THE CONTRIBUTION OF MEDICAL ROBOTS TO CLINICAL PERFORMANCE: UP-TO-DATE

Gabriela Savuc[1]*, Doriana Forna[2], Norina Consuela Forna[2]
[1]"Gheorghe Asachi" Technical University, Faculty of Machine Manufacturing and Industrial Management, Iasi
[2]Faculty of Dental Medicine, University of Medicine and Pharmacy "Grigore T. Popa" - Iasi, Romania

*Corresponding author: Gabriela Savuc
Faculty of Machine Manufacturing and Industrial Management, Iasi
"Gheorghe Asachi" Technical University
67, Dimitrie Mangeron Street, 700050, Iasi, Romania
E-mail: gabisavuc@yahoo.com

ABSTRACT
The paper presents several theoretical aspects regarding the current stage of robots' performance in the medical field. While robots have the potential and ability to improve the precision, movements, skills and capacities of the human hand, their presence in clinics is rather reduced, although their use is necessary in a variety of branches of the medical "industry". Medical robots are made of almost rigid connections which comprise articulations that allow relative movements from one connection to another, robots being controlled by a computer system towards any point and in the orientation desired inside the working space.
Keywords: medical robots, Minerva, Neoromate, Da Vinci, Robodoc, Orthodoc, Robodent

The essential characteristics of contemporary medicine are precision, avant-garde, technologization and successful clinical finality. In order to reach competence in a field of permanent evolution, governed by exigency, aesthetic rehabilitation and rigor, it is vital to have a sound theoretical and practical preparation.

The robots' role in medical practice is particularly important in achieving performance and competitiveness, importing evolutionary aspects on the scale of complexity, in agreement with the particularity of each medical entity.

Concerns regarding the use of robots in medicine have been registered since 1985, when a robot played the role of a simple positioning element which oriented a needle for brain biopsy.

The use of robots in the **neurosurgical field** requires special accuracy, a lot of precision in attaining the anatomical target as well as the minimization of lesions to human tissues. The systems used in this field are the following:

Minerva is a robot designed for the placement of precision needles used in brain biopsy. It works inside the CT scanner so that the surgeon is able to follow the position and to orient the instruments in view of successive CT scanning. An overall view of this robot is shown in Fig. 1.

The system components are: scanner that belongs to the CT unit, storage unit, robot, guide-ways, reference system, scanning table of the CT unit, adjustable connection with the table, rigid connection, and working station.

The robot is mounted on a horizontal guide-ways support transporter. A BRW (Brown-Roberts-Wells) reference stereotactic system is attached to the robot's portal, which is coupled to the CT monitored table by two spherical serial mounted articulations. This system was used only for two surgeries carried out at the CHUV Hospital, Switzerland, in 1993, and hasn't been used since.

NeuroMate is s redesigned robot, a special attention being paid to the safety aspects. The current version is shown in Fig. 2.

Since 1989 until now, this system has been used in over 1600 procedures, out of which we can mention:

1. Tumour biopsy (1100 cases)
2. Stereo-encephalographic investigations for patients with epilepsy (over 200 cases)
3. Stereotactic and functional neurosurgery of basal ganglia (200 cases).

The typical clinic procedure consists of a first step of data collection and their subsequent transfer to a control computer, followed by the medical procedure as such. The collection of data involves getting pictures of the brain by means of which can be traced the trajectory from the entering point (skin) to the target point, using a specially designed software. The images may be digital (CT, MRI, DSA) or digitalized (RX radiographies) using a digitalization mass or a scanner. The images are then transferred directly from the projection station to a working and control station situated in the surgery room. To complete the procedure, the robot needs to be programmed in relation to the anatomy of the working point. After the position is locked, the doctor may use this guiding system to insert a probe, drill or electrode.

The basic structures of the brain are best viewed using Magnetic resonance images (MRI). In Japan, at the Tokyo University, Dohi and Masamune have designed an insertion manipulator of the needle that is MRI compatible for stereotactic surgery, the frame being made of polyethylene terephthalate (PET), and ultrasound motors being used as drivers. The bearings, journal bearings and feeding devices must be sturdy, precisely executed of non-magnetic materials (brass, aluminium, ceramic).

