ARE ROBOTIC SURGICAL SYSTEMS SUSTAINABLE METHOD OF MINIMALLY INVASIVE SURGERY FOR HEALTHCARE SYSTEMS OF DEVELOPING COUNTRIES - CAN BENEFITS JUSTIFY HIGH COSTS?

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Abstract: *In 2001 first transatlantic robotic surgery on a human was successfully conducted. Since, developed countries have started implementing robotic surgical systems, providing patient/doctor benefits, but with significant costs, which focuses our research on possibility of implementing these systems in developing countries as well. Robotic surgeons help perform complex procedures with greater accuracy, flexibility and control, compared with conventional techniques. They are correlated with minimally invasive surgery due to small incisions, but can sometimes be used in open (invasive) procedures. System consists of 3 units: slave, with 3 to 4 robotic arms for surgical instruments and camera; master console, where surgeon is located and manages the arms by movement and voice and monitoring unit. Surgical robots cover diverse medical areas: general surgery, urology, gynaecology and have been in focus of studies that investigated various metrics, of which most important success and complication rates. Some measured system set-up, console and procedure time. Others calculated material and personnel costs for different procedures. A study compared prices and technical characteristics of 2 commercially available robots, da Vinci and Radius. Benefits of robotic surgery: patients have small incisions, some not even visible, postoperative recovery is faster, there is less blood loss and element of aesthetics. Doctors can easily reach different parts of the body, having a feeling they are "inside a patient", the system is ergonomically suited to support their body and learning curve is fast. However, robot is not the best alternative for gynaecological procedures - complication rate is slightly higher than with laparoscopy and it costs a lot more. Surgical robot costs a few million dollars, it has to be maintained every year, generating expenditure of hundred thousand dollars, each instrument must be changed after 10 uses, if it lasts that long, meaning another few hundred dollars per every changed instrument. Doctors have to be trained on simulators to use these systems, which generates expenditures of going to education centres. There are doctors who are refusing these technologies as well as patients. The purpose of conducting this research is to answer the main question: can developing countries implement this technology, bearing in mind patient/doctor benefits with high expenditures? After analysing benefits, risks and costs through relevant papers from scientific databases and noticing resource reallocations were made in Serbian budget, it is concluded that financial resources could be obtained for implementing this system. However, potential threat lies within rejection of new technology by patients and possibly doctors. Therefore, system implementation should be shaped in the following way: educate citizens and doctors via social media campaigns first and then conduct acquisition of the robot parallel with medical staff training. Only then implementing this expensive robot can be recommended.*

Key words: *surgical robots, costs, benefits, sustainability, process*

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1. INTRODUCTION

Robotic surgical system (RS) is a self-powered, computer-controlled manipulator designed to aid in positioning and manipulating surgical instruments. It is a remote arm extension governed by surgeon's movements and enables performing more complex tasks than standard laparoscopic surgery [13]. The most noted achievement was "Lindberg", the first successful transatlantic telesurgery in 2001 [2], [3] (Appendix 1). Since then, developed countries have started implementing RS, providing patient/doctor benefits, with minimal risks and significant costs, which focuses our research on possibility of implementing RS in developing countries. The purpose of conducting it is to answer the main question: can developing countries implement this technology in a sustainable way, bearing in mind patient/doctor benefits, risks, and high expenditures? Analysis of benefits, risks and costs of RS was based on relevant papers from scientific databases (Mendeley, Google Scholar) and website of RS manufacturer Intuitive Surgicals. Resource reallocations in Serbian budget were examined to answer the question in focus of this research.

