Zbigniew Nawrat

6 Virtual operating theater for planning Robin Heart robot operation

6.1 Introduction

Virtual reality (VR), artificial reality, cyberspace, and augmented reality are the new languages of communication. The ability to use it allows you to transfer information to the previously unavailable level: multidisciplinary but specific, local and personalized but global and based on knowledge (artificial intelligence, big data analysis), spatial and physical, fictional and real, and pictorial and interactive. Let's learn this new language, a new method of communication, to shorten the learning curve; plan the treatment, taking into account all patient data and prospective knowledge; and provide the necessary information during surgery, in short, to reduce the number of medical errors.

6.2 Introduction to surgical operation

Surgery is a specific type of medical activity, assuming the use of direct physical methods of intervention, in a place damaged by illness or injury. Surgical operations and management system are a type of medical activity that is used to diagnose, prevent, and treat a patient.

Division due to objective and outcome of the operation includes the following:

1. An exploratory surgery, also called diagnostic, is aimed at diagnosing the disease.
2. Radical surgery, also called radical dissection, is a procedure aimed at complete cure of the disease (often excision of a part of a single organ).
3. Palliative surgery, also called alleviating, only improves the patient's condition, not removing the proper cause.
4. Plastic surgery changes the appearance or function of the organ.

The complexity of action is based on the need to assess the initial state (diagnosis) and to make decisions about the action spread over time and the roles of members of a special team.

The operation is a part of the patient's treatment strategy. The full treatment plan also includes the adoption of an appropriate method of rehabilitation and the planning of subsequent operations (including the preparation of the operation area for reoperation).

The planning of the operation includes defining the space and the object of the operation, the choice of methods, the materials and devices, the use of the operating

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and accompanying team, and finally the selection of sequences of a series of tools activities on tissue and organs. It is necessary to locate and describe pathological part of the human body operation space first. Describing means providing information about location, geometric features, and physical properties of tissues. Next, the approach path through patient's body for tools should be selected and optimized.

Operation optimization refers to the time and place of the operation (personalized based on diagnostic and prognostic data), human team, materials, instrumentation, and costs. Surgical operation by the adopted strategy (goal setting) and tactics (implementation method) is described. The tactics provide a possible and effective approach to use resources (human and material ones, knowledge, and tools) to achieve objectives.

In the simplest form, a typical planning process can be divided into the following elements: analysis of the patient's condition; goals—defining what is the subject of our intervention, what is the task to do; and strategy—defining how the goal can be achieved.

Tactics are the details of the strategy, precisely the specific actions and methods used during the performance of the task. Tasks and operations in surgery require the introduction of a specific impact (using physical, chemical, and biological phenomena) on biological tissues. A new area of surgical treatment is the corrective action on implantable elements (materials and devices). The strategy is modified by a constant flow of information during a surgical operation.

For surgery to be a planned process (standardization), it should have objective measurable features such as the following:

1. motion measurement (kinematics), physical (dynamics) and biological (e.g., by using biotechnological methods, stem cells, and cultured tissues) or chemical one;
2. assessment of the biological/physiological state before and after surgery;
3. economic evaluation (direct costs: materials and equipment; indirect costs: occupational and postoperative room occupancy; software/hardware costs: costs of using the IT network and maintaining telemedical readiness); and
4. staff activity (number, team members and time, and type of work).

The description of the work of the band resembles the recording of the theater scene—according to the scenario, actors written into the roles of action, choreography of people and tools (robots), language of communication, objects, division into acts, and a clear goal. It is not surprising that this place in the hospital is called the operational theater.

6.3 Modeling and planning of a surgical procedure

Modeling as a cognitive method plays a particularly important role in medical sciences, where the method of a physical experiment is difficult to implement because of the need to intervene in a living object (risk of losing health or life) and for ethical reasons [1].

Computer simulation methods and laboratory tests of physical models can be the basis for the preparation of surgical operations. The effectiveness of using robots in endovascular surgery largely depends on the optimization of design solutions for specific operations and proper planning of operations. The introduction of telemanipulators changes the perception [2] and, therefore, requires new training techniques to achieve the correct precision of the surgeon's work. Appropriate planning of the robot setting at the operating table, the correct location of the holes in the patient's body shells through which the tools with specific functionality and workspace will be inserted, provides the opportunity to perform a safe surgical procedure. The subject of planning is also a sequence of robot movements (choreography) and the selection of the right tools. The possibility of operating in the virtual space of the patient's body allows the surgeon to determine whether a given tool with defined geometric dimensions with defined degrees of freedom has the right range to perform the planned activities. VR technology is the perfect language for communication with surgeons and the field of testing innovative solutions.

In 1997, the team of the Foundation of Cardiac Surgery Development (Fundacja Rozwoju Kardiochirugrii im. Prof. Zbigniewa Religi [FRK]) led by the author started the first project in Poland (financed by the National Science Committee), a program of simulation of cardiac surgery procedures to optimize the operation effect.

The advisory system for the Robin Heart robot is currently being developed, available online during operations on the technical monitor of a control console. Adding physical features (e.g., blood flow and pressure) to the spatial objects (organ geometry) is a huge help in making decisions during surgery [1].

One of the pioneers of Polish robotics, Prof. A. Morecki, in a review [3] considers the following phase of robotic procedures:

1. Preoperative planning: the optimal strategy is defined based on the 3D computer model
2. Beginning of robot work: periodic robot calibration and telemanipulator operation in space with defined boundaries and areas of interest
3. Updating opinions and replanning: the robot starts working under the supervision of a doctor

The information (mainly the image) from the field of surgery allows us to confirm the compliance of the anatomy with expectations. If there is a deviation, the surgeon decides to change the strategy.

There are many publications proving the need of planning operations as a strategy deciding on the success of a surgery and a treatment process. Various management methodologies and their appropriate modifications are used. A detailed analysis of the operation requires the process to be divided into elements of the entire system (a surgeon, instruments, and a patient) with clearly defined evaluation parameters [4].

A very interesting analysis of operations and research on this subject can be found in the book edited by Dankelman et al. [5]. In the work of Kwon et al. [6], the sequences of 21 tasks, the so-called surgery task model of cholecystectomy, were obtained as a result of the analysis of recordings of six laparoscopic clinical operations. Research and analyses were conducted to optimize treatments. In the book of Gharagozloo and Najama [7], one can find a plan of almost all types of operations performed by the da Vinci robot. In Polish literature, it is worth paying attention to Marek Cisowski's postdoctoral dissertation describing selected cardiac surgeries [8], which is a summary of the performance of the Zeus robot as used for the first time in Katowice, Poland. The next interesting work in the field of general and colon robotic surgery (da Vinci robot) is from Wroclaw [9].