Fig. 3 shows a curved mechanism, mounted on a support platform with a carrier for a linear needle, the system being controlled by a personal computer, the control computer being remotely located in the MRI control room and cable connected to the robot.

At the hospitals from Boston and Massachusetts (U.S.A.) a robot placed between two parallel magnets is in use, the distance between them of 560 mm, the robot being mounted in the upper side of the unit, as shown in Fig. 4.

Orthopaedics is another field where robots have been used successfully.

In 1992, Robodoc, produced by Integrated Surgical Systems (ISS), was used for the hip implants in the drilling procedure. Starting with 1994, in a hospital from Frankfurt, this robot has been used for over 1000 cases.

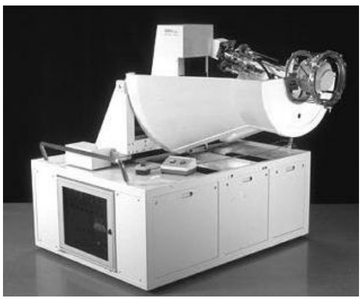


Fig. 1. Overall view of the Minerva robot

Fig. 2. Neuromate neurosurgical robot

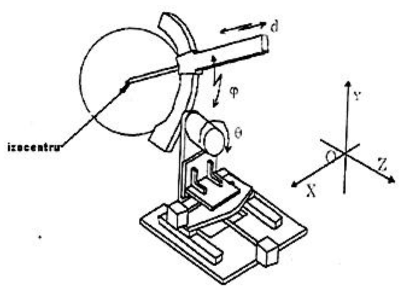
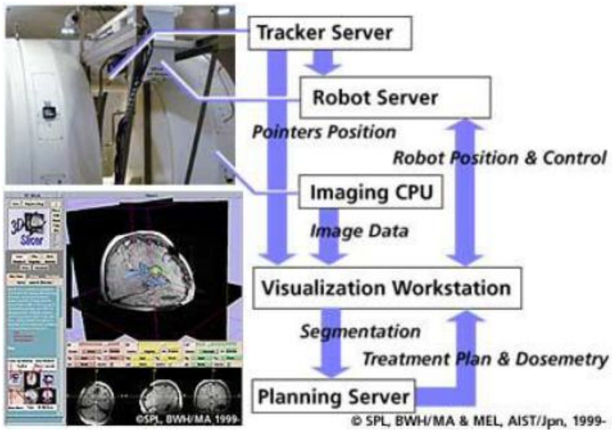


Fig. 3. Model of MRI compatible robot

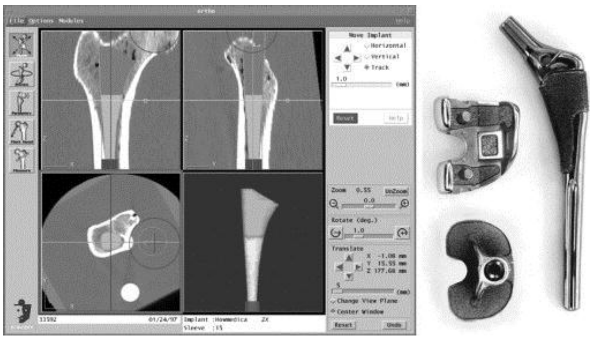
(a) Robot with scanner attached between magnets



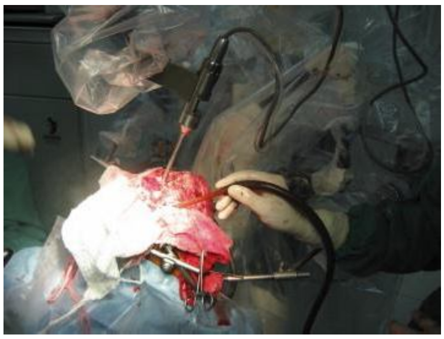
(b) MRI compatible robot software

Fig. 4. MRI Robot

Robodoc System components



Orthodoc - Planning and projecting station



Robodoc during the surgical procedure

Fig. 5. Robodoc

The robot components are (Fig. 5):
1 - working station for planning and projection,
2 - working station for guiding and control,
3 - robot that performs the actual incision.