2. BENEFITS AND RISKS OF ROBOTIC SURGICAL SYSTEMS

Development of computer technology, micromechanics and data transfer have led to implementation of RS in hope of overcoming limitations of open and laparoscopic surgery (Appendix 2) [8]. RS help in performing complex procedures and are correlated with minimally invasive surgery (MIS) due to small incisions [5]. RS can be Supervisory-Controlled, Telesurgical and Shared-control [6]. It has 3 units, offers many benefits and covers diverse medical areas. Doctors achieve better patient outcomes for specific operations, have greater dexterity, accuracy, ergonomics, [13], voice command, 7 degrees instrument freedom (imitating human wrist) [17]. Patients benefit from improved outcomes, shorter hospital stays, reduced postoperative pain, lower incidence of wound infections, greatly enhanced cosmetic outcomes. Hospitals who own RS market themselves as cutting edge [13] and are prepared to absorb additional cost in order to gain bigger market share [11], because RS can attract more health consumers and generate higher incomes. Others are also following this trend [11], so if aiming higher incomes, owning a RS with highly skilled doctors with rich training and practical experience on RS will create high reputation for both and more incomes. RS have certain disadvantages: lack of tactility and force feedback, less control over patient safety and malfunction/failure can occur. It can take longer than laparoscopy, costs more than other techniques, due to fixed cost of RS - maintenance, support and equipment upgrades [13] (Appendix 3).

3. ROBOTIC SURGEONS – ACHIEVEMENTS, PROBLEMS AND SOLUTIONS IN THE SURGICAL ARENA

RS have been in focus of many studies, which have investigated benefits and risks for doctors, patients and generated expenditures. Since 2001 until 2005, 128 patients, 78 female, 50 male, mean age 52 (18–78) years have been operated with da Vinci by 6 experienced laparoscopists. 3 were trained at manufacturer's laboratory, 3 at the hospital's department. Success rate was 95%. Open conversion occurred in 4 cases - surgical problems: pulmonary lobectomy - dissection of the lower stem pulmonary artery led to major bleeding (300 ml); problems arose due to anatomical anomaly of pulmonary artery. In 1 thymectomy collateral tissue damage was made by instrument (blood loss of 90 ml). The 4th regarded a patient with neurinoma. Conversion to laparoscopy occurred in 2 cases due to technical robotic problems which did not compromise patient safety (sudden total breakdowns of the system which could not be rebooted). Besides 2 mentioned, there was no relevant (>50 ml) bleeding in other procedures. 1 redo operation was necessary. 2 patients had lower complications without surgical re-intervention; wound infection was observed in 4 patients. 30-day mortality was 0%. Procedure length and expenditures are in Tables 1 and 2 [8].

	Time in minutes		
	Set-up	Console	Total
	connection of the components, booting surgical arm cart.	surgeon operating on the console (effective robotic act from first cut to skin closure)	
Procedure (=n)			
Cholecystectomy (29)	35	52	98
Partial fundoplication (16)	35	154	198
Colonic intervention (14)	45	178	310
Extended thymectomy (16)	40	130	150
Splenectomy (10)	35	107	147
Bariatric procedures (10)	45	137	167
Hernioplasty (7)	40	67	118
Oesophageal intervention (6)	40	117	147
Adrenalectomy (5)	40	128	181
Lower lobectomy (5)	70	270	318
Neurinomectomy (4)	30	51	65

Table 1 – Time necessary for system set-up, console procedure and total time of procedure in minutes
Source: [8]

Procedure	Material	Personnel	Overall
Cholecystectomy	2.308	518	2.826
Partial fundoplication	3.732	990	4.722
Extended thymectomy	2.857	704	3.561
Splenectomy	4.815	747	5.562

Table 2 – Material, personnel and total cost in euros by procedure
Source: [8]

Mechanical failures/malfunctions of da Vinci during various surgeries in 6 different departments are rare. From July 2005 to December 2008, 1797 robotic surgeries were performed using 4 da Vinci RS (1 standard from July 2005 to July 2007 and 3 S from July 2007 to December 2008). Surgeries were evaluated according to type and department. Solutions were also evaluated. Mechanical failures/malfunctions occurred in 43 cases (2.4%): 24 (1.3%) of mechanical failure/malfunction and 19 (1.1%) of instrument malfunction. Mechanical malfunction included 1 on/off failure, 5 console malfunctions, 6 robotic arm malfunctions, 2 optic system malfunctions and 10 system errors. 1 open and 2 laparoscopic conversions (3 cases; 0.17%) were performed [9].

[10] analysed malfunction of da Vinci standard 4 arms RS in a hospital in Taiwan, from December 2005 to April 2011 to provide potential solutions. 400 patients underwent robotic urological surgery by experienced laparoscopists. Procedures included radical prostatectomy (351), bilateral pelvic lymph node dissection (10), dismembered pyeloplasty (8), partial nephrectomy (16), nephroureterectomy (6) and radical (8) and partial cystectomy (1). In 14

cases (3,5%), malfunction occurred: robotic arm system and joint (11), optical system (1), power system and connector (1), endoscopic instrument (1) and software (1). 4 cases were critical failures (1%): 3 were converted to laparoscopy (0.75%); 1 was rescheduled (0.25%). 10 cases (2.5%) were recoverable failures by exchanging/adjusting the arms and joint, restarting the power, reinstallation of software, exchange of endoscopic instrument, fastening of the cables or exchange of the endoscope. 5 malfunctions (1,25%) occurred before surgery, 9 intraoperatively. Malfunction rates were divided in 4 groups (by 100 cases) historically and were 11%, 1%, 1% and 1%, with a significant decline as the case number increased. There were 5 cases of major complications (III-IV - Appendix 4). When the accumulative amount reached 200 cases, there were no more major complications. Overall complication rate was 6%.

[11] described results from researchers at Columbia University, regarding usage of da Vinci and MIS in gynaecology with focus on costs and complication rates for ovary and cyst removal. RS is not the best solution, because of higher complication rates and higher expenditures (Table 3).

	Ovary Removal	**Cyst Removal**
Average Costs		
Robotic	7.426 $	7.444 $
Laparoscopic	4.922 $	4.133 $
Complication rate		
Robotic	7,1%	3,7%
Laparoscopic	6,0%	2,7%

Table 3 – Average cost and complication rate of ovary and cyst removal by surgery type
Source: [11]

da Vinci and Radius were compared by 8 criteria (Table 4) [12].

Robotic surgeon / **Criteria**	da Vinci	Radius
1. Instrument freedom		
instrument functioning	like a human wrist - 7 degrees of freedom and 90 degrees of articulation	cannot imitate human wrist - deflectable and rotatable tip provides 7 degrees of handling freedom
instrument tip design	free	fixed
2. Tips		
instrument replacement	inter-operatively (in a few seconds)	inter-operatively (in a few seconds)
instrument number	40	4
instrument type	(suturing and dissection),	(suturing)
3. Dexterity	translates hand, wrist and finger movements into precise, real-time movements of instruments with motion filter for unintended movements due to tremor	manipulated through port axis, causing tremor at the tip end (leverage principle), thus making delicate manoeuvres difficult

4. Total size		
system size set-up time instrument diameters	big, bulky longer 8 mm	smaller shorter 5 mm
5. Tactility	lacks it (no information about consistency of tissue and sutures – surgeon has to rely on visual feedback from camera)	has it (provides tactile feedback similar to conventional endoscopic instruments)
6. Learning curve	short (natural hand-eye alignment at the console enables intuitive instrument control)	long (requires a lot of practice for acquiring skills needed to manipulate instruments with unique movements)
7. Economic aspect		
system cost instrument cost	3.750.000 $ 500 $	35.000 $ 200$
8. Regulatory body approval	European CE Mark, approved for several procedures by the FDA	European CE Mark, approved in Japan, not approved by the FDA

Table 4 – Comparison of da Vinci and Radius
Source: [12]

4. CREATING FINANCIAL RESOURCES FROM THE SERBIAN BUDGET FOR IMPLEMENTATION OF A SURGICAL ROBOT

Budget analysis has revealed that financial resources for healthcare have been increased [20], [21], gamma ray has been purchased, new clinic in Niš has been opened. Despite positive reallocations of taxpayers' money, there are certain problems for this and previous years. There is also a significant amount of unpaid taxes from companies, lawyers, sport clubs. The last tax debtor list of companies, entrepreneurs and private citizens published in 2011 stated tax debt of 2 billion euros [22]. In April 2018, Serbian Tax Administration published latest tax debtor list with 389 active companies and 1647 entrepreneurs who owe significant amount of taxes measured in billions of dinars. For more details see lists in [23]. So, resources for acquiring RS can be provided. These billions are enough to purchase a RS, maintain it for years, acquire instrument replacements many times and send laparoscopic surgeons to specialized school to be educated to use RS. With better actual control of tax payments, prudent reallocation of resources to healthcare and continuous economic development will ensure sustainability of robotic surgeries in Serbia.

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5. IMPLEMENTING ROBOTIC SURGEON IN A DEVELOPING COUNTRY

Implementing a RS from financial aspect in a developing country is possible. Potential threat lies within rejection of new technology by patients and possibly doctors. [13] emphasizes that **self-governance** (adoption depends on doctor's perception of a technology), **long training requirements** (learning new technologies means interrupting practice to attend training; for RS, uniform training standards among hospitals are lacking) and **lack of clear benefits** (some believe traditional practices are sufficient; e.g. in general surgery RS has not improved patient outcomes [18]) influence on acceptance of new medical technologies by doctors. Patients could reject undergoing a robotic surgery, because of fear of new and unknown, despite the benefits. This technology is very sophisticated, in experimental stage and very expensive. It is not designed for relatively easy procedures e.g. pericardiocentesis, but for complex ones with difficult maneuverability. Hospitals have taken it a step further by using RS wherever, thus generating higher expenditures [11]. So prior understanding that RS is designed for complex procedures in diverse medical areas is important. Pricy, it should be shared among different departments [8]. Implementing RS should be shaped in the following way; first, educate citizens and doctors, via social media campaigns, about positive effects of robotic surgery, how it would be incorporated in their practice and for which procedures it should be used and for which laparoscopic surgery is still a better solution; second, start the process of purchasing the RS, while simultaneously training the best laparoscopic surgeons from various departments in the company's laboratory and IRCAD/EITS. The learning curve would take effect and improve surgeons' performance by the time first patients arrived. It is important to regulate reimbursement of these procedures and ensure that RFZO will cover the expenses. These surgeries should be conducted as clinical trials, so financial resources could be obtained from various research grants. Only then can we recommend implementing this expensive technology. RS is sustainable method of MIS for developing countries, but only if used for complex procedures among various departments to share fixed costs, knowing that robotic surgery is not the best solution for e.g. ovary and cyst removal. RS bring higher costs and patient/doctor benefits. Each developing country should carefully analyse its budget, introduce RS to doctors and patients and decide whether its implementation could be done in a sustainable way.

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6. CONCLUSION

Despite patient-doctor benefits, dissemination of RS could be slowed down by those for whom it was made to make procedures and recovery safer, faster and more convenient. The key to eliminate this is for patients and doctors to know these systems and realize that benefits are higher than risks and that for now certain procedures should still be done laparoscopically. Complication rates can be decreased when surgeons are well trained, due to the effect of the learning curve. Further development of technology, micromechanics, higher quality materials will decrease RS's price, maintenance and upgrade costs, they will become more reliable, set-up time will decrease, thus enabling the RS to be used in simpler procedures, the risk of malfunctioning and failure will be rarer, the instruments will become more durable and smaller, thus reaching targeted area without damaging surrounding structures. These changes will eventually enable adoption of this technology in many developing countries in a sustainable way.

