3 METHOD OF SURGICAL STAFF COMPETENCE IMPROVEMENT USING THE AUGMENTED REALITY TECHNOLOGY

3.1 Introduction

Certainly health is one of the key factors determining the prosperity of a society. However, as specified by the report worked out by the American Institute of Medicine in 2000, the number of people who died because of medical errors each year exceeded the number of people dying each year from car accidents, breast cancer or AIDS [5]. The report results forced to take corrective actions and develop recommendations for improving the health system and ensuring the safety of patients. One of the recommended actions was to improve staff competencies through carefully designed training program based on the simulation of certain types of activities occurring in hospital processes.

The research results in this article meet the need for new and effective methods of improving the professional competencies of surgical staff and are a continuation of the research undertaken by the authors [10], within which there was developed a basis of knowledge management methodology for constructing trainings for a vocational group of surgery nurses working in orthopaedic and trauma operating theatre. In particular there is indicated the importance of diversification of training contents and forms of communication using modern Information and Communication Technologies (ICT).

3.2 Definition and scope of competencies of medical personnel

Competence is defined as a combination of features enabling an employee to achieve the desired results and performance in the labour process. This combination of features consists of knowledge, skills, self-perception, social motivation, personal characteristics, attitude, behaviour patterns, ways of thinking, feeling and acting [1, 2]. Competencies are observable, measurable, and may be developed in order to gain competitive advantage and increasing of future results.

They can be considered not only in relation to an employee, but also to the entire organization - then the question is about corporate competencies. According to [3] such competencies belong to the given organization and are embedded in processes and its structure. They remain within the organization, even if employees leave it. But one must keep in mind that these two categories of competencies are not completely independent. Individual competencies may affect the way of realization of the mentioned processes, as well as can build a corporate culture embedded into the organization. On the other hand, the specificity of the given organization can force possession or development of specific employee competencies that are necessary for effective and efficient work.

Both the corporate competencies, as well as the individual ones should be developed and improved because of their enormous impact on functioning of the organization. According to the report prepared by the International Labour Organisation, ILO [4], development of competencies and skills is a very important factor in improving productivity and gaining more profit for the organization. In the macro scale, benefits derived from the process of competence development are: salary increase, creation of more jobs, economic improvement and social conditions for residents. The report also shows that countries, that have properly formulated the policy of competence development key sectors of the economy, have reached a higher level of productivity and employment growth. But the impact of competencies cannot be considered solely in terms of direct micro- or macroeconomic measures. These are appropriate and useful for the industrial sector and private sector. In the public sector, where the objective of entities is meeting the basic needs of society, the impact of competencies reveals in the extent to satisfy these needs and consequently in the level of life quality. A special case of the public sector field is health protection. Here, development of competencies goes hand in hand with the level of satisfaction of health services. In this case, one can consider an indirect impact of the process of competence improvement while carrying out this type of service to the micro- and macroeconomic indicators, especially the increased labour costs associated with sick absence, size of unemployment rate associated with sickness, or the percentage of people with disability living allowance.

Due to the specificity of hospital activities, the scope of competencies of medical staff is extensive and includes both hard skills (technical) related to specialized knowledge and specific skills, as well as soft skills, including interpersonal and personal ones. Particularly in relation to medical personnel there are listed six competence areas according to [6]:

- Patient care. A physician should provide appropriate and effective treatment and take actions on health promotion.
- Medical knowledge. A physician should demonstrate both knowledge of the well-established and emerging biomedical, clinical and related (epidemiological and social-behavioural) sciences, and should have the ability to apply that knowledge in treatment and patient care.
- Learning and improvement based on the practice. A physician should be able to independently analyze and evaluate his/her practical skills in patient care, as well as acquire new knowledge in this field and improve the practical aspects of working in a hospital.
- Interpersonal and communication skills. A physician is responsible for effective exchange of information with colleagues, patients and their families during treatment and patient care.
- Professionalism. A physician should demonstrate commitment in the respect of duties fulfilment and conduct of professional care based on the principles of professional ethics and with a sense of vulnerability in relation to a diverse patient population.
- Medical practice based on a system approach. A physician should act consciously and responsibly, taking into account the broader context of health system and be able to make efficient use of system resources to ensure effective patient care.

In case of surgical staff a special attention is paid to the skills of a technical nature [7, 8, 9], while pointing out the lack of competence in this field [7].