Robodoc performs the same procedure of hip replacement as the physician, starting by implanting three localization needles in the hip, later used as reference needles. A CT scan follows, the data being later transferred to a planning and projecting working station, called Orthodoc. The surgeon may choose, out of a vast array of possible implants, a convenient one so as to virtually position the implant on the planning station and check various positions for evaluation.

After this stage, the data are transferred to the robot controlling computer. The time of the surgical intervention is of 20-30 minutes and the surgeon monitors the process on a computer screen. The robot may be turned off at any time and when the operation ends, the rest of the surgery is carried out in the classical way.

By grinding the bone with a higher precision than that of a surgeon, the robot ensures a cement free prosthesis and may accomplish a long-term fixation, thus allowing the bone to grow in the implant's porous layer. With the help of this robot the first total knee replacement was performed.

Another robot, designed by the Centre of Research and Engineering (CISST) from Johns Hopkins University is used for the precise placement of instruments in the minimally invasive procedures on the spine.

The robot which guides the needle is composed of the following elements:

1. platform with three degrees of liberty in a translation movement;
2. platform with seven degrees of liberty with a role in positioning;
3. platform with three degrees of liberty used for orientation.

The robot is mounted on the intervention table and the physician controls the system by means of a touch screen (the screen allows the execution of various functions by a mere finger contact – joystick interface.

Another collaboration between the University from Tokyo and J. Hopkins has led to designing an integrated robotic system for the cutaneous placement of needles under CT guidance. The dual recording is based on the simple image of the PACKY-RCM robot and the image space was realized by stereotactic localization using a miniature version of the forward moving frame found in the driving and guiding device of the needle.

Marconi medical systems have been designed for the placements of trocars in the abdomen, the information being transmitted to the robot through CT scans, the robot moving automatically to the entrance point at the level of the skin and then orienting and driving the needle to the anatomical targets.

In 1991 the first patient in the field of urology was treated by removing a large quantity of tissue by means of a resectoscope. This robotic frame, shown in Fig 7, consists of three moving axes, a supplementary axis being ensured by the resectoscope. The system geometry is designed to allow the execution of a cavity inside the prostate and to restrict the movements outside the allowed range, this restriction also ensuring a further safety measure.

The clinical application is made of 4 stages:

1. measurement;
2. image acquisition;
3. designing the cavity;
4. incision.

The user's interface allows the surgeon to see to internal anatomy on a video camera inside the resectoscope. An ultrasound probe is placed in the resectoscope and the robot scans every 5mm to acquire a 3D image of the prostate. Then the surgeon may trace the cavity to be incised in each "slice" on the image acquired by ultrasounds, using an optical pencil. The last stage is the actual resection procedure.

The image of the prostate in real time is shown in the upper left corner of the monitor and the layer of the incisions in the lower right, as shown in Fig. 6, 7.

In order to create an interactive robot, in the field of oro-maxillo-facial surgery, an experimental surgery room was set up at the Chante Hospital of Humboldt University from Berlin.

The SurgiScope robotic system, designed to be fixed on the ceiling, displays six degrees of liberty and is made up of: a fix base, three parallel connections and a mobile terminal effector. The parallel cinematic structure ensures a stable structure for precision surgery (Fig. 8).

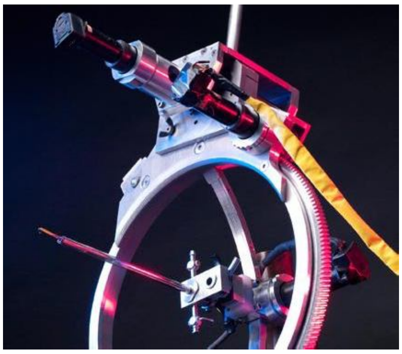


Fig. 6. Robotic frame for the prostate

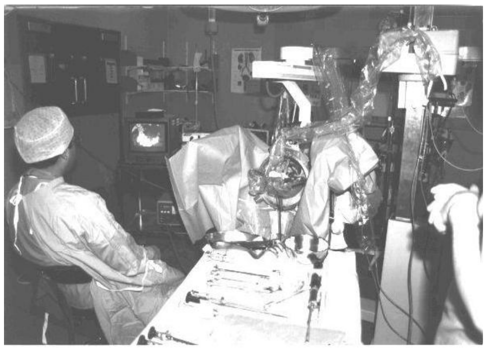


Fig. 7. Probot during clinical use

Fig. 8. SurgiScope robotic system

The clinical duties of a robot used in maxillofacial surgery are:

1. Guidance for the implant of inflexible catheters (brachytherapy);
2. Manipulation of electric drills, threads and screws for fixing bones and implants (anaplastology);
3. Manipulation of electric saws and retracting hooks.

The surgeon guides manually the robotic arm along the trajectory, where the perpendicular movements on the incision line are limited.

Oral implantology, a field of excellence of dental medicine, benefits from the contribution of 3D navigation by means of the Robodent system. In Romania, this system was first used in the dental medical education, at the Faculty of Dental Medicine, University of Medicine and Pharmacy "Grigore T. Popa" - Iasi, as a result of the POSDRU Project no. 62208, project manager Univ. Prof. PhD. Norina Consuela Forna.

The contribution of robots to clinical performance is spectacular, providing precision and reducing dramatically the failure rates in this therapy.

The working stages with the ROBODENT system are the following (Fig. 9):

1. **Acquisition of radiological images:** Scanner or Cone Beam – the radiological exam is carried out with a dental guard
2. **Planning Software:** After the patient's data are loaded, the implants are selected from the database and adapted to the mandible support: the actual working stages are the following:

- Digital processing of radiological images
- Visualization of the images from all angles (axial and coronary)
- 3D rendering with anatomical precision
- Simulation of implants position

3. **Surgical navigation – virtual guide**: Automatic recording allows real time visualization on the screen of the turbines and hand instruments, the following equipment being necessary:

- High fidelity telemetry camera
- PC for real time simulation
- System of optic sensors for acquiring complex images

The insertion of implants is made with maximum precision. The constant cooling of the implant support is ensured.

