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Research Article

SURGICAL ROBOTICS: TIMELINE AND FUTURE

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A R T I C L E I N F O

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A B S T R A C T

Introduction and background: Robotic revolution in the surgical field is a milestone. It is important to have knowledge about the past in order to proceed towards the future for maximum utilization of the advantages of the surgical robot. The aim of the present review article is to explore the timeline of surgical robotics and future applications and changes in surgical robotics.
Methods: A review of the literature on robotics was undertaken using Google search. Various studies describing the history and development and the future of robotics in the field of surgery were included in the present study.
Results: This article gives an introduction to robotic technologies and their chronology in the health sector, studies the evolution of the surgical robot, and discusses future possibilities for renovation. Robotic surgery has no doubt provided some clear advantages but the associated cost and complexity of handling and learning curve cannot be ignored.
Conclusion: The future surgical robots should be aimed at creating a small-sized, cost-effective, feasible robot that integrates emerging technologies from various fields. Moreover, as novel systems come into the market, the curriculum should incorporate robotic training among residents via validated schemes. Evidence-based strategies must be implemented to ensure patient outcomes remain the primary focus.

INTRODUCTION

The word robot came from Karel Capek, a Czech playwright in the 1921, in his ironic play named "Rossum's Universal Robots" [1,2] The Czechword robota which means slave labor is the basis of the word robot. Over the past more than 35 years, various surgical robots have evolved for a wide spectrum of clinical application. In a CT-guided brain biopsy the first robot PUMA 200 (Westinghouse Electric, Pittsburgh, PA) was used for needle placement [3]. Since then it has been thrilling to observe the giant stride in the field of robotic surgery. This is due to the number of benefits that robotics provides which are not found in conventional surgical techniques. Robots using modern imaging technology offer greater range of motion, telesurgery along with stability, accuracy and various other benefits in different surgical specialties[4]. It is important to have a knowledge about the past in order to proceed towards the future for maximum utilization of the advantages of the surgical robot.

Application of surgical robotics has been curbed significantly by elevated costs, but increasing competition in the market should help in alleviating this obstacle, expanding the use of the technology. Robotics in health sector will continue to revolutionize modern surgery in near future with quantum leap in haptic feedback, artificial intelligence (AI)/ machine learning and training. This review explores the timeline of surgical robotics and future applications and changes in surgical robotics.

Aims and objectives

- To review the chronology of robotics
- To foresee the future applications and changes in surgical robotics

METHODOLOGY

A review of the literature on robotics was undertaken using Google search. Various studies describing the history and development and the future of robot in the field of surgery were included in the present study.

RESULTS AND DISCUSSION

The very first robotic surgery was performed in the year 1985 at Memorial Medical Center, LongBeach, CA, USA, when a CT-guided stereotactic biopsy of brain was done with an accuracy of 0.05 mm using an adjusted industrial robotic arm named as Unimation PUMA 200, being the prototype for Neuromate robot which is currently used. This got the Food and Drug Administration (FDA) approval in the year 1999[5].

Probot was next developed at Imperial College London six years later in the year 1991.The autonomous removal of a significant amount of tissue during a transureteral resection of

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prostate (TURP) was performed for the first time in London, UK[5].

In 1992 Japan adjusted an industrial robot for performing total hip arthroplasty (THA) named SCARA robot with 5 degrees of freedom. In the same year Integrated Surgical Systems (ISS) in Sacramento, CA, USA developed a similar autonomous robotic system, used for performing total hip arthroplasty (THA) and named it as Robodoc. This system received FDA approval for THA in1998 and for total knee arthroplasty (TKA) in 2009[5].

Germany for the first time in the year 2000 adapted an industrial PUMA robot for THA, TKA and to repair the anterior cruciate ligament named it as CASPAR—Computer Assisted Surgical Planning and Robotics similar to Robodoc[5]. Computer Motion Inc. in 1995 developed Zeus robotic system which comprises of three robotic arms—one passive arm for handling the laparoscope and the other two active arms for replicating surgeon’s movements from a remote console which results in moving specially developed surgical instruments[6].Margossian and Falcone *et al*.[7] in their study on Zeus robotic system in complex gynecologic surgeries on 10 pigs who underwent adnexal surgery or hysterectomy showed that robotic surgery is feasible and safe for such surgeries.