3.3 Description of process and methods for improving competencies of medical staff

The process of shaping and improving the competencies of physicians takes place on two levels: formal, by which we mean documented possession of the knowledge necessary to practice medicine and informal, which means undocumented self-education.

The formal path of educating physicians in Poland is based on regulations contained in the three main legal acts:

- Act on the professions of a physician and a dentist dated 5 December 1996 [11].
- Regulation of the Minister of Health dated 6 October 2004 on methods of fulfilling the professional training requirement for physicians and dentists [12].
- Regulation of the Minister of Health dated 24 March 2004 on the postgraduate internship of physicians and dentists (Journal of Laws of 2004 No. 57, item 553) [30].

The above regulations include in particular the eligibility requirements for receiving the MD degree, completing specialization and the requirements for self-education to improve professional competencies.

The prerequisite entitling to gain the medical professional title and the right to practice is:

- Completion of at least six years of study at a medical faculty, including two-semester practical teaching in clinical fields during the 6th year of study;
- Completion of postgraduate internship for a physician lasting at least 13 months;
- Passing the Medical State Exam (LEP).

In addition, a physician can get the title of specialist in a particular field of medicine after meeting the following conditions:

- Completion of a specialized training,
- Passing the Medical Specialist State Exam.

Both in Poland and in the European Union physicians have a duty to participate in the documented professional training, a quantitative measure of which is a number of educational points that need to be received in a given period.

In addition to the formal path of improvement of professional competencies, a physician should preserve and improve the everyday elements of treatment and patient care process, such as medical procedures and working methods, manners of using instruments and equipment, or get familiar with the novelties in the field of medicine.

While the formal training path includes specific mechanisms to acquire educational points, the self-improvement or consolidation of skills, especially surgical skills, are mostly based on professional literature, mainly in English language, directories of procedures, catalogues and manuals for use of tools and medical equipment (often with strong technical nature), or reports published on the special web portals. The problematic aspect of such self-study is the lack of time to acquire new knowledge, or even more to consolidate skills, taking into account the necessity of assigning additional time to locate, gain and process the traditional and not very clear information materials into the information possible to digest and use. The following barriers: lack of time, lack of suitable mechanisms to seek knowledge and to process resources into understandable form, can be eliminated by applying a new approach to self-study based on knowledge repositories made available by use of modern Information Technologies.

The literature reports that the medical industry experienced distinct changes in the development and application of IT technologies, which will affect the functioning of health services by, among others, providing high quality health services, reduction of medical errors, streamlining of workflow processes, reduction of costs and improvement of relationships between physicians and patients [13]. Not surprising is the fact, therefore, that IT tools are increasingly applied in trainings of medical personnel, especially surgery staff. These courses are usually structured and formal in nature, often used to verify the technical skills of doctors, but they are not treated as a constantly available assistance in hospital practice.

One of the IT technology used in the training of surgeons is the Virtual Reality (VR) or Virtual Environment (VE). The essence of such technologies is to provide the user, by means of special input and output devices (computer, goggles, motion controllers, touch sensors, etc.), with artificial stimuli affecting his/her sensory receptors, and thus simulating phenomena that could occur in the real world [14].

The main advantage of this technique is the possibility for the trained person to interact with three-dimensional computer models, subject to the distortion in real time and allowing to learn in a fluent way of procedures and methods of surgical treatment. However, the main problem of using the virtualization technologies is the difficulty in obtaining such computer models that would not only visually imitate human anatomy and physiological phenomena, but also reflect the physical phenomena, such as voltage, resistance and flexibility of tissues [9].

The form of training based on VR technology includes, among others, interactive games. Typical areas of application of such games in health care are: treatment and alleviation of pain, diagnostics, surgery (including activities carried out during the surgery and pre- and postoperative ones), patient education, medical trainings, motor and sensory rehabilitation e.g. after a brain injury [9, 15, 16, 17].

Trainings based on virtual reality are not widely applied yet and their subjects are narrowed to a small number of medical procedures, mainly the course of laparoscopic procedures. This is due, inter alia, to high production costs of simulators with implemented interactive computer models of the highest quality.

Another technique based on the IT, used to improve the competencies of medical staff and to educate medical students in the field of histology and histopathology are so called virtual microscopes. Application of this type of technique, using virtual samples, requires access to traditional computer hardware, not to usually very expensive microscopes. Therefