Surgical robotics – past, present and future

F. Graur[1, 2], E. Radu[2], N. Al Hajjar[1, 2], C. Vaida[3], D. Pisla[3]

[1]*University of Medicine and Pharmacy "Iuliu Hatieganu" Cluj-Napoca, Romania*
[2]*Regional Institute of Gastroenterology and Hepatology "Octavian Fodor", Cluj-Napoca, Romania*

[3]*CESTER, Technical University of Cluj-Napoca, Romania*

Abstract. Robotic surgery is in continuous development proving to be not only a better therapeutic option in certain procedures but also a pioneer field in which research occupies a very important role. The history of robotic begins with science-fiction literature, but it profiles the industrial and also health robots that are nowadays used. Robotic surgery begins later on with modified industrial robots, but from that point it has its own development. This article is a short history of surgical robotics, continued with the presentation of some surgical robots currently used. At the end, the characteristics of the future surgical robot are discussed, as well a proposal for a minimally invasive SILS robot.

Key words: surgical robot, minimally invasive, SILS robot, robotic surgery

1 Introduction

Development of general surgery in recent decades was centered on minimally invasive procedures. This term refers to any procedure less invasive than open surgery used for the same pathology and was introduced by E. John A. Wickham, a promoter of this type of surgery [10]. The old assumption that "a big surgery requires a big incision" is no longer true for a long time [4]. In minimally invasive surgery as the access ports and incisions became smaller and smaller, the same size tools are developed [4], aiming not only to provide smaller dimensions but also enhanced functionality [30].

Surgical robots were introduced in mid-century when science fiction became reality. Surgical robot is defined as a machine that perform complex surgical tasks in master-slave configuration system [4]. In the last 3 decades surgical robots have experienced geometrical evolution and development, reflected on an extended number of robotic solutions reaching experimental stages and demonstrated by the growing number of articles published in scientific magazines and because of the growing interest in this field [6, 17]. If at first surgical robots were used to support, move and orient the camera in the operating field, subsequently it came to complex surgical robots in which the surgeon operates from a remote console far from the patient.

As in the case of industrial robots, in surgery were introduced robots in areas where accuracy and better precision were needed (Neurosurgery), to perform repetitive tasks (Urology) and higher speed compared to manual labor performed by humans. The desired shortening of surgical procedures time performed by robots has not yet been achieved in most areas where they are used [10].

In order to develop and implement into practice new surgical techniques with a shorter time, with a quicker recovery of the patient, with increased efficiency, it is mandatory to use advanced computer technologies: surgical robots, 3D imaging, augmented reality and surgical simulators (to shorten the learning curve of the new techniques) [16]. Development of surgery, which led to the surgical robots, developed new fields as: minimally invasive surgery, fetal surgery, virtual reality surgery, neuro-informatics surgery and today appeared the term of non-invasive surgery [3, 14].

2 Evolution of surgical robotics

2.1 History of robotics in surgery

Robotics started in 1921 with the play "Rossum's Universal Robots" by Karel Čapek, in which we find for the first time the word "robot", derived from the Czech word "robota" which means forced labor. Irony is that although the play was a satire on the industrialization of Europe, in the century that followed robots led to explosive industrialization of the entire planet [1, 2, 7, 8, 19].

The term "robotics" was introduced by Isaac Asimov in 1938 in his short story "Runaround" published in the magazine Super Science Stories, followed in 1942 by publishing of a collection of short stories "I Robot" in which robots coming into conflict with their owners are described. Asimov was the one that described also the first 3 Laws of Robotics, laws that govern the behavior of robots [1, 19]:

1. A robot may not injure a human being, or, through inaction, allow one to come to harm.

2. A robot must obey all orders given to it from humans, except where such orders would contradict the First Law.

3. A robot must protect its own existence, except when to do so would contradict the First Law or the Second Law.

From Capek and Asimov, many famous works of science fiction appeared and popularized the notion of "robot". In the George Lucas's series "Star Wars" they were friends with the people but in the movie series Terminator, they were people enemies [5].

The 3 Laws of Robotics remained actual and ethically acceptable in the development of surgical robots today [5].

Starting with the 2nd half of the twentieth century robots imagined by Capek and Asimov became reality, first in the industry, being used for mechanical work in factories to increase productivity, minimizing human error and accidents at work [11, 17]. General Motors was the first company that made the transition from fiction to reality in the field of robotics by introducing the Unimate robot in the assembly line in 1958 and it was first used in 1961.

2.2 Current use of robots

After that start point of robotics, the use of robots has experienced explosive development. They are used in a variety of applications, including space exploration, military field, medicine, etc [17, 32].

Robots can be represented in the form of automatic arms, mobile devices or telerobotic systems. Regarding robots taxonomy they can be active, semi-active or passive. Semi-active and passive robots transmit the operator's commands and movements to the arms of the robot. Active robots are those who have a predefined schedule and runs on a computer algorithm, without the need for real time operator's intervention [17].

Robots have several advantages over humans, including the accuracy and repeatability of movement, which is why they get so extensively in industrial field, but the medical field is not as accurate and structured as industry. Such robots have several disadvantages in this area: low adaptability and a low level of applied force feedback (haptic). Regarding these considerations it is ideal and simple to use a robotic system to prepare the femoral head prosthesis (RoboDoc is a surgical robot used in orthopedic arthroplasty of the hip, a robot imaging guided after a plan drawn up by the surgeon before the operation on CT examinations, thus establishing the exact place and position of the prosthesis), but it is hard to imagine a robot that autonomously perform a cholecystectomy [5, 26].

The first use of a robot surgery was in 1985 at Memorial Medical Center, Long Beach, CA, USA, when an adjusted industrial robotic arm (Unimation PUMA 200) allowed a CT-guided stereotactic biopsy of brain, with an accuracy of 0.05 mm, being the prototype for Neuromate robot (which received approval from the Food and Drug Administration - FDA in 1999) [10, 31].

There was a gap for 6 years before the next stage in robotic surgery development. In 1991 in London, UK a surgical robot was first used (Probot - developed at Imperial College London) for the autonomous removal of a significant amount of tissue during a TURP (transureteral resection of prostate) [10].

In 1992 another industrial robot was adjusted for surgery in Japan: SCARA robot, with 5 degrees of freedom. It was used for total hip arthroplasty. A similar robotic system, Robodoc, was developed in Sacramento, CA, USA by Integrated Surgical Systems ISS. Robodoc system was first used on humans in 1992 as an autonomous robot for total hip arthroplasty (THA), and received FDA approval in 1998 and for TKA (total knee arthroplasty) in 2009 [10].

A few years later, in 2000, in Germany was used for the first time a robotic system similar to Robodoc called CASPAR - Computer Assisted Surgical Planning And Robotics. This is actually an industrial PUMA robot adapted for THA, TKA and to repair the anterior cruciate ligament [10].

The first class of surgical robots are based on autonomous industrial robots, or with an autonomous approach, which means that the robot will enable the fulfillment, at a certain point, of a lower or higher degree task without the intervention of the surgeon [10].

A second class of surgical robots is represented by those robots that are designed to assist the surgeon and work with it during interventions being capable to move autonomously, but are not scheduled in this regard but are programmed to replicate surgeon movements in a master / slave configuration of the system (such as da Vinci or Sensei).

Visionaries in telepresence surgery and its benefits were Scott Fisher, Ph.D. - NASA scientist and Joe Rosen, MD - plastic surgeon at the University Palo Alto, CA, USA. They have imagined this virtual presence of the surgeon in the operating field via remote manipulation of robotic arms. Their project, in collaboration with Phil Green, Ph.D. Stanford Research Institute and the Pentagon was to create a device to rescue the wounded person on the battlefield and giving them first aid by a surgeon from a remote console [3, 11, 12].

Some robots are designed to move the laparoscope during minimal invasive abdominal interventions. The surgeon commands such robots either by voice or by head movements. The first such prototype of voice commanded robotic arms is AESOP developed by Intuitive Surgical Inc. [20] followed by others like Viky or EndoAssist.