APPENDIX 1 – LINDBERG OPERATION

Lindberg operation is the first transatlantic surgical intervention performed on a human patient on September 7, 2001, with partnership of IRCAD/EITS, France Telecom, Computer Motion and a team of surgeons. The surgery was performed from a building in Manhattan, not from a hospital. Professors, dr Marescaux and dr Gagner, were in New York. Dr Leroy and dr Smith were in the operating room in the Strasbourg hospital to intervene if necessary. A 68-year-old woman, with chronic gall bladder problems, was operated under a general anaesthetic. The team performed laparoscopic cholecystectomy (removal of the gall bladder using a minimally-invasive procedure). The choice was based on the fact that minimally-invasive gall bladder removal has become a "gold standard" among the international surgical community. It is simple, yet difficult, even dangerous, thus providing an opportunity to demonstrate the possibility of sharing surgical actions in the event of complications or difficulties during the procedure. An optical link, a camera and 2 surgical instruments were inserted in the patient's stomach. The operation lasted for 45 minutes and 40 team members (doctors, France Telecom engineers and robotic system specialists from Computer Motion) were present. The patient was briefed on details of the operation. She toured IRCAD/EITS in Strasbourg, saw the robot function and understood the concept of telesurgery and its risks. The first telesurgical trial on a pig was successfully conducted in September 2000, in Strasbourg via Paris (return distance of 1,000 km), with transmission delay of about 200 milliseconds. Improvements reduced time delay to 150 milliseconds. In July 2001 several transcontinental trials between New York and Strasbourg were held, with data travelling a total route of about 15,000 kilometres. The success and reliability of these tests made it possible to begin planning an operation on a human.

With expertise in telesurgery, IRCAD (Institute for Research into Cancer of the Digestive System) and EITS (European Institute of Telesurgery) have acquired international reputation in 7 years of their creation, reflected in the number of surgeons (3000) from around the world who enrol for training by an international team of 800 experts. IRCAD-EITS ranks among the world's top surgical schools and EITS is a recognized world leader, since no other university structure of this scope exists worldwide. Telesurgery is at the training core and research work. Minimally-invasive surgery enables a surgical procedure to be performed with guidance by a camera and without opening the abdomen or thorax, which enhances procedure safety and rendering surgeon's movements more accurately. At the same time, these breakthroughs have introduced the concept of distance between a surgeon and a patient. IRCAD-EITS has focused on challenges posed by distance between a surgeon and a patient, extrapolating from the current few meters in an operating room to distances of several thousand kilometres.

To support success of this operation, France Telecom had to address many challenges: flawless service quality, totally reliable and secure, with end-to-end management; guaranteed 10 mbps bandwidth; continuous transmission delays less than 200 milliseconds (outbound and return links). It had to bring 2 continents closer at 5 levels: *surgeon's actions*, via the robot and data transmission; *voice*, using Voice-over-IP; *eyes*, using endoscopic camera and video monitor; *videoconference link* for visual coordination between the two rooms; continuous *control of data* exchanged between two PCs at each end. Therefore, it organized multiple teams: **Large Business Division** (coordination of Operation Lindbergh and providing the MultiLAN solution for France); **Equant** (managed the international segment using the Equant ATM (Asynchronous Transfer Mode)); **Networks Division** (physical infrastructure for the network, with fibre optic links); **Transpac** (technical coordination for network operation and surveillance); **R&D** (reduced time delay for coding/decoding of the video signal. They deployed and operated service access equipment and performed end-to-end supervision of service quality and reliability by inserting test cells in the ATM frame).

Telesurgery was performed with the ZEUS RS, developed by R&D teams at Computer Motion, which introduced SOCRATES Telecollaborative System and Microwrist technology. The Zeus RS, initially developed in 1995 for endoscopic microsurgery, could be efficiently employed for general and thoracic surgery, gynaecology, and urology. It has 3 robotic arms (2 to manipulate instruments, in reaction to the surgeon’s hands, and 1 voice-controlled arm controlling the endoscope), and a surgical console (where the surgeon is seated and manipulates the joysticks that control the two instruments held by the robotic arms). Each articulation on the robotic arms is equipped with a dual security system. Signals are checked more than 1,000 times per second [2].

APPENDIX 2 - TYPES OF SURGICAL PROCEDURES

Depending of the incision size and surgical equipment, surgeries can be classified as open, laparoscopic and robotic. Previously, **open surgery** was the only option for exposing and accessing soft tissues, organs and other structures, thus providing direct access to operative site with depth perception and dexterity for one/more set/s of hands. It is the only option for many procedures and certain types of patients (e.g. obese, with prior surgeries, multiple adhesions) [13]. It is very invasive, usually requires a long incision, with visible scar, causes trauma due to accessing organs, which results in more painful recovery, longer healing process, prolonged hospital stays, higher risk of infection [14], [15] and even disability and morbidity [16]. With technology development, new surgical techniques, laparoscopy and robotic surgery, have substituted (some) open (invasive) procedures [13].

