for carcinomas, hepatobiliary surgeries, and biliary reconstructions. The liver carcinomas generally include focal nodular hyperplasia, adenoma, lithiasis, cholangitis, and hepatocellular carcinoma. DVS is one such robotic system that has applications for image-guided liver surgery, which has improved surgeon's orientation during the procedure and increased accuracy in tumor resection.[28]

In a study with 45 years data, DVS for hepatobiliary surgeries improved ease of use for both liver resections and biliary reconstructions with the benefit of minimally invasive surgeries.[29] The benefits associated with robotics in hepatologic procedures are a shorter learning curve, the power to overcome unfavorable ergonomics, less intraoperative complications and conversion rates. However, long-term oncological outcomes are unreliable. Comparative studies for assessing the significance of conventional procedures are expected. In addition, cost-effectiveness analysis of robotic procedures should be evaluated further to assess its feasibility.

ROBOTICS IN ORTHOPEDICS

A first of its kind robotic-assisted surgery was done with the help of Arthrobotatat 1980's at the UBC Hospital in Vancouver.[30] Commercially five orthopedic robots are available namely: ROBODOC, ACROBOT/Sculptor, Mako Robotic Arm Interactive (RIO) (Mako Surgical Corporation, Florida), MazorSpineAssist (Mazor Robotics, Israel) and PraximiBlock (Apex Robotic Technology, France) for hip replacement, knee surgery, spine surgery, foot ankle prosthesis, lower limb prosthesis and for other minor procedures. ROBODOC was probably the first commercially available robotic system developed jointly as a collaboration technology

between the University of California and International Business Machines Corporation. Studies conducted with ROBODOC conclude that there is an enhanced technical outcome (implant to fit cavity), better functional outcome (hip scores and time to walk) and decreased intra-operative risk.

The most recent commercial offering is iBlock (previously Praxiteles) and is theoretically similar to Mazor Spine Assist, intended primarily in total and unicompartmental knee surgeries. On the basis of cadaver studies, it has proven its worth to be both time efficient and accurate, but comparative studies need to be done in future. In general, we found that the evidence to use robotics in orthopedics remains diffident which may be because of the lack of comparative studies, expensive nature, and less availability of alternative techniques.[31]

ROBOTICS IN NEUROLOGY

Neurosurgical robotics consolidates the quality of neuronavigation, high-resolution imaging and robotic technologies for the advancement of treatment in the brain. Robotic neurosurgery was first done using programmable universal machine for assembly by Kwoh et al for holding and manipulating biopsy cannulae.[32] Intra-operative imaging was later coupled with robots to achieve accuracy and precision during surgical dissection. Neurosurgery robots like Minerva with image guidance were later developed by University of Lausanne, Switzerland, which allowed the surgeon to monitor the operation by making accurate adjustments.[33] It also decreased the total procedure time of the surgery.

Frameless Neuromate robots can be used to locate the biopsy needle on preoperative magnetic resonance imaging (MRI) instantaneously and it improves the diagnostic yield of biopsies of brainstem lesions in an accurate, safe and efficient manner. Robotic based radiosurgery for skull meningiomas can be done using cyber-knife technology.[34] Telecontrolled microscopic micromini-pulators called Neurobots were developed further to remove tumors of patients with recurrent atypical meningiomas.[35] All of these had limited microsurgical applications along with diminished quality.

As the earlier robots were mechanical guided further research resulted in the incorporation of various features for doing specific tasks with more precision and accuracy. Robot-assisted microsurgery system equipped with adjusted tremor filters and motion scalars to enhance dexterity were developed by US National Aeronautics and Space Administration. Neuro-arm prototype which is designed for deployment within an MRI magnet bore helps in performing a full range of neurological procedures but data is insufficient to prove this. More simulative neurosurgical tools should be developed in the future for surgical planning.

ROBOTICS IN GYNECOLOGY

We found the applications of robotics in gynecology from early 2000's. The DVS was first used to perform robot-assisted hysterectomy followed by sacrocolpopexy in 2004.[36] Gynecologic oncology used robot-assisted devices in mainly hysterectomies, lymphadenectomies and in staging as well as debulking of ovarian cancer. It is also applied in endometrial cancer, endometriosis, endometrial hyperplasia, cervical intraepithelial neoplasia, tubal re-anastomosis and pelvic organ prolapse repair. Robotic-assisted hysterectomy procedures have grown exponentially in removing all types of tumors.[37]

Seamon et al compared robotics with laparotomy for staging endometrial cancer in obese patients and complication rates were found to be less with robotic surgery. Post-operative complications were found to be relatively rare in modified radical hysterectomy techniques.[38] Currently another project that is under development by Strasbourg, France is single access transluminal robotic assistance for surgeons (STRAS) which is a telerobotic system to perform lapro endoscopic single-site surgery. STRAS is in its building phase to implement a high-resolution camera, an intuitive haptic interface and a visual tracking system.[39] Some of the concerns regarding robotic surgeries found were the high cost of the procedure, lengthy operative time, vaginal cuff dehiscence and dissemination of undiagnosed sarcoma. Studies may be required to be performed in a simulated model to get more learning experience. The areas to be dealt in future are decreased field of vision, inability to apply force and improved haptic feedback.

ROBOTICS IN UROLOGY

The first urological robot was the PROBOT in 1989, used for transurethral resection of the prostate. In urology, there are vast afflictions for robotics includes prostatectomy, cystectomy, nephrectomy, pyeloplasty, urolithiasis, management of urinary fistula, ureteroneocystostomy and ureteroureterostomy.[40] The DVS is the most commonly used robotics for all these procedures.

The first robotic-assisted surgery done in pediatrics is robotic-assisted pyeloplasty (RAP).[41] Robot-assisted radical prostatectomy (RARP) was used by Menon et al, Vattikuti Institute Prostatectomy (VIP) technique by them achieved equivalent oncological outcomes compared to conventional nerve sparing modalities.[42] However, the use of RARP remains controversial because there are no randomized studies comparing radical, laparoscopic and robotic procedures. With its enriching qualities that facilitate intracorporeal reconstruction and suturing, RAP has been performed for uteropelvic junction obstruction in adults. A prospective randomised controlled trials of robotic versus open radical cystectomy for bladder cancer by Nix et al concluded that robot-assisted radical cystectomy has longer operative time, less intraoperative

bleeding, quicker time to bowel movement with less use of analgesic and favorable postoperative outcomes.[43]

Robotic ureteroneocystostomy, ureteroureterostomy, ureteral stump excision and ureterosciatic hernia repair are some of the ureteral pathologies which are repairable by robotics as per Hemal et al.[44] Even though long-term follow up data are required for stating the superiority of robotic-assisted procedures, short-term and intermediate data for efficacy stands along favorably to accepted standards. The lack of laparoscopic skills makes easier learning platforms like robotics crucial for surgeons.

ROBOTICS IN DENTISTRY

The use of robotics in dentistry is caving in with all the necessary technologies. For example, image-based simulation of implant surgery, followed by surgical guides and creating digital impressions of preparations using an intraoral scanner, after which a milling device produces the restoration. Dental training robot, realistic human like robots, simroid, endo-micro robots, nano-robots, surgical robots, sensor-equipped implant setup are the known robots in the field of dentistry. The dental training robots are used for dental therapy training.[45] To allow dental students for a real time experience, the realistic robot Sowa Hanako was developed. Using nanotechnology and computer assisted procedures task the dental nanorobots used to wipe out caries causing bacteria or to repair tooth blemishes where decay has set in.[46]

ROBOTICS: EVOLVING IN REHABILITATION CARE

The field of robotic rehabilitation is under rapid growth. It includes artificial limbs to robots supporting rehabilitation therapy for providing individualized assistance in the hospital and residential setup. Robotic assisted devices are having diverse applications in reinstating patients with stroke, Spinal cord injury, cerebral palsy, Parkinson's disease and multiple sclerosis mainly on gait recovery. Types of robots available are Lego (Lego Mindstorm EV3) robot, robot-assisted gait training devices like Lokomat, robot-assisted arm training devices; social robots like personal assistive robot and humanoid robots have applications in assistive technology. Robot driven exoskeletons and end effectors are also of immense usage.[47,48] Traditional rehabilitation techniques are time-consuming, costly and labor intensive. In future efficient robotic counselors can be developed.

Robotic assisted treadmill exercise by Lokomat promotes cardiopulmonary fitness and help to evaluate the aerobic capacity in the early poststroke stages of patients. This orthosis system is a motor driven body weight support system with real time feedback control for precise body weight unloading.[49] The first robot based services were reported in 2010 known as WikiTherapist which was developed by Eindhoven University of Technology followed by NAO developed by Aldebaran robotics for the Autism community.[50] Combination of robotics and telecommunication technology has enabled therapists to concentrate more on intervention.

CONCLUSION

There is a dire need for the refinement of user interface information and multidisciplinary integration in robotics. Cost of acquisition, installation, and maintenance of robotic systems, the moral and legal aspects of their usage and liability upon their employment in medical care should be surveyed and considered for in the near future. An efficient and proactive surgical team must be present in hospital setup as we believe that a qualified and technically sound team can decrease the turnover time by facilitating proper flow of each procedure. In turn, this would be beneficial in reducing intra-operative matters.

As per our review of the literature, the simulated practice of robot-assisted surgery and understanding of robotics in non-surgical care will have an added benefit to the performance of a physician in a clinical scenario. In the future prospect of robotics in medical care, we recommend that studies on genetic predisposition of a patient to a therapy should be systematically addressed to its robotic applications in human. Evidence from diverse random controlled trials in a physician-patient scenario is required to assess and evaluate the robotic-assisted surgical procedures over conventional surgical procedures. An online live-streaming transatlantic robot-assisted surgery may further be developed to remove current geographical constraints across the globe. Robotics in medical care with its certain set of challenges is a rapidly emerging field. It is clearly evident that no system is free from errors but need a constant evolution phase to progress; we find the robots are indeed a fine craftsmanship by and for the humankind.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank the Department of Science and Technology - Fund for Improvement of Science and Technology Infrastructure in Universities and Higher Educational Institutions (DST-FIST), Govt. of India, New Delhi for their infrastructure support to Department of Pharmacology. The authors thank Dr. S. P. Dhanabal, the Principal, JSS College of Pharmacy, Ooty, for providing all the needed support and encouragements to do this work. We would like to thank Ms. Sini Sathish B.Sc., B.Ed., PGD HRM, IELTS British Council certified trainer for making necessary language correction of the manuscript.

Funding: No funding sources
Conflict of interest: None declared
Ethical approval: Not required