In this field the, a joint team of from CESTER, Technical University of Cluj-Napoca and Surgical Clinic III, University of Medicine and Pharmacy Cluj-Napoca, achieved a series of national premieres, Pisla et al [13, 22, 23, 28, 29]:

- PARAMIS – the first Romanian parallel robot with voice control for laparoscope positioning in minimally invasive surgery (2009), presented in 2011 at the Congress of the European Association of Endoscopic Surgery as an oral presentation [27] and included as one of the acknowledged solutions in a "review" published in 2010 by a group of Japanese researchers, entitled "Classification, Design and Evaluation of Endoscope Robots", which presents the 27 robotic structures developed worldwide for endoscopic surgery [25];
- PARASURG –5M – the first Romanian parallel robot for active instruments positioning in minimally invasive surgery (2011),
- PARASIM the first Romanian robotic surgical active instrument with enhanced dexterity (2012),
- HEPSIM the first Romanian liver surgery pre-planning and virtual training simulator [9].

Zeus robotic system (developed by Computer Motion Inc.) consists of three robotic arms – one handles the laparoscope and the other two are the active arms replicating surgeon's movements from a remote console, moving specially developed surgical instruments [24].

The da Vinci Surgical System created by Intuitive Surgical Inc. and launched in 1999 consists of 1 or 2 working console for surgeons with 3D visualization system of the surgical field and a cart placed near the operating table that has three or four robotic arms for endoscopic visualization system and special tools. Da Vinci transmits movements of the surgeon hands, wrists and fingers to the instruments in the surgical field, in real time, with tremor filtration [10].

Figure 1 - Da Vinci Si system. ©2009 Intuitive Surgical, Inc.

Sculptor Acrobat (acronym for Active Constraint Robot) is also a synergistic robotic system, but with "hands-on" control. It was first used in 2001 for a series of seven TKA. Another "hands-on" device, similar to Acrobot used in orthopedic surgery for hip and knee joints plasty is RIO (Robotic arm Interactive acronym for Orthopaedic system), produced by Mako Surgical, Florida, USA. The latter one got FDA approval in 2005 [10].

2.3 Future robots

A third group of surgical robots has to be defined in the future. It will include intelligent miniature robotic devices and perhaps even disposable or resterilizable. A good example could be HeartLander - a miniature mobile robot, designed to be disposable and developed by Carnegie Mellon University and is designed to perform invasive targeted therapy on the surface of a beating heart. Therefore, while "nano-robots" or "micro-robots" capable of being injected into the bloodstream, or to be swallowed to make targeted therapy (even gene therapy or repair tissue at the cellular level), are just fantasy today. Mini-robots, like HeartLander are in the process of development and in the next decade will likely be part of surgical therapeutics [10].

Surgical robots can be divided into two categories: autonomous or teleoperated robots. Another less commonly used classification is that of the medical branch where the robots are used: urology, neurosurgery, orthopedics, general surgery, etc [26].

A better and more useful classification of surgical robots was proposed by Camarillo DB et al. [5]. This classification is based on the role that the robot has during surgery and has been compared to the professional evolution of a surgeon from student (smaller responsibilities - low risk), then resident (responsibilities and risk are medium) and eventually specialist (full responsibility and maximum risk). Such surgical robots are classified by their active or passive role during surgery, being grouped in three categories: the passive robots that perform low-risk maneuvers, simple and precise tasks; active robots, which are deeply involved into the intervention; and a last category, restricted role robots, which includes robots performing tasks and invasive maneuvers with higher risk than those with passive role, but lower than active role. According to this classification, we can conclude that as robot autonomy grows, the role of the robot goes from active to passive. Therefore computer tomography and CyberKnife are the most passive robots used for medical purposes, having a much greater autonomy and also a very low risk during usage, and da Vinci and the surgical robots having an active role during the procedure, yet the slightest autonomy, in direct correlation with an increased risk during the procedure. RoboDoc, Acrobot and NeuroMate are classified on intermediate positions [5].

Camarillo et al. highlight that robots with active role seem to be superior to the passive ones, but the situation is contrary because the active ones, execute high risk tasks that require human supervision and significant human intervention during surgery, compared to those with passive role, which are autonomous and can perform tasks without supervision, these tasks having a very low risk or no risk [5].

Another classification of surgical robots could have three categories: internal, external and mixed robots:

1. External robots: those who perform surgical maneuvers on the body surface (Acrobot, RoboDoc, CT-scanners, CyberKnife);

2. Mixed robots: during the procedure have a segment located inside the patient and one outside the patient (NeuroMate, da Vinci, PARASURG-9M);

3. Internal robots: during the procedure they are entirely located inside the patient's body (endoscopic capsule, surgical robots of the future: miniature and easily managed from outside the body).

Da Vinci robotic system is the most versatile master / slave system existing at the moment. The system consists of 3 main components: 1-2 surgeon consoles, surgical robotic cart placed near the operating table with 3-4 robotic arms and Visual System, which features a 3D endoscope. It has 2 high resolution digital cameras with dual lens and three chip technology, each one recording the operating field from different angles and provides a different image to each eye, which is why the image formation on the cerebral cortex appears in 3D. The system also benefits from a flexible endoscope with 3 degrees of freedom, allowing much better synchronization of the image to surgeon eye and working tools [15, 16, 21].

Working console is actually a workstation from which the surgeon performs the entire surgery. It can be located up to 10 m far from the operating table. At the system console, besides 3D visualization of the surgical field there are also the 2 controllers from where the surgeon handles the tools in operatory field. The controllers are equipped with motion scaling and tremor reduction functions [4].

Tools tip of the instruments used by da Vinci robot are identical to that of conventional instruments used in open surgery, since these instruments are the result of over 150 years of evolution and experience in handling different types of dissection and tissue suture. The remaining components are entirely technically new. Thus the surgeon can transmit to the instruments the same movement as in the case of open surgery, thanks to the joints that mimics the joints of the fingers and wrist (EndoWrist robotic joint). These tools have the advantage of multiple use and sterilization and the possibility to be interchanged during the operation [5]. However there is still a limited number of available instruments in robotic surgery, this topic being an open field of research where the scientific community can contribute.

The reason for which da Vinci robotic system is the most efficient master / slave is because these technologies give the surgeon the feeling of presence in the surgical field, its immersion in the surgical field.

The future of robotic surgery will consist primarily in miniaturization of surgical robots as much as possible [17]. Also offering the surgeon the ability to use more than 2 arms while working, to be its own aid is a very important element that will be enhanced more and more in the future [5]. Decreasing scale to which the surgeon operates in the present and offering the opportunity to perform procedures at millimeter, using miniature robots that have multiple sensors (tactile, chemical, pressure, ultrasound etc.) that can provide the surgeon with valuable information in real-time, which may have an important role in surgery.

Recent research in the field Microelectromechanical systems (MEMS) opens the horizons in miniaturization. Ability to create miniature robots with multiple sensors (optical, pressure, accelerometer, chemical, force feedback sensors etc.) of multipurpose therapeutic robotic catheters, implantable mini-robots to measure real-time of the blood pressure in conjunction with the patient effort, to release the exact dose needed for antihypertensive necessary under the circumstances, or to release insulin dose, in diabetics patients. We can also go further and imagine nano-robots or micro-robots to be injected into the bloodstream or be swallowed and act at the cellular level and repair the destruction cell, particularly the brain cells, or to repair genetic mutations [5].

There are proposals of intelligent robots, stick to the section of spinal cord and leading to nerve fibers and thus restore their continuity and lead to the recovery of patient mobility. Earlier this new era in robotic surgery was done with the advent of endoscopic capsules that can be called the "bioMEMS" device.

2.4 Proposal of SILS robot

SILS (Single Incision Laparoscopic Surgery) developed few years ago, introducing the concept of no-scar surgery. This, in combination with NOTES (Natural Orifice Translumenal Endoscopic Surgery) lead to the development of specific surgical instruments. We propose a concept of a new robot for the use in these types of surgeries.

The intervention begins with the patient in dorsal decubitus and in general anesthesia with oro-tracheal intubation. A skin incision is placed at the level of umbilicus. The pneumoperitoneum is created with the help of a Veres needle, used to introduce the carbon dioxide inside the abdominal cavity. The entrance place inside the abdominal cavity is the umbilicus (through a small hole of 10-15 mm in diameter) where a 10-15 mm trocar is inserted. Through this trocar the robotic arms, shaped after the SILS and NOTES instruments are inserted. This robot should be small and versatile, being capable to be used in different abdominal interventions. At the beginning we propose a mixt robot with the instruments tips inside the human body (into the abdomen) and the active parts (motors) outside the body. With the future miniaturization of the motors, the robot could became totally intracorporeal, inserted through the umbilicus or even through natural orifices.

In the lists below are the main characteristics of the both models:

A. Robot's specifications and performance – mixt robot, intra and extracorporeal parts;
1. Curved robotic arms to overcome the spatial limitation of the small access port;
2. 3-5 mm laparoscope with cold light and enhanced optical characteristics – for surgical field visualization;
3. Electrocautery at the tip of scissor or surgical hook;
4. Carbon dioxide insufflation port;
5. Motor hub outside the patient to control the robotic arms either by rigid transmission or by wires;

6. Surgeon’s console with 3D visualization, adapted joysticks with haptic feedback;
7. Easy to use;
8. The dynamic range of force compatible to tissue resistance;
9. Low price and the possibility of being disposable or multiple sterilization;
10. Biocompatibility;
11. Multiple safety measures that can lock the robot’s action in case of faults or inability to be controlled safely by the surgeon.

One model of such adaptation of Da Vinci robot was developed recently by Intuitive Surgical Inc.

Figure 2 - Da Vinci Si system with Single-Site™ instruments. ©2009 Intuitive Surgical, Inc.

B. Robot’s specifications and performance – total intracorporeal robot
1. Maximum size 12 to 15 mm, to be swallowed or inserted into the peritoneal cavity region through a trocar - "pil like" or "snake like";
2. Ability to travel within the peritoneal cavity and reach the target organ with or without being coordinated from a console outside of the body;
3. Multiple optical drive for an overview of the surgical field, including cold light;

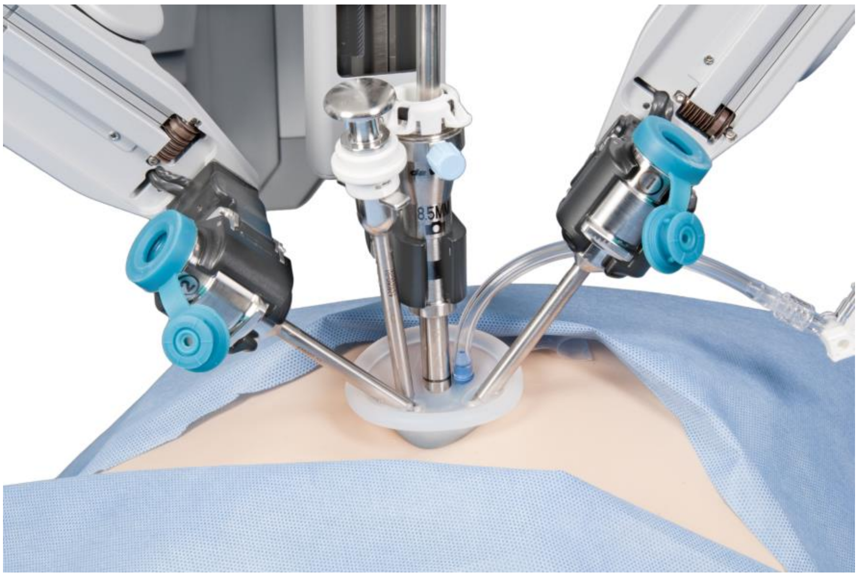

Figure 3 - Da Vinci Si system with Single-Site™ instruments – docked position. ©2009 Intuitive Surgical, Inc.

4. Optical Drive working with high power magnification for precise interventions;
5. Ability to analyze the surrounding tissue through ultrasound or even be able to puncture or biopsy the target lesion under ultrasound guidance;
6. Ability to have at least two miniature working arms, providing high accuracy in the execution of movements;
7. Minimum 5 degrees of freedom for working arms;
8. The possibility of achieving a work space
9. Possibility to suture the hollow organs wall hole after exiting the peritoneal cavity – in cases with NOTES robot
10. The dynamic range of force compatible to tissue resistance;
11. Easy to use;
12. Low price and the possibility of being disposable or multiple sterilization;
13. Biocompatibility;
14. Multiple safety measures that can lock the robot's action in case of faults or inability to be controlled safely by the surgeon;

The robots, which play now a crucial role in our everyday life, appeared as a science fiction concept at first [17]. However robots can currently be seen rather as an extension and intensification of human capacities, than as theirs replacement. Not the same thing can be said, however, about the industrial field [18].

Now we can say that seems feasible to perform major surgery without incisions in the skin, surgery performed using natural orifices as access ports. Thus it can truly be "the Holy Grail" of "keyhole" surgery, given that MIS uses today smaller and smaller skin incisions [10].

A new field totally different is nanorobotics. All known structure are modified at this level, the motors are replaced with enzymes and proteins, assembled as molecular macro-aggregates capable to perform different tasks: transport chemotherapy in specific places, to deliver drugs in the cancerous cells; transport DNA or RNA sequences to replace the altered parts; cut or link proteins or other molecules; etc. They have to have sensors and also motion possibilities; to be biocompatible or biodegradable; to produce no or minimal harm to the host.

3 Conclusions

The future of surgical robots is definitely toward miniaturization. There is a problem whether to develop specific robots for each organ or pathology, or to develop very versatile robots able to operate on various tissues. The miniaturization toward nanorobots, is the field of molecular engineering and could offer the possibility of corrections at cellular, molecular and even genetic level. But these fields will not be in competition at least in the future decades, because various types of interventions will be needed at all levels, from microsurgery to nanoscale corrections.

Acknowledgement: The authors are grateful for the financial support from the Romanian National Authority for Scientific Research UEFISCDI for project no. PN-II-RU-TE- 2014-4-0992 and Iuliu Hatieganu University of Medicine and Pharmacy, 3rd Department Of Surgery, Cluj-Napoca, Romania, internal grant no. 4945/14/08.03.2016.

References

1. Asimov, I., *Runaround*, in *Astounding science fiction*. 1942, Street & Smith Publication Inc.: New York.
2. Asimov, I., *I, Robot*. 1950, Greenwich, CT: Fawcett Publications Inc.
3. Ballantyne, G.H., *Robotic surgery, telerobotic surgery, telepresence, and telementoring. Review of early clinical results.* Surg Endosc, 2002. **16**(10): p. 1389-402.
4. Bozovic, V., *Medical Robotics*. 2008: I-Tech Education and Publishing.
5. Camarillo, D.B., T.M. Krummel, and J.K. Salisbury, Jr., *Robotic technology in surgery: Past, present, and future.* The American Journal of Surgery, 2004. **188**(4): p. 2-15.
6. Capek, J., *Opilec*, in *Lelio A Pro Delfina*. 1925, Aventinum: Prague.
7. Capek, K., *The Meaning of R.U.R.* . Saturday Review, 1923. **136**(79).
8. Capek, K., *Rossum's Universal Robots*. 2004, New York: Penguin Group USA.