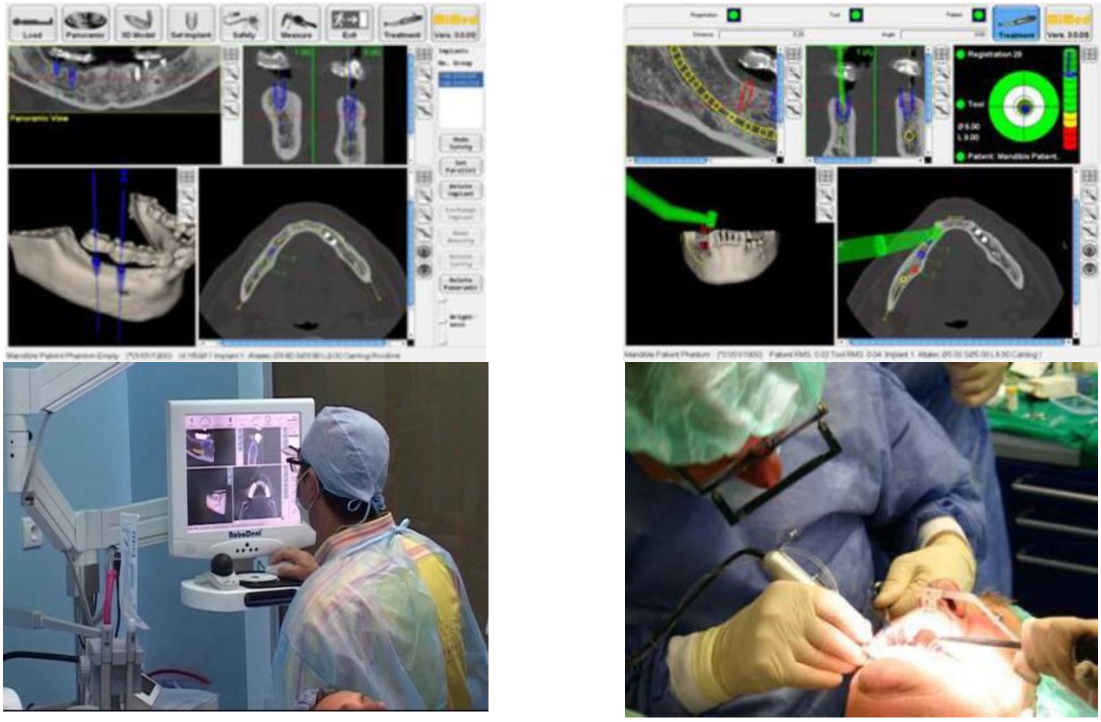


Fig. 9. ROBODENT system

Radio surgery is the radiation of a tumour while saving the normal adjacent tissue. At the level of the brain, radio surgery has been typically performed by using stereotactic frames that are rigidly fixed on the patient's skull. A new method for the precise irradiation (radio surgery) guided for the image was established by Adler and co. from Stanford University, California - U.S.A.

The system is made up of a light linear accelerator, a KUKA robot, orthogonal X-rays devices working in pairs and a treatment couch.

During a treatment session, the system of X-rays determines the location of the lesion. These coordinates are transferred to the robot, which adjusts the orientation of the accelerator's ray towards the lesion. The robot's arm moves the ray by a series of pre-set positions to minimize the dose of X rays to the lesions, reducing to a minimum the irradiation of the normal tissues neighbouring the tumour (Fig. 10).

Das and Hunter Taylor, as well as the researchers from Johns Hopkins University, have designed a steady hand robot in the field of ophthalmology for the eye surgery (Fig. 11).

Fig. 10. System of robotic radio surgery

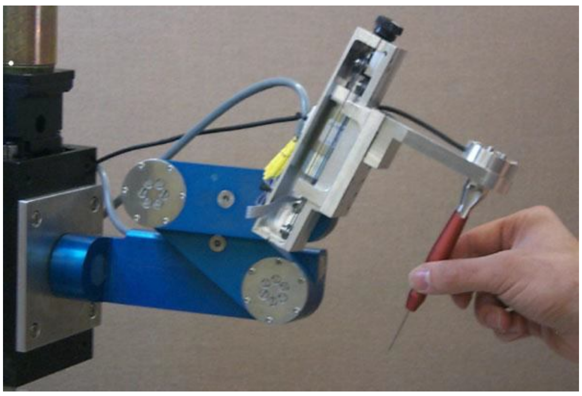


Fig. 11. Steady-Hand Robot used in microsurgery

The system is made up of four modular subassemblies: an assembly of XYZ translation in the console, an orientation one, a guiding and movement assembly for the arm by means of sensors. The steady-hand robot is designed to work in cooperation with the doctor; during surgery, the doctor takes over from the robot the working instrument and will manipulate it for the rest of the intervention. The robot's control system "feels" the forces applied by the doctor's hand on the instrument, making smooth movements, tremor-free, with a precise positioning and force measurement. The use of this robot has significantly improved the man's ability to position the needle, the success rate improving from 43% to 79% for orifices of 150 micrometres (the automatic performance being even better that 96.5%).

Cardiology, a complex field of medicine, uses a series of robots, materialized in the following high performance systems:

a) The DA VINCI surgical system

The Da Vinci robot, designed in 1980 by NASA and the American Defence Department to remotely "surgically treat" soldiers from the battlefields, is a landmark in robotic surgery. The components of the robots in a surgery bloc are distributed as shown in the figures below (Fig. 12-14):

The robot is made up of the following components:

1. surgeon's visualization field
2. control console
3. surgical manipulator with three arms.

The system is designed to combine the free movements of the hands used in surgery with the less traumatizing methods of minimally invasive surgery. The surgeon's hands grab the handles of the device that controls the endoscopic and terminal effectors handles. The manipulators ensure three degrees of liberty and the terminal effector is made up of a miniature wrist that adds three more degrees of liberty and a movement for operating the instrument.