Outstanding works describing the technique of operations using the da Vinci robot are related to the activity of the student of Prof. Zbigniew Religa, Romuald Cichoń, at the clinic in Dresden (coauthor of many, commonly cited publications). Another pioneer of the surgery, Falk [10], clearly points out that progress depends on the introduction of new, functional tools; tissue stabilization techniques at the surgery site; and new methods of suturing, combining tissues, planning, and navigating computer tools. Falk [11] was the first to introduce and confirm the advantages of computer simulations and VR technologies and the so-called mixed reality (allows you to enter elements of real natural images) to plan coronary bypass surgery using the da Vinci robot.

It is worth noting that the main element of the management plan is a human—a surgeon. The studies of the ergonomics and biometrics of the surgeon's work are the basis for optimizing the way the surgery is carried out. Bernstein is regarded as one of the founders of the modern theory of human motor activity, and he included its foundations in his work on the structure of movements (1947). The beginning of the movement is, according to Bernstein, possible after imagining the goal and constructing the program of action. Movement of a human is based on keeping comparing the desired value with the current one regarding the indicators characterizing movement. Therefore, the motor coordination is "(...) overcoming the excessive number of degrees of freedom of the moving organism, that is, converting it into a controllable system" [12].

According to Bernstein, the information circulation time in an organism is 0.07–0.12 s. This is characterized by a frequency of 8–14 Hz, which is typical of the α wave of brain waves and muscle tremor. Movement coordination is the ability to perform complex movements accurately and quickly. The key role in the coordination of movements is played by the spatial orientation and kinesthetic skills of the differentiation of motion, based on sensory information. The introduction of robots and consoles as the operator's station changes the global system into a local one. The dexterity of the hand is important, not the movement of the whole body [1].

The possibilities of training conditional motor skills are unquestionable. Also in terms of motor skills coordination, there are great opportunities for improvement as a result of training impact. It has been shown that the learning curve, the time of reaching the appropriate efficiency, for robotic surgery is much faster than classic methods [13, 14].

Doctors expect rapid progress in the implementation of tools that are not only manipulative but also informative. During teleoperation, there is a problem of time shift between the movement and its image on the monitor. We are exploring the possibility of increasing the precision of operation by the appropriate formulation of a symbolic image associated spatially and an object related with the real image.

Surgery is also, and perhaps above all, a decision-making process. Making the right decisions is always a critical element of activity that involves the lack of full information from the past and uncertain future evaluation, as well as the lack of appropriate inference algorithms. Bernstein conceived biological "activity" or the ability of living organs to "anticipate" in such way. "The brain functions in two ways. It constructs the models of the past-present as well as stochastic extrapolations of these (models of the future). Any difference between the two not only constitutes a problem but also entails a probability distribution of its solution. This probability distribution will lead to the construction of a motor 'engram' (program)" [15]. Fact-based medicine and advisory programs greatly increase the likelihood of a doctor making the right "now" decisions to get the best solution for "tomorrow."

Let's try to analyze the decision-making process by the operator from the point of view of artificial intelligence methods used in process automation. This chapter contains a few basic definitions and discussions [16].

Decision-making situations can be divided into the following:

Determined (making decisions under conditions of certainty)

Random (in risk conditions)

Conflict (in conflict conditions, game theory)

In the decision-making process, the following phases can be distinguished:

Recognition (collection of information)

Modeling (construction of a decision-making model)

Deciding (choosing the best decision)

The implementation of the objective requires the use of available resources (material, financial, time, human, etc.) in the form of a strategy.

The surgeon often makes decisions in conditions of external uncertainty (lack of sufficient knowledge about the operating environment) and internal uncertainty (lack of knowledge and experience). The area of uncertainty can be reduced by using advisory and training systems and by planning using computer simulations and physical modeling [1].

The human decision-making process is based on one of two thought patterns:
1. Cartesian (cause-and-effect thinking based on classic logic, thinking precedes action, “I think ... so I decide”)
2. Darwinian (trial and error method, action precedes decisions, “I check the effect of a decision”) [16].

Robotic operators use both patterns. It is the surgeon, the operator, who decides about every move. According to the current rules, the robot cannot make the move itself. However, the time for autonomous robots is coming. For this kind of robotic surgery, planning will become the creation of a surgical robot task program. We can count on the rapid development of artificial intelligence and sensory devices necessary to achieve the right level of decision making based on the assessment of the space and the operation object. It will be a surgery based on facts obtained directly from the field of operations and analysis of databases, the so-called big data. The role of IT solutions is growing. According to R. Satava, a surgical robot today is more of an IT tool rather than a mechanical tool [17].

The principles of ergonomics should be applied when creating software—ensuring the effectiveness, efficiency, and satisfaction of the employee. These three properties describe software usability.

A surgical telemanipulator is a tool that must be adapted by the surgeon who controls it. Once we understand everything, we will be able to create independent surgical robots. Surgery will stop being an art and will become a science.

6.4 Training

Planning starts the process of preparing for a surgery. If the successful performance of surgical tasks requires the acquisition of new skills and their improvement, the appropriate training process should be implemented. In the past, the only way to know and control the patient’s anatomical space, including the capture of pathological features associated with a given disease, was anatomical tests on the cadaver (or animal model). Currently, this role can be taken up to a virtual patient (anatomy) and a virtual operating room (operating room organization with tools and devices cooperating with surgeons at the operating table).

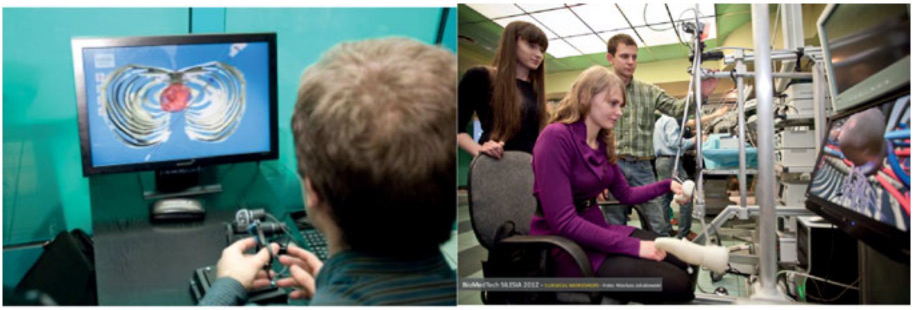
Introducing new surgical techniques moving the surgeon away from the operating table, like in teleoperations, introduces responsibility problems because of the risk of communication errors. To date, not all problems have been resolved. Ethical, practical, philosophical, and economic factors influence the development of remote control operation. The first evolution/revolution was associated with the introduction of endoscopic techniques, during which the surgeon’s hands are only a few dozen centimeters away from the operation area. Currently, when we deal with the transmission of the signal, i.e., the will of the surgeon regarding the operation of the tools inside the patient’s body in another city or on another planet, we must respond to new challenges (mastering physical phenomena and unknown technical solutions). Therefore, we need to develop research on the process of transmission of action, the effect of the work of a surgeon at a distance (optimization, i.e., adequate effectiveness with minimal risk). However, let's not forget about training. We also need to prepare the surgeon for this new type of profession. In surgery, training should include various technologies: (a) physical modeling, (b) VR, (c) manual training stands, and (d) computer stations. This story begins with the pelvitrainer recommended by Kurt Semm, a German surgeon and pioneer of endoscopic surgery. The pelvitrainer consists of a fiberglass box, single lens optic laparoscope, fiber optic light source, endoscopic camera, and video monitor. The first structured surgical training program in the United States (based on clinical service with subjective feedback from mentors [apprenticeship]) was created by Dr. William Halsted [18]. Currently, because of economic constraints, more attention was paid on the efficacy of surgical education [19].

The measurement of surgical efficiency is mainly related to the precision of movement and the implementation of mechanical (e.g., tying the knot or separation of tissue) and biological tasks (assessment of the patient's condition immediately after surgery, quality, and lifetime). The use of mini-invasive surgical methods has many advantages for the patient but is a technical challenge for the surgeon. Endoscopic tools deprive certain movement possibilities. The endoscopic tool is inserted into the patient's body through the hole (hereinafter referred to as the port), which is suitably reinforced as a type of ball joint during maneuvering the tool. On the one hand, the port plays the stabilizing role of this long tool during work; on the other hand, it limits the freedom of movement (reduces the number of degrees of freedom by 2) and changes the direction of the tool's movement opposite (left-right) to the movement of the hand holding the tool holder. A sense of touch the tissue is also changing. For the surgeon to be able to operate with the required precision in the conditions of reduced touch sensitivity (lack of force feedback) and space often presented on a two-dimensional monitor only (lack of sense of depth), it is necessary to acquire psychophysical skills during training exercises. A system of training devices for doctors to operate with the use of new developed mechatronic and robotic tools has been prepared in the Biocybernetics Lab of FRK [1, 20–26]. The photographs shown in Fig. 6.1 present good examples from the FRK history.

Medical simulations should be based on the geometrical representation of anatomy, soft tissue modeling (physics), and physiology. Currently, in most simulators, accurate haptic feedback is lacking—we have no connection between the deformability of the tissue and the physical interactions and feeling during the control of tool movements [27].

The training process of the medical team also requires a more natural, biological reality, which consists of the following:

a. Cadaver study
b. Animal preparation
c. Clinical experimental application



Virtual laparoscopic training station & Robin Heart Shell console with virtual robot [25].

Classic laparoscopic training stations

Fig. 6.1: An original system of training stations prepared in the Biocybernetics Lab of FRK.

Training is the key to the success of future surgeons, but the learning curve, measured by the number of operations carried out to achieve the routine (time and effect of the operation), is much shorter for operations using telemanipulators. Currently, the importance of virtual space technology in training is growing because of the increasing reality of scenes and ease of access to launch training. The VR operating room, with Robin Heart robots, can be manipulated realistically with all of their functionality: an endoscope camera viewport displayed in a picture-in-picture technology; a human model with basic organs that might be exchanged to the ones from a patient

CT or NMR; and a surgery room with a surgery table, lamps, and all the basic equipment. The Robin Heart training system has been performed using EON software by the FRK team [20, 21].

6.5 Planning of robotic operations

Virtual surgery is a tool for the transparent visualization of an advanced surgical procedure. Using the VR technology, an interactive, fully controllable operating room model equipped with various Robin Heart surgical telemanipulators was made at the FRK.

Given the appropriate planning of the robot setting at the operating table, the correct location of the holes in the patient's body shells, through which the tools with specific functionality and workspace will be inserted, has a strong impact on the safe implementation of the surgical procedure. The subject of planning is also a sequence of robot movements (choreography) and the selection of the right tools. An important way to implement operations planning is to use virtual space technology. As a part of the Robin Heart project, the first virtual and robotic operating room in Poland was developed. The ability to operate in the virtual space of the patient's body allows the surgeon to determine whether a given tool with defined geometrical dimensions and certain degrees of freedom has the right range to perform the planned activities.

To prepare the robot well for the operation, it is necessary to know the principles of its operation. Robin Heart is a spherical robot with the appropriate range of permissible arm movement and the effective range of the tool inside the patient's body. The main assumption about the functionality of the Robin Heart telematic video kinematic chain is the construction of a double articulated quadrilateral to provide constant motion. The geometrical range and the mobility of the tool determine the potential operation space. The analysis of the impact of the tool selection and the location of the patient's intersection are the basis for surgery planning.

VR in the FRK in Zabrze is currently used in four extremely important and mutually related research areas:

1. as a training station for future surgeons, who can become familiar with the behavior of the model and way of controlling the Robin Heart robot,
2. as a tool for planning operational procedures with possible instruction in the course of proceedings,
3. as a tool to prepare the choreography of the robot (numerical set of information about the robot's position and all tools for various elements of the procedure) for the online consultancy program during the operation, and
4. as verification of the robot's design solutions based on their usefulness for a specific surgical procedure.

The VR room was equipped with all designed robots, mechatronic tools (Robin Heart Uni System), and selected typical surgical tools and elements of the operating room. VR technology can perfectly serve as an interactive training tool. The developed, among others, model of the FAMED operating table was controlled from the original or virtual remote control. The user has all structural cross sections to understand the operating principles and the ability to run specific device control functions. A laparoscopic surgery training set was made with position adjusters, which are physical holders of laparoscopic instruments. A robot training stand is prepared with the full features of a natural Robin Heart robot management position.

The original operating planning system allows saving selected sequences of images of robot and tool settings and a digital, unambiguous record of these settings in the coordinate system with respect to selected points on the patient's body, on the table, or on the operating room map. Images can be recalled on the consultant monitor of the Robin Heart Shell console. The recording of the coordinates of the robot's settings (settings of all the robot's degrees of freedom and its basis) will enable the reconstruction of the planned settings [1].

Figs. 6.2a–6.2d illustrate the planning of selected surgical procedures, mainly related to Robin Heart robotic animal experiments [1].

6.6 Robin Heart

The results of the project initiated by the author are the family of Robin Heart robots and the universal mechatronic tool series Robin Heart Uni System, which can be used during minimally invasive surgery on the heart and other soft tissues.

Robotics, as the technical discipline, deals with the synthesis of certain functions of the man by means of using some mechanisms, sensors, actuators, and computers. Among many types of robotics at present, one of the newest, but rapidly developed, is the branch of the medical robotics, which includes the manipulators and robots, dedicated to support surgery, therapy, prosthetics, and rehabilitation. Currently, several types of medical robotic systems have been applied in the surgery, including the following: robots replacing the assistant during the operation, such as Einstein, EndoAssist, or Polish prototype Robin Heart Vision, and surgical robots, such as da Vinci, Senhence, Versius, or Polish prototype Robin Heart (Fig. 6.3). The purpose of surgical robots is to improve efficiency and repeatability (standardization) and to reduce the invasiveness of surgical procedures (extension of the group of patients for whom successful surgical intervention is possible) [1].

The surgical robot has overcome the limitations of traditional endoscopic instruments that have only four degrees of freedom. Some of the robot's executive tools currently have 5–6 degrees of freedom and, additionally, some possibilities to perform complex, programmed movements. Robots have interchangeable tools used depending on the needs—harmonic knives, forceps, etc. The so-called quick connector should enable the quick replacement of the tool by the assistant

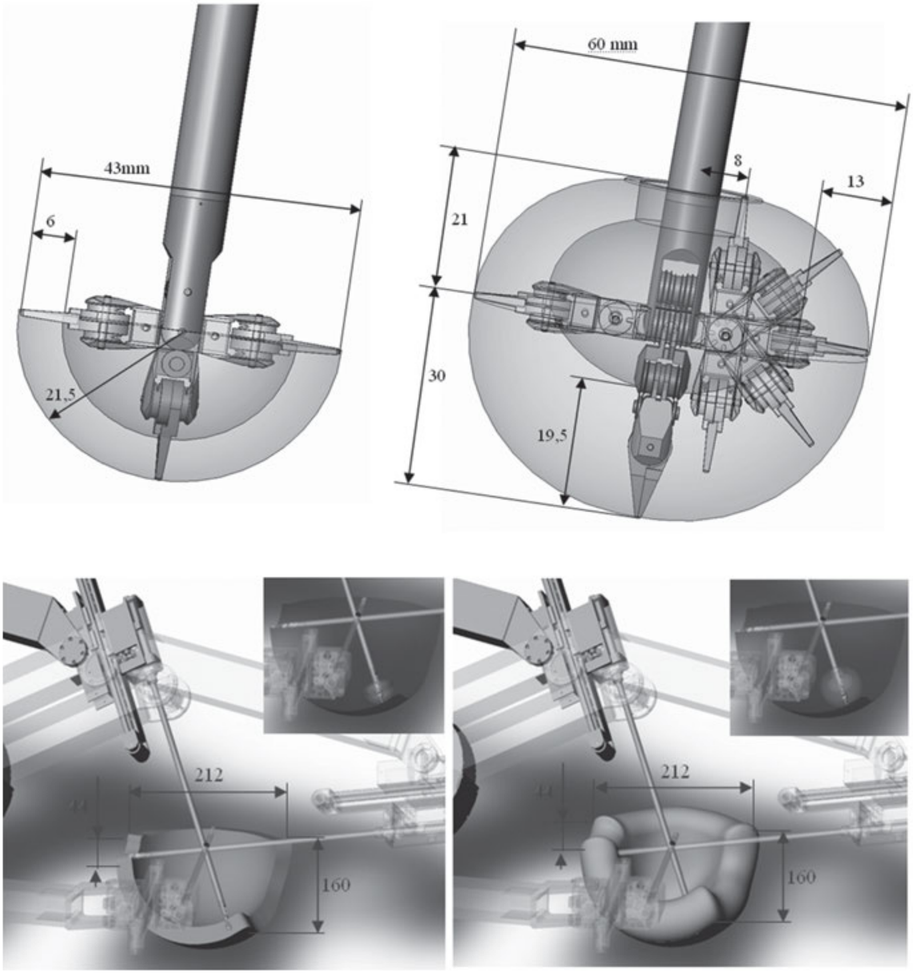


Fig. 6.2a: Working space for the Robin Heart tool with two and three rotary axes [1, 20, 21].

and ensure the possibility of sterile connection of the “clean” tool with the robot’s fixed arm. The robot is a telemanipulator—a remote control device. The robot does not have to reflect the human’s natural movements, but as a telemanipulator it is controlled.

The upper limb of a man fulfills two basic functions: (a) manipulative (manus—hand) performed by the hand with fingers and (b) extension arm performed by the arm with the forearm. The performed measurements (work space) and observations indicate that the surgeon works mainly by moving the wrist. The analysis of anatomy shows that wrist movements are possible in the range of –80° (palm flexion) and +70° (dorsal elevation) and in the perpendicular axis +20° and –20° (radial deviation). An ergonomic, appropriately designed motion detector, a haptic device, and a joystick play very important roles during precision telemanipulation.