9. Furcea, L., et al., *Avantajele implementãrii unei platforme de e-learning pentru chirurgia laparoscopicã hepaticã.* Chirurgia, 2011. **106**: p. 799-806.
10. Gomes, P., *Surgical robotics: Reviewing the past, analysing the present, imagining the future.* Robotics and Computer-Integrated Manufacturing, 2011. **27**(2): p. 261-266.
11. Gourin, C. and D. Terris, *History of Robotic Surgery*, in *Robotics in Surgery: History, Current and Future Applications*, A.F. Russell, Editor. 2006, Nova Science: New York.
12. Gourin, C.G. and D.J. Terris, *Surgical robotics in otolaryngology: expanding the technology envelope.* Curr Opin Otolaryngol Head Neck Surg, 2004. **12**(3): p. 204-8.
13. Graur, F., et al. *Experimental laparoscopic cholecystectomy using paramis parallel robot*. in *21st International Conference of Society for Medical Innovation and Technology*. 2009.
14. Hashizume, M., et al., *A new era of robotic surgery assisted by a computer-enhanced surgical system.* Surgery, 2002. **131**(1, Supplement 1): p. S330-S333.
15. Hashizume, M., et al., *Early experiences of endoscopic procedures in general surgery assisted by a computer-enhanced surgical system.* Surg Endosc, 2002. **16**(8): p. 1187-91.
16. Hashizume, M. and K. Tsugawa, *Robotic surgery and cancer: the present state, problems and future vision.* Jpn J Clin Oncol, 2004. **34**(5): p. 227-37.
17. Hockstein, N.G., et al., *A history of robots: from science fiction to surgical robotics.* Journal of Robotic Surgery, 2007. **1**(2): p. 113-118.
18. Howe, R.D. and Y. Matsuoka, *Robotics for surgery.* Annu Rev Biomed Eng, 1999. **1**: p. 211-40.
19. Kalan, S., et al., *History of robotic surgery.* Journal of Robotic Surgery, 2010. **4**(3): p. 141-147.
20. Kraft, B.M., et al., *The AESOP robot system in laparoscopic surgery: increased risk or advantage for surgeon and patient?* Surg Endosc, 2004. **18**(8): p. 1216-23.
21. Lobontiu, A., *The da Vinci surgical system performing computer-enhanced surgery.* Osp Ital Chir, 2001(7): p. 367-372.
22. Pisla, D., et al., *PARASURG hybrid parallel robot for minimally invasive surgery.* Chirurgia (Bucur), 2011. **106**(5): p. 619-25.
23. Pisla, D., et al., *PARAMIS parallel robot for laparoscopic surgery.* Chirurgia (Bucur), 2010. **105**(5): p. 677-83.
24. Sawa, Y., O. Monta, and H. Matsuda, *[Use of the Zeus robotic surgical system for cardiac surgery].* Nihon Geka Gakkai Zasshi, 2004. **105**(11): p. 726-31.
25. Taniguchi, K., et al., *Classification, Design and Evaluation of Endoscope Robots*, in *Robot Surgery*, S.H. Baik, Editor. 2010, InTech.

26. Taylor, R.H., *Robots as surgical assistants: Where we are, wither we are tending, and how to get there*, in *Artificial Intelligence in Medicine: 6th Conference on Artificial Intelligence in Medicine Europe, AIME'97 Grenoble, France, March 23–26, 1997 Proceedings*, E. Keravnou, et al., Editors. 1997, Springer Berlin Heidelberg: Berlin, Heidelberg. p. 1-11.
27. Vaida, C., et al. *Voice–controlled parallel robot for minimally invasive surgery*. in *17th International Congress of the European Association for Endoscopic Surgery (EAES) Prague, Czech Republic, 17--20 June 2009*. 2010.
28. Vaida, C., et al., *Development of a Voice Controlled Surgical Robot*, in *New Trends in Mechanism Science: Analysis and Design*, D. Pisla, et al., Editors. 2010, Springer Netherlands: Dordrecht. p. 567-574.
29. Vaida, C., et al., *Development of a Control System for a Parallel Robot Used in Minimally Invasive Surgery*, in *International Conference on Advancements of Medicine and Health Care through Technology: 23–26 September, 2009, Cluj-Napoca, Romania*, S. Vlad, R.V. Ciupa, and A.I. Nicu, Editors. 2009, Springer Berlin Heidelberg: Berlin, Heidelberg. p. 171-176.
30. Vaida, C., et al., *Orientation module for surgical instruments—a systematical approach.* Meccanica, 2013. **48**(1): p. 145-158.
31. www.biomed.brown.edu.
32. www.robothalloffame.org/.