Intuitive Surgical Inc. launched the da Vinci Surgical System in 1999 which comprises of a patient cart and surgeons console. The patient cart which is placed near the operating table contains three or four robotic arms for special surgical tools and endoscopic visualization system. There are 1 or 2 working console for surgeons comprising of binocular lens providing 3D visualization system. Da Vinci replicates surgeons’ wrist, hand and fingers movements allowing seven degrees of freedom in the surgical field with the added advantage of tremor filtration property and in real time[5].

A study conducted by Cadiere *et al*. to evaluate the feasibility of robotic laparoscopic surgery in 146 patients[8] performed with a Da Vinci robot. The procedures included were 48 cholecystectomies, 39 antireflux procedures, 28 tubal reanastomoses, 10 gastroplasties for obesity, 3 intrarectal procedures, 3 inguinal hernia repairs, 2 artiovenous fistulas, 2 prostatectomies, 2 cardiac procedures, 2 hysterectomies, 1 endometriosis cure, 1 appendectomy, 1 lumbar sympathectomy, 1 varicocele ligation, 1 laryngeal exploration and 1 neosalpingostomy. They were successful in establishing the feasibility of robotic laparoscopic surgery. They also showed that the robot was very useful for manipulations in very small intra-abdominal spaces and no robot related morbidity was reported in those cases.

Falcone *et al*.[9] in their study on 10 patients who had past history of tubal sterilization procedure underwent tubal reanastomosis. They found that the 19 tubes were successfully reanastomosed and on follow up 6 weeks postoperatively 17 of the 19 were still patent and resulted in 5 pregnancies.

Marescaux *et al*, in a prospective study on 25 patients concluded that robotic laparoscopic cholecystectomy is safe and feasible[10]. Another study conducted by Abbou *et al* showed that telerobotic laparoscopic radical prostatectomy are safe and feasible with improved dexterity[11].

Various randomized controlled trials (RCTs) were conducted for noncancerous gynecologic disease to compare robotic surgery with traditional laparoscopy and none of the study showed robot-assisted approach to be superior[12-19].

The Versius system developed by a British private limited company CMR surgical, has small form factor and modular design includes individually cart-mounted mobile arms, helping it to move between operating rooms and even hospitals/clinics. By replicating the human arm, this robotic system gives surgeons the freedom of port placement, but with the benefits of small fully-wristed instruments. The system also includes 3D HD vision, easy-to-adopt instrument control and a choice of ergonomic working positions. This is the next-generation robotic system introduced in the year 2018 and since then it has been useful in conducting over 1000 surgeries globally by November 2020.A study conducted in north India by Rahul Manchanda *et al*.[20] shared their experience of seven cases of total robotic hysterectomy with or without bilateral salpingoophorectomy showed shorter hospital stay and less blood loss with a learning curve and less fatigue for the operating surgeon.

Israeli robotically-assisted surgery company Memic Innovative Surgery has developed the Hominis surgical robotics platform, is now approved for the purpose of single-site, natural-orifice laparoscopic-assisted transvaginal benign surgical operations such as hysterectomy for benign lesions with or without salpingo-oophorectomy.