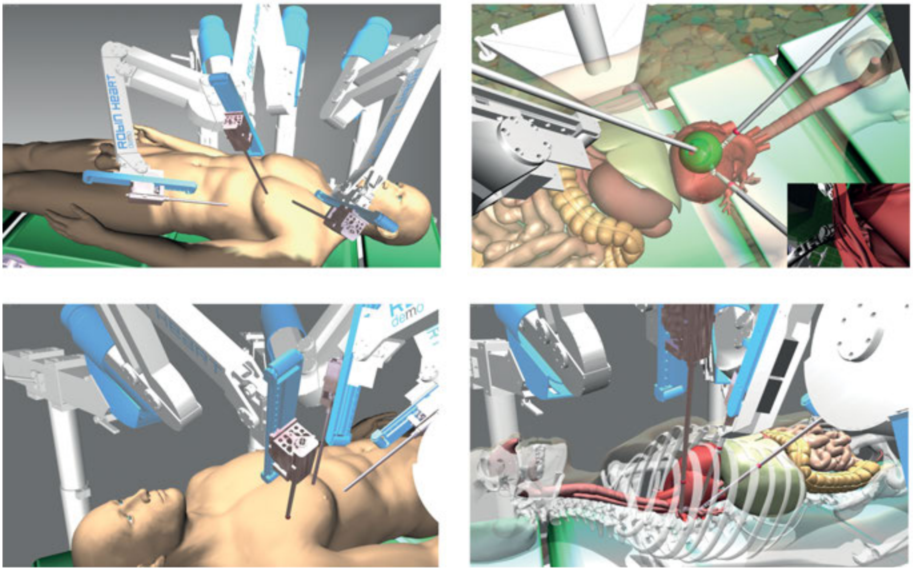


Fig. 6.2b: Operation planning for Robin Heart 1: (A) TECAB operation; (B) mitral valve surgery [1].

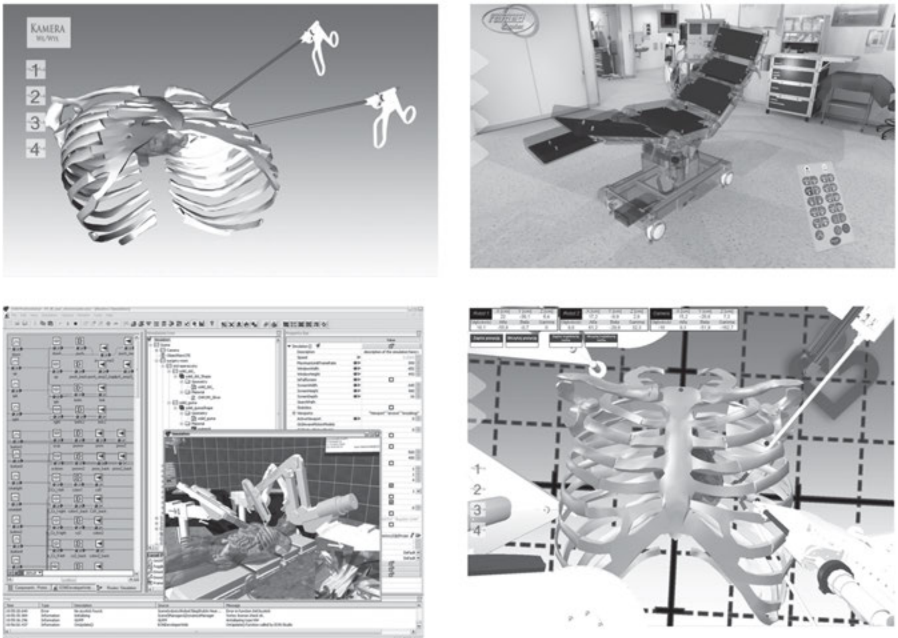


Fig. 6.2c: 3D model of laparoscopic tools, surgical table, and robot simulation made using EON Software by FRK [1, 22].

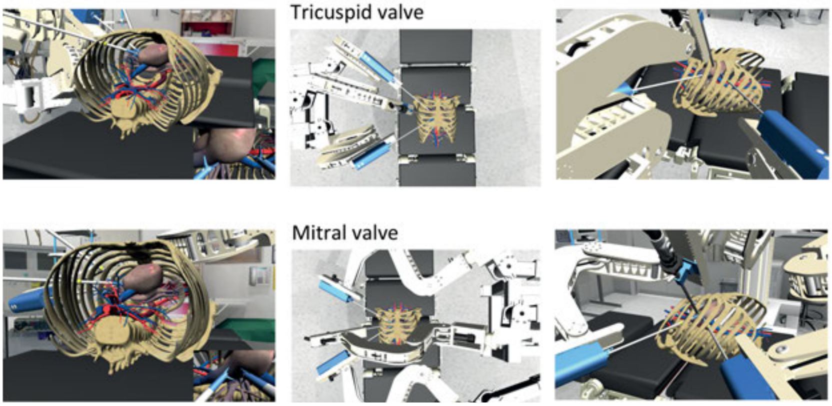


Fig. 6.2d: Example of planning the valve operation using the Robin Heart mc^2 robot [1].

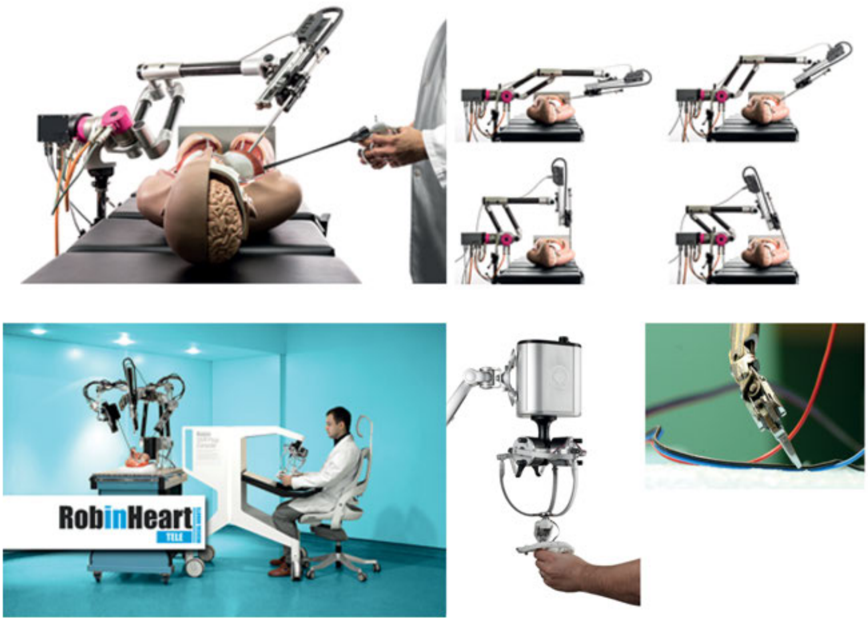


Fig. 6.3: Robin Heart PortVisionAble as a robot used to control the position of endoscope during laparoscopic operation and Robin Heart Tele as an example of surgical telemanipulator.