REFERENCES

1. Capek J. Opilec. In: Lelio A Pro Delfina. Aventinum, Prague; 1925.
2. Capek KR.: Rossum's Universal Robots. Penguin Group USA, New York: 2004.
3. Katashev A, Dekhtyar Y, Spigulis J. 14th Nordic-Baltic Conference on Biomedical Engineering and Medical Physics: Nbc 2008. 16-20 June 2008. Riga, Latvia. Springer Science and Business Media; 2008: 662.
4. Nishihara S, Sugano N, Nishii T, Tanaka H, Nakamura N, Yoshikawa H, et al. Clinical Accuracy Evaluation Of Femoral Canal Preparation Using The Robodoc System. J Orthop Sci. 2004;9(5):452-61.
5. Cobb J, Henckel J, Gomes P, Harris S, Jakopec M, Rodriguez F, et al. Hands-on Robotic Unicompartmental Knee Replacement. Bone Joint J. 2006;88(2):188-97.
6. Satava RM. Surgical Robotics: The Early Chronicles: A Personal Historical Perspective. Surg Laparosc Endosc Percutan Tech. 2002;12(1):6-16.
7. Ballantyne. Robotic Surgery, Telerobotic Surgery, Telepresence, and Telementoring. Review of Early Clinical Results. Surg Endosc. 2002;16(10):1389-402.
8. Patel VR, Tully As, Holmes R, Lindsay J. Robotic Radical Prostatectomy In The Community Setting—The Learning Curve And Beyond: Initial 200 Cases. J Urol. 2005;174(1):269-72.
9. Shah BC, Buettner SL, Lehman AC, Farritor SM, Oleynikov D. Miniature In Vivo Robotics And Novel Robotic Surgical Platforms. Urologic Clin North America. 2009;36(2):251-63.
10. Lobe TE, Wright SK, Irish MS. Novel Uses Of Surgical Robotics In Head And Neck Surgery. J Laparoendoscopic Advanced Surg Tech. 2005;15(6):647-52.
11. Lee JD, Srivastava M, Bonatti J. History And Current Status Of Robotic Totally Endoscopic Coronary Artery Bypass. Circ J. 2012;76(9):2058-65.
12. Chitwood WR. Robotic Cardiac Surgery By 2031. Tex Heart Inst J. 2011;38(6):691-3.
13. Lehr EJ, Guy TS, Smith RL, Grossi EA, Shemin RJ, Rodriguez E, et al. Minimally Invasive Mitral Valve Surgery Iii. Innovations (Phila). 2016l;11(4):260-7.
14. Vasilyev NV, Dupont PE, Del Nido PJ. Robotics and Imaging in Congenital Heart Surgery. Future Cardiol. 2012;8(2):285-96.
15. Weisz G, Metzger DC, Caputo RP, Delgado JA, Marshall JJ, Vetrovec GW, et al. Safety And Feasibility Of Robotic Percutaneous Coronary Intervention: Precise (Percutaneous Robotically-Enhanced Coronary Intervention) Study. J Am Coll Cardiol. 2013;61(15):1596-600.
16. Wutzler A, Wolber T, Haverkamp W, Boldt L-H. Robotic Ablation of Atrial Fibrillation. J Visualized Experiments. 2015;(99):52560.
17. Seco M, Edelman JJB, Yan TD, Wilson MK, Bannon PG, Vallely MP. Systematic Review of Robotic-Assisted, Totally Endoscopic Coronary Artery Bypass Grafting. Ann Cardiothorac Surg. 2013;2(4):408-18.
18. Molaei A, Abedloo E, De Smet MD, Safi S, Khorshidifar M, Ahmadieh H, Et Al. Toward The Art Of Robotic-Assisted Vitreoretinal Surgery. J Ophthalmic Vis Res. 2017;12(2):212-8.
19. Ida Y, Sugita N, Ueta T, Tamaki Y, Tanimoto K, Mitsuishi M. Microsurgical Robotic System For Vitreoretinal Surgery. Int J Comput Assist Radiol. Surg. 2012;7(1):27-34.
20. Taylor R, Jensen P, Whitcomb L, Barnes A, Kumar R, Stoianovici D, et al. A Steady-Hand Robotic System for Microsurgical Augmentation. The Int J Robotics Res. 1999;18(12):1201-10.
21. Patritti BL, Sicari M, Deming LC, Romaguera F, Pelliccio MM, Kasi P, et al. The Role Of Augmented Feedback In Pediatric Robotic-Assisted Gait Training: A Case Series. Tech Disability. 2010;22(4):215-27.
22. Balicki M, Han J-H, Iordachita I, Gehlbach P, Handa J, Taylor R, et al. Single Fiber Optical Coherence Tomography Microsurgical Instruments For Computer And Robot-Assisted Retinal Surgery. In: Medical Image Computing And Computer-Assisted Intervention - Miccai 2009. Springer, Berlin, Heidelberg; 2009.
23. Oliveira Cm, Nguyen Ht, FerrazAr, Watters K, Rosman B, Rahbar R. Robotic Surgery In Otolaryngology And Head And Neck Surgery: A Review. Minimally Invasive Surg. 2012;2012:1-11.
24. Weinstein GS, O'malley JR, Snyder W, Hockstein Ng. Transoral Robotic Surgery: Supraglottic Partial Laryngectomy. Ann Otol Rhinol Laryngol. 2007;116(1):19-23.
25. Cho JN, Park Ws, Min Sy, Han S-A, Song J-Y. Surgical Outcomes of Robotic Thyroidectomy vs. Conventional Open Thyroidectomy for Papillary Thyroid Carcinoma. World J Surgical Oncol. 2016;14(1).
26. Ye B, Tantai J-C, Li W, Ge X-X, Feng J, Cheng M, et al. Video-Assisted Thoracoscopic Surgery Versus Robotic-Assisted Thoracoscopic Surgery In The Surgical Treatment Of Masaoka Stage I Thymoma. World J Surg Oncol. 2013;11:157.
27. Leung U, Fong Y. Robotic Liver Surgery. Hepatobiliary Surg Nutr. 2014;3(5):288-94.
28. Goja S, Singh Mk, Soin AS. Robotics In Hepatobiliary Surgery-Initial Experience, First Reported Case Series From India. Int J Surg Case Rep. 2017;33:16-20.
29. Ho C-M, Wakabayashi G, Nitta H, Ito N, Hasegawa Y, Takahara T. Systematic Review Of Robotic Liver Resection. Surg Endosc. 2013;27(3):732-9.
30. Mohammad S. Robotic Surgery. J Oral Biol Craniofac Res. 2013;3(1):2.