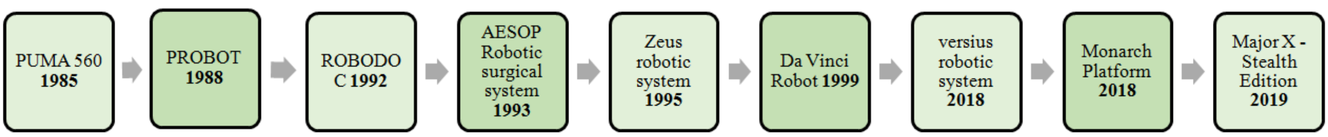

Fig 1 Chronology of robotics

Table 1 Chronology of surgical robotics

Robot type	Company	Year	Approval status	Procedures
PUMA 560 (prototype for Neuromate robot)	Victor Scheinman at pioneering robot company Unimation.	1985	FDA in 1999	CT-guided stereotactic biopsy of brain[5]
PROBOT	Imperial College London	1991	--	transureteral resection of prostate[5]
ROBODOC	Currently: Think Surgical, USA	1992	FDA in 1998 for THA and In 2009 for TKA	Total hip arthroplasty, Total knee arthroplasty[1,5,21,22,23,24]
ZEUS	Computer Motion Inc., USA	1995	FDA in 2001	MIS and cardiac procedure[21,25]
DA VINCI	Intutivesuirgical, USA	1999	FDA in 2000 (1st model)	MIS[21,25,26,27,28]
VERSIUS	CMR surgical, UK	2018	CE mark 2019	Minimal access surgery, colorectal procedures[29-31]
MONARCH PLATFORM	Aruis Health, USA	2018	FDA- 2018	Peripheral bronchoscopy, endoscopy[32]

In this device a video camera inserted laparoscopically through a single abdominal port and specially designed surgical instruments are inserted through the vagina, renders Hominis procedures less invasive as compared to traditional laparoscopic procedures. This device comprises of humanoid robotic arms, which contains multi-planar flexibility and 360 degrees of articulation and are designed to provide human-level dexterity. Lowenstein L *et al*. in their documentation of eight bilateral salpingo oophorectomies performed on Hominis surgical robots showed robotic vaginal natural orifice transluminal endoscopic surgery (RvNOTES) procedure was favourable to surgeon and has a fast learning curve and time of surgery decreases with practice[33].

A pill-sized robot named gastroscope capsule is developed by Chinese tech firm Ankon at a hospital in Wuhan, China's Hubei province. This capsule is capable to perform 360-degree examinations of the digestive tract in patient's stomach which is painless, non-invasive, it doesn't require anaesthesia and has no cross-infection chances.

Magnetically controlled capsule endoscopy (MCE), is shown as more reliable approach and gave promising results for gastric examination in several trials[34-37]. Zhuan Liao *et al*. in their study showed that magnetically controlled capsule endoscopy is preferred by patients over conventional endoscopy and it detects focal lesions in the upper and lower stomach with comparable accuracy[38]. The only disadvantages with MCE are that it requires training is costly and more time consuming as compared to conventional endoscopy.

The intelligent miniature robotic devices are the future of robotics and also they can beresterilizableor disposable. Heart Lander-a miniature mobile robot is in the process of development by Carnegie Mellon University and one such example. It is designed to per-form invasive targeted therapy on the surface of a beating heart. Therefore, these robots can be injected into the bloodstream, or swallowed to perform targeted treatment and to repair tissue at the cellular level or provide gene therapy is not just fantasy for us today. These mini robots will be the part of our surgical armamentarium by the next decade[5].

In forthcoming times robotics in surgery is surely approaching miniaturization. The real challenge is whether to develop versatile robots that can operate on various tissues, or to produce organ or pathology specific robots. There could be possibility of corrections at cellular, molecular and even genetic level with the advent in the field of molecular engineering and nano robots. But different types of interventions will be needed at all levels, from microsurgery to nano scale corrections then only these nano robots may come to the competition in the future decades.

It is important to note that with fast progress in the different medical and technological aspects, for example in nanorobotics and gene therapy, the mode of treatment may differ grossly in the near future. However, we must seek to make treatment modalities as simple and efficient as possible. In the future, we may witness the evolution of nanotechnology that could make current medical robotic systems outdated.

CONCLUSION

With increasing competition in the field of marketing of robotic surgical systems, focus should be on reducing the cost of various robotic operating systems along with the instrumentation and their maintenance. However, the initial expenses will still be high, hence a national acquisition policy is needed to help bring down price and ensure fair access.

Moreover, as novel systems come into the market, the curriculum should incorporate robotic training among residents via validated schemes. Evidence-based strategies must be implemented to ensure patient outcomes remain the primary focus.

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