The Robin Heart Shell model constructed we constructed is an attempt to implement a natural mediator between the surgeon and the robot. A characteristic feature of the construction is its support on the operator’s natural idea placed inside the operation space.

The process of projecting the Robin Heart robot starts by determining the tool-tissue reaction (the mechanical characteristic, the forces for specific operations, and the dynamic analysis of the work of a tool) and the person-tool/man-machine contact (kinematic analysis of the surgeon's motion). The surgeon's motion and the tool trajectory in a natural environment are analyzed with the use of optical biometry techniques. The forces applied during the impact of tools on tissue during typical surgical activities are measured. The construction assumptions as well as the functionality and ergonomics of the innovative tools can best be verified by means of video recording. As a result, a user-friendly surgical workstation (console) and an efficient surgical tool are constructed [1].

The robot, or rather a "telemanipulator" (which in its definition means that between the tool inside the patient's body and the surgeon's hand is the robotic arm and computer control system), is the first tool of the surgeon that allows support directly during work using the previously developed plans and advisory programs. It enables the introduction of a new standard in the surgeon's quality system.

The Robin Heart system (Figs. 6.3–6.5) includes a series of telemanipulators and automatic surgical tools as well as planning system, training system, and experts' program. The Robin Heart Shell console is equipped with a consulting program (online access on the screen) with patient's diagnostic information and picture/navigation data from operation planning. The 3D virtual operating theater introduced in our laboratory allows surgeons to train some elements of an operation and check the best placement of the ports.

In the Polish Robin Heart surgical robot, many of the original solutions were introduced: telescopic sliding motion to move the tool (2002), mechatronic tool "for the hand (2006) and the robot," and Robin Heart mc^2 (2010), which is the first surgical robot that can work for three persons (two surgeons and assistant responsible for endoscope orientation). The tool platform was modified in the TeleRobin project (2010). Robots and mechatronic tool have been in vitro and in vivo (animal) tested (Fig. 7). The Robin Heart family of Polish robots has a chance of becoming a commonly used high-tech technical and telemedical system facilitating the performance of some parts of operations in a minimally invasive, precise manner, safe for the patient and the surgeon [1].

6.7 Exercises with students

This chapter shows the proposal of exercises with students for "robotic surgery and virtual reality."

1. The use of robots and endoscopic tools introduces the elements of mechanics and limitations that are best understood by means of exercises during which we try to operate, gradually limiting the mobility in the next operator joints.
   Do you like detective stories, books, and crime movies? Imagine, therefore, that you only know the end of each story, losing the pleasure of seeking a solution. Hence, you are like customers who get a finished product. Scientific work has all the attributes of this joy of searching for the right answers. In the education process, we should recreate

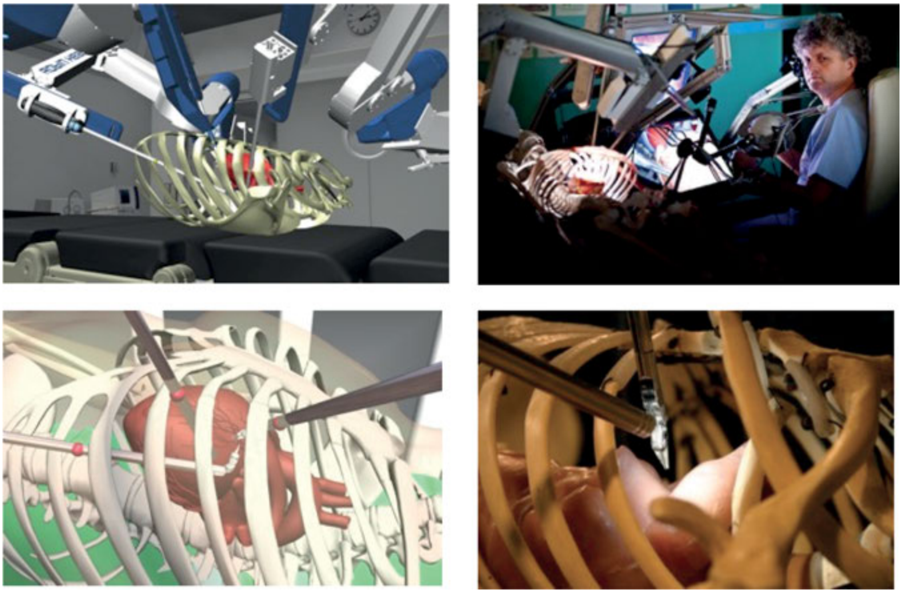


Fig. 6.4: Virtual and real conditions for testing the Robin Heart robot. The link between this type of modeling and computer-aided design (CAD) techniques is using an accurate CAD robot models in VR software together with a precise reflection of workspace geometry. This approach gives a surgeon easy and intuitive ways to understand technical information and use it to optimize and plan medical process [1, 24].

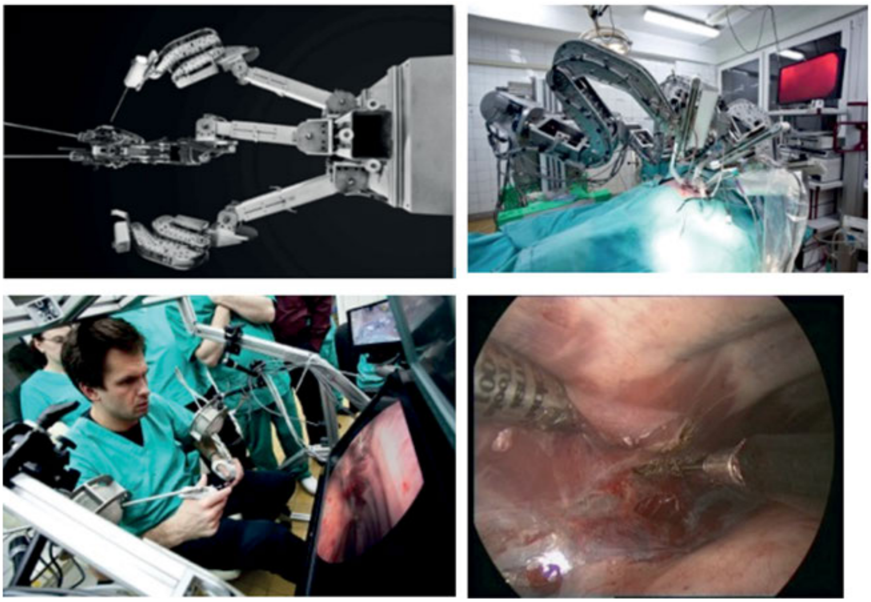


Fig. 6.5: Robin Heart mc^2 robot test during animal experiments [1].

for the students, although selected elements of the scientific work, to better understand the essence of the problem or the principle of operation of the device, which they get at their disposal. A good, simple, and easy example of such an approach is the modeling of movement limitations when using various surgical tools. To learn how to operate endoscopic tools or surgical robots, let us create a model of their work in limited mobility of the locomotor system of student. Let's put on the elbow, then the wrist of the hand, then the selected finger-stiffening bands, limiting the movement, and let's try to perform basic surgical operations in such a situation. Surely, the surgeon will be more precise and adequate to the possibilities after such a lesson.
2. The use of robots and endoscopic tools introduces limitations in the observation of the operation space. The video path with the camera inserted through the hole in the body of the patient can create a flat 2D or 3D spatial image on a monitor or eyepiece (depending on the equipment). To understand the limitations of the sense of depth and the resulting danger, an attempt should be made to perform the surgery with a 2D and 3D image.
3. The use of robots and endoscopic tools introduces limitations in terms of sensing the impact of tools on tissues. To understand the limitations of lack of force feedback and the resulting threats, it is necessary to carry out experiments to perform a given task, a surgical task in the situation of having the ability but also the inability to feel the respond of tools when working on a physical or virtual model. The best proposition for such tests is the use of a robot control console in the version with and without force feedback during the performance of a surgical task.
4. The use of robots—telemanipulators—introduces time delays in observing the effect of the tool during work. The best training and research station for the impact of information delay on the ability to perform precise operations is the use of a robot control console, predefined using an appropriate software with a different level of delay of the currently displayed image on the monitor.
5. Virtual operating room—exercises from the organization of an operation field. It is necessary to arrange the robots and decide on the location of the passage through the body shells of the patient (ports) in such a way that after choosing a tool with a given work space (associated with geometric dimensions and the number of degrees of freedom), it is possible to perform a specific operation such as heart or abdomen ones.
6. For the purpose of training the use of mechanical, mechatronic, and robotic endoscopic instruments, a virtual operating room with appropriate real handle can be used.
7. The use of robots—telemanipulators—introduces elements of the surgeon's ergonomics with the help of various types of motion units. To understand the role of the relationship between your haptic tool and the precision of the task, a series of experiments using a computer equipped with various drivers, mouse and joystick, can be performed. The simplest task can be, for example, the passage of the labyrinth with the help of various motion units.

All such possibilities, training stations, and research were developed and tested in the FRK in Zabrze (Fig. 6.6).

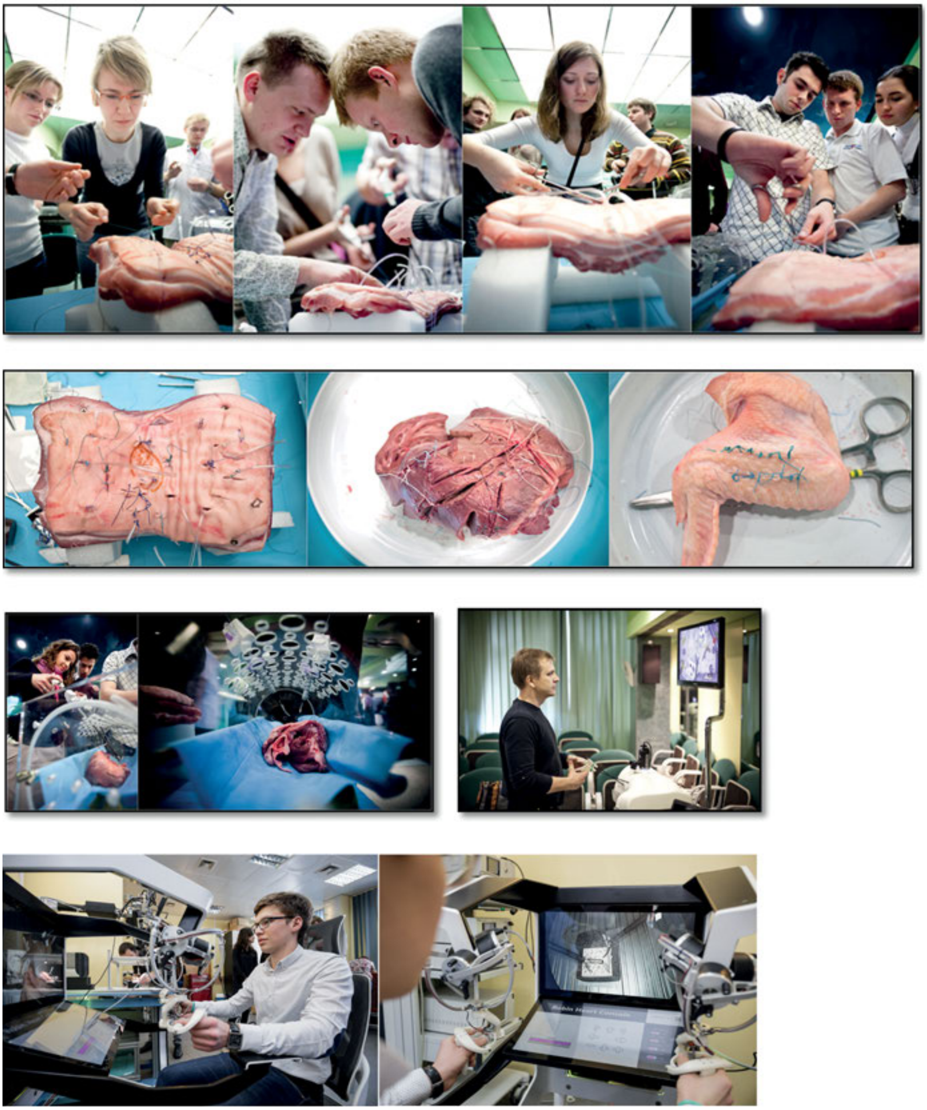


Fig. 6.6: Surgical workshop created by FRK & Medical University of Silesia. The principle of the workshops that have been going on for nearly 20 years is that participants start sewing on natural tissue, then use all training devices—from classic to laparoscopic to robotic ones. Both tests on natural tissue as well as plastic models are prepared (we have recently used fast 3D printing technology) and simulations in virtual space. Over 3,000 young people have participated in the free workshops in the FRK so far.

6.8 Summary

6.8.1 Robots and virtual space technologies

Robots have marked a breakthrough in many areas of modern science and life. They have already played an invaluable role in the development of manufacturing methods, and nowadays, they are entering the fields of medicine and education. Service robotics encourages the development of telemedical technologies used by patients and by medical staff. Surgical robots (new kind of tools) improve the quality and precision of surgical intervention and often reduce the invasiveness of operations.

Very important for current medicine education, VR technologies have been initiated by Ivan Sutherland who proposed the concept of "virtual worlds," giving an illusion of being present in a three-dimensional space created by means of a computer. In 1968, he demonstrated his "headband," which was a kind of helmet with screens in front of the eyes [22]. One of the best VR applications is for people with disabilities (simulation of lost physical activity in quasi-natural conditions). The modeling of behaviors in various situations in the therapy process of various phobias will also be used.

The implementation of VR techniques and stereoscopic imaging into telemedical systems requires certain conditions to be fulfilled by users. Beside a PC with an installed browser, users need stereoscopic glasses (to be able to see the image in 3D). The benefits involve, first, access to a lot of information transmitted in an understandable way in comparison with traditional methods of imaging and communication. Users have an opportunity of experiencing virtual operating theaters and tools used during operations, together with their technical description. They have a chance of controlling a cardiosurgical robot, of getting acquainted with the construction and mode of operation of different surgical tools and medical devices. Nevertheless, the most important quality of the VR technology is its interactivity, i.e., the possibility of involving participants in the space offered by the software and the inception of some physical features concerning the objects and the laws that govern their operation. It is possible to introduce "real" objects into virtual space [22].

The first applications of virtual space technology in Poland were related to medicine. FRK conducted pioneering works in Poland in the field of using virtual space technology in medicine. We were the first to buy software (EON) enabling the creation of an interactive operating room to be able to plan and train the use of new tools—surgical robots. We have introduced the solution in the form of a virtual operating theater to the educational package of implementing the Polish Robin Heart robot and to academic education.

Virtual surgery is a tool for the transparent visualization of an advanced surgical procedure. Using the VR technology, an interactive, fully controllable operating room model equipped with various Robin Heart surgical telemanipulators was made at the FRK. VR technology is the perfect language for communication with surgeons and the field of testing innovative solutions.

A proper development of surgeon skills requires joint work, through the use of both computer (including virtual) systems and tests on physical or hybrid models (with the elements of natural tissues). Tests with real tissues allow to the get to know properties of the natural object of the operation, what means to understand the crucial points of tool-tissue interaction. The essence of this abilities, so-called "the surgeon experience" (it is the most important factor of successful operation according to well-known literature), consists of the suitable relationship between a spatial imagination, manual efficiency, and medical knowledge and the abilities of taking quickly proper decisions connected with next stages of the executed procedure. This thing, which cannot be taught, is called "the talent," and it is the property reserved not for everyone. Medicine still tends to be an art despite more and more modern tools [27].

However, the use of virtual space technology has introduced a completely new quality: manipulation space enriched with information—real images, diagnostic + scientific data and imagination. The use of solutions based on the technology of virtual space has already changed the education of doctors, and now it is entering the operating rooms, supporting doctors in making decisions and increasing the chance of precision based on facts.

The surgeon, who usually works with limited access to information because many parts of the body are simply invisible, now obtains new possibilities, thanks to the enriched technology (augmented reality). This will bring a new quality of medical activity and measurable opportunities for patients.

The educational possibilities offered by virtual technologies are very important in areas inaccessible for testing because of ethical (medicine) or physical (space exploration) reasons. On the grounds of our experience, we claim that VR technologies constitute an excellent communication language to be used by engineers and physicians in the process of designing new surgical tools and robots.

A good choice of technologies required for the educational process is a standard that should be followed, even at the expense of teachers being replaced by avatars in some cases.

The future of the development of virtual space technologies in medicine depends on the implementation of new, ergonomic, and technical solutions. Soon, the introduction of the 5G networks will reduce the delay in sending high-resolution images. This means that the use of telemanipulators (at a distance of 100 km or more) will be more common—especially in the fields of consultancy, rehabilitation, and treatment tasks. Physical limitations remain because the speed of light or the transmission of information is limited. This means that in the category of cosmic medicine—e.g., related to the care of people traveling to Mars—we need to find other solutions. The development of artificial intelligence, sensory, and VR technologies will soon allow the robots to become independent. There are now completely new devices on the market that allow introducing the possibility of using augmented reality in real time. Perhaps the breakthrough will be Microsoft's introduction of the HoloLens 2 system with spatial anchors (will allow to share holograms with others via the Internet) and remote rendering (it will allow direct streaming of holograms in high quality to 100 million polygons).

Today, new technological equipment allows you to present spatial images on monitors, screens, or glasses, adding real elements. More and more companies are introducing professional applications of even a smartphone in medical practice to education, planning, and medical measurements. However, new developments in the form of presentation methods combined with measurements online and advanced medical data analysis (artificial intelligence) will be the future. In many academic centers, virtual technology has been introduced into the scope of training, and we also have several world-class Polish companies creating applications implemented clinically (Fig. 6.7). In this way, engineers help reduce the area of uncertainty that accompanies decision making during a doctors' work. They increase the effectiveness of medical actions undertaken, and they cocreate new medical standards. This future has already come.

Fig. 6.7: (Right) In May 2017, an ablation of the base of an atrial fibrillation was performed in the electrophysiology workshop of the cardiology clinic at the Medical University of Warsaw (as a permanent treatment for cardiac arrhythmia), during which medical personnel in Poland were presented for the first time with the capabilities of the Carna Life analytical telemedicine system (https://medapp.pl/projekty-rd/projekt-holo/). (Left) HoloSurgical Inc., a digital surgery company, announced in 2019 a successful first in human surgical procedure utilizing the ARAI™, an augmented reality and artificial intelligence-based surgical navigation system, with 3D anatomical visualization for presurgical planning, real-time intraoperative guidance, and postsurgical data analytics (https://www.newgenapps.com/blog/5-incredible-uses-of-virtual-reality-in-medicine).

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