31. Hodgson A. 5 - Robotics in Orthopaedic Surgery. In: Gomes P, Editor. Medical Robotics. Woodhead Publishing; 2012: 90-112.
32. Kwoh Ys, Hou J, Jonckheere Ea, Hayati S. A Robot With Improved Absolute Positioning Accuracy For Ct Guided Stereotactic Brain Surgery. IEEE Tran Biomed Eng. 1988;35(2):153-60.
33. Glauser D, Fankhauser H, Epitaux M, Jaccottet A. Neurosurgical Robot Minerva: First Results And Current Developments. J Image Guid Surg. 1995;1(5):266-72.
34. Combs Se, Ganswindt U, Foote Rl, Kondziolka D, Tonn J-C. State-Of-The-Art Treatment Alternatives For Base Of Skull Meningiomas: Complementing And Controversial Indications For Neurosurgery, Stereotactic And Robotic Based Radiosurgery Or Modern Fractionated Radiation Techniques. Radiat Oncol. 2012;7:226.
35. Das H, Zak H, Johnson J, Crouch J, Frambach D. Evaluation Of A Telerobotic System To Assist Surgeons In Microsurgery. Comput Aided Surg. 1999;4(1):15-25.
36. Iavazzo C, Gkegkes ID. Application of Da Vinci® Robot In Simple Or Radical Hysterectomy: Tips And Tricks. J Turkish German Gynecological Association. 2016;17(2):106-9.
37. Bouquet De Joliniere J, Librino A, Dubuisson J-B, Khomsi F, Ben Ali N, et al. Robotic Surgery In Gynecology. Frontiers Surg. 2016;3:26.
38. SeamonLg, Bryant SA, Rheaume PS, Kimball KJ, Huh WK, Fowler JM, et al. Comprehensive Surgical Staging For Endometrial Cancer In Obese Patients: Comparing Robotics And Laparotomy. Obstetr Gynecol. 2009;114(1):16-21.
39. Diana M, Marescaux J. Robotic Surgery: Robotic Surgery. Br J Surg. 2015;102(2):E15-28.
40. Babbar P, Hemal AK. Robot-Assisted Urologic Surgery in 2010 - Advancements And Future Outlook. Urol Ann. 2011;3(1):1-7.
41. Howe A, Kozel Z, Palmer L. Robotic Surgery in Pediatric Urology. Asian J Urol. 2017;4(1):55-67.
42. Menon M, Shrivastava A, Kaul S, Badani KK, Fumo M, Bhandari M, et al. Vattikuti Institute Prostatectomy: Contemporary Technique And Analysis Of Results. Eur Urol. 2007;51(3):648-57.
43. Nix J, Smith A, Kurpad R, Nielsen ME, Wallen EM, Pruthi Rs. Prospective Randomized Controlled Trial of Robotic Versus Open Radical Cystectomy for Bladder Cancer: Perioperative and Pathologic Results. Eur Urol. 2010;57(2):196-201.
44. Hemal AK, Nayyar R, Gupta NP, Dorairajan LN. Experience With Robot Assisted Laparoscopic Surgery For Upper And Lower Benign And Malignant Ureteral Pathologies. Urology. 2010;76(6):1387-93.
45. Rawtiya M, Verma K, Sethi P, Loomba K. Application of robotics in dentistry. Indian J Dent Adv. 2014;6:1700-6.
46. Shetty NJ, Swati P, David K. Nanorobots: Future in dentistry. Saudi Dent J. 2013;25:49-52.
47. Gupta N, Raja K. Rehabilitation Robotics in India. J Neurosci Rural Practice. 2011;2(2):207.
48. Timmermans AAA, Seelen HAM, Willmann RD, Kingma H. Technology-Assisted Training Of Arm-Hand Skills In Stroke: Concepts On Reacquisition Of Motor Control And Therapist Guidelines For Rehabilitation Technology Design. J Neuroeng Rehabil. 2009;6:1.
49. Stoller O, de Bruin ED, Schuster-Amft C, Schindelholz M, de Bie RA, Hunt KJ. Cardiovascular rehabilitation soon after stroke using feedback-controlled robotics-assisted treadmill exercise: study protocol of a randomised controlled pilot trial. Trials. 2013;14:304.
50. Gillesen J, Boere S, Barakova E. "WikiTherapist," in Proceedings of the 28th Annual European Conference on Cognitive Ergonomics. New York, USA: 2010: 373-374.

Cite this article as: Balasubramanian S, Chenniah J, Balasubramanian G, Vellaipandi V. The era of robotics: dexterity for surgery and medical care: narrative review. Int Surg J 2020;7:1317-23.