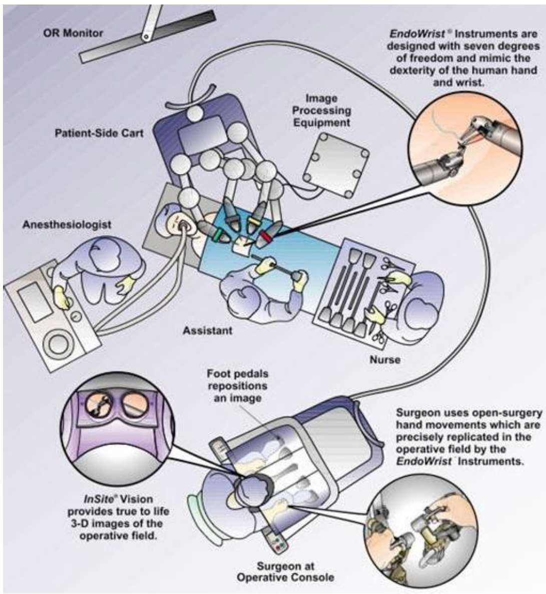


Fig. 12. View from above on the distribution of the Da Vinci robot in a surgery bloc

Fig. 13. Da Vinci surgical system in the OR

Fig. 14. Da Vinci surgical system in București

In 2005, the Da Vinci robot was used in our country as well, at Floreasca Hospital in Bucharest, for implanting an epicardial electrode, by means of three surgical robotic arms: an endoscopic arm with a 3D camera that can easily navigate inside the thorax, two arms with articulated surgical instruments that can perform high precision and complex surgical gestures.

b) Computer MOTION: ZEUS

The Zeus secondary system is made up of three interactive robotic arms (two endoscopic arms and an endoscopic arm with a video camera) mounted on the operating table. Generally, an intuitive surgical system is made up of mechanisms that display six degrees of liberty (plus the prehension movement). The ZEUS system, with only 4 degrees of liberty, has a low dexterity and small efficiency, the research being in progress. The clinical application in the by-pass of the coronary artery was performed only on 50 patients, being described by Boehm (Fig. 15).

c) The PADYC robot was designed by Troccaz and co. from the University hospital of Grenoble for pericardial punction. The robot is a SCARA model with six degrees of liberty, made up of a vertical translation axis and three rotary vertical axes.

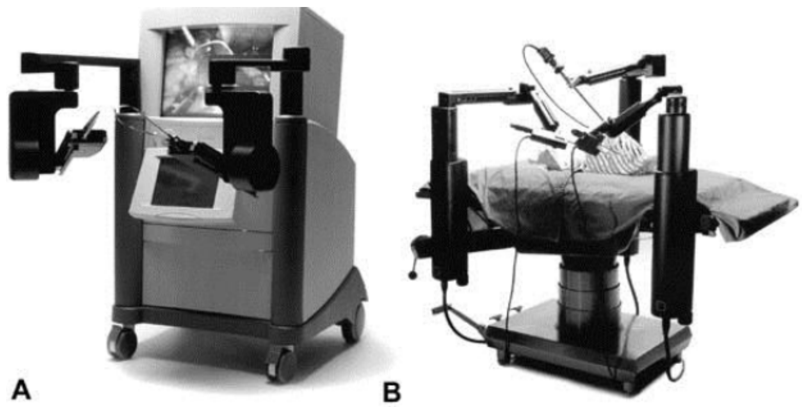


Fig. 15. Zeus robotic surgical system

CONCLUSIONS

The field of medical robotics is only at the beginning, given the complexity of the working environments, the introduction of new technologies being a difficult task as it implies a supplementary research of the following aspects; the system's architecture, software design, the mechanical design, compatible image models; interface with the user; safety.

If, in the field of telesurgery, robots are already used successfully in the operating rooms, the same doesn't apply to the way they are used for remote operations, lacking a good informational system for distance and precision.

The corroboration of performance, precision and the human factor is carried out by the harmonious combination of the modern methods of simulation in dental medicine with the incontestable rigor of contemporary medical practice, governed by exacting principles.

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