Minimally invasive surgery became a milestone in operative medicine, offering patient benefits for certain procedures: reduced tissue trauma, quicker recovery, early reintegration into normal social and working processes [8], reduced postoperative pain, shorter hospital stays, fewer infections and better cosmetic outcomes [13]. However, it is limited to relatively simple procedures which have a gold standard: cholecystectomy, fundoplication, pulmonary wedge resection and all kinds of hernia repairs. More complex procedures, carried out successfully in some centres have not yet achieved general acceptance [8]. It also poses disadvantages for surgeons: limited dexterity [13]; looking at distant 2D vision monitor leads to change in normal hand-eye target axis [17] and eliminates stereoscopic depth perception [13], [17], which needs to be compensated [17]; camera is unstable [13] – vision is not under a surgeon's, but under her/his assistant’s control, causing assistant’s fatigue, thus leading to unsteady vision field [17]; awkward movement of instruments and scopes (e.g. fulcrum effect – reverse movements for the surgeon in laparoscopic surgery [13], [17]); poor ergonomics and miscommunication caused by the reversed image on the monitor [13]. Laparoscopy has a technically more demanding learning curve than open surgery. Instruments are rigid and provide only 4 degrees of motion. Ligation and suturing are much more complex. All these factors lead to surgeon’s and assistant’s fatigue [17]. Further development of computer technology, micromechanics and data transfer have led to implementation of **robotic surgery** in hope of overcoming these limitations and becoming more forthcoming to surgeons and procedures [8].

APPENDIX 3 - ROBOTIC SURGICAL SYSTEMS

Robotic surgery is a method of surgical intervention with the help of small tools attached to robotic arms, which are coordinated by a surgeon on a computer [4]. History of RS begins with PUMA in 1985, which was used for neurosurgical biopsy. In 1987 RS was used for cholecystectomy. Imperial College developed PROBOT for prostate surgery, with imaging, simulation and on-line video monitoring and proved that a RS can be successful on soft tissue. ROBODOC made it to history in 1992, when it assisted in hip replacement procedure and was approved by FDA for orthopaedic procedures. ZEUS was used for reconnection of fallopian tubes in 1997 in Cleveland. da Vinci was used for heart bypass procedure in Leipzig in 1998. In Canada, ZEUS was used for beating heart coronary artery bypass graft [1], [6].

Robotic surgeons help in performing complex procedures with greater accuracy, flexibility and control, compared with conventional techniques. They are correlated with minimally invasive surgery due to small incisions, but can sometimes be used in traditional open (invasive) surgical procedures [5]. RS is a self-powered, computer-controlled manipulator that can be programmed to aid in positioning and manipulating surgical instruments. It acts as a remote arm extension governed by surgeon's movements and enables performing more complex tasks than standard laparoscopic surgery, achieves better patient outcomes for specific operations, offers greater dexterity, accuracy, scalable motions, camera stability, ergonomics, depth perception, better patient outcomes [13], 3D vision, motion scaling, intuitive movements, visual immersion and tremor filtration, voice command and 7 degrees of freedom thus imitating a human wrist [17]. RS lacks tactility and force feedback, surgeon has less control over patient safety, malfunction or failure can occur, it is incompatible with conventional laparoscopic instruments, has less availability of parts, sometimes requires a surgeon troubleshooting [13]. Robotic procedure can take longer than laparoscopic, because of set-up time. It costs more than other techniques, due to fixed cost of RS, maintenance, support and equipment upgrades. From reimbursement aspect, RS procedures receive the same treatment in the USA as laparoscopic from commercial health insurance and federally administered Medicare [13].

RS consists of 3 units: slave unit - arm cart, with 3 to 4 robotic arms for surgical instruments and camera; master console, where surgeon is located and manages robotic arms by movement of hands, fingers, feet and voice and monitoring unit for the rest of the surgical team. It covers diverse medical areas: general surgery, cardio-thoracic surgery, urology, gynaecology. Depending on a human surgeon's inclusion, RS are classified as:

1. Supervisory-Controlled
2. Telesurgical robots and
3. Shared-control [6].

Supervisory-Controlled RS have the highest level of autonomy. Their functioning is based on series of instructions written by a surgeon and are executed by series of precise movements which constitute surgical intervention. When working with human lives, there is no room for mistakes and these RS cannot make adjustments in real time, so surgeons have to monitor the RS and be prepared to intervene in case of deviation(s) [6]. Although highly autonomous, they are in need of human surgeons, who can adapt to unexpected situations, find and resolve problems successfully [7]. Operation begins with human planning. Since every person has unique body structure, there is no universal program for a RS to execute, so patient body mapping is necessary. With the help of imaging methods – CT scan, MRI, ultrasonography, fluoroscopy, X-ray – an unique image of a patient's body is constructed. Sometimes, it is necessary to insert pins in the bones to mark a specific pathway a RS has to take. Registrations phase is the procedure of matching points on a patient's body to the points on the images previously created. Then navigation (surgery) begins with the perfect alignment of a patient and a RS, so that a precise set of instructions could be applied. These RS are not intelligent - they cannot make decisions and have to be instructed what to do. High precision, reduced trauma and faster recovery are reasons why this type of RS should be used. It is popular in hip and knee replacement procedures [6]. Although automated, they are still relying on human surgeons to map a patient's body, write instructions and react in case of an emergency.

Telesurgical robots are telesurgical devices - meaning a surgeon is manipulating with a robot entirely. These RS enable doctors to see better and deeper thus overriding limits set by their eyes and reach small, hardly accessible parts of human body through small incisions, as opposed to open and minimally invasive surgery [6]. RS consists of 3 units: slave - arm cart, with 3 to 4 robotic arms for surgical instruments and endoscope; master console, where surgeon is located and manages robotic arms by moving arms, fingers, feet and by voice and monitoring unit, from which the rest of the team can keep up with a procedure and intervene in case of an emergency. da Vinci, ZEUS, AESOP [6] and RAVEN are telesurgical robots.

Shared-control RS are designed to assist doctors during surgical interventions. A surgeon maneuvers the surgical instruments directly, as opposed to previous RS. Their main role is to monitor procedures through active constraint (AC) system, providing support and stability. AC procedure divides a patient's body onto regions. Each region is awarded with a single status, either safe, or close, or boundary or forbidden. E.g. orthopaedic surgical tools can make a serious damage to soft tissue. Safe region is the focus of intervention e.g. a site on a hip. Close region borders the area of soft tissue. As a surgeon approaches the soft tissue, a haptic response – force feedback – from RS indicates that she/he is getting really close to the tissue, so RS responds by pushing back against the surgeon's hand. Further closing in is registered as boundary region, from where robotic resistance becomes greater indicating the necessity to move away. If the surgeon continues, the robot locks in place, marking everything as forbidden area. RS does not know what a safe region is, unless a surgeon programmes it through planning, registration and navigation phases with a patient. [6].

APPENDIX 4 – CLAVIEN CLASSIFICATION OF SURGICAL COMPLICATIONS

According to Clavien scale, surgical complications are classified in five groups [19]:

1. **Grade I** - Any deviation from the normal postoperative course without the need for pharmacological treatment or surgical, endoscopic, and radiological interventions.
2. **Grade II** - Requiring pharmacological treatment with drug other than such allowed for Grade I complications.
3. **Grade III** - Requiring surgical, endoscopic or radiological intervention.
   - *Grade IIIa* - Intervention not under general anaesthesia.
   - *Grade IIIb* - Intervention under general anaesthesia.
4. **Grade IV** - Life-threatening complication.
   - *Grade IVa* - Single organ dysfunction.
   - *Grade IVb* – Multi organ dysfunction.
5. **Grade V** - Death of a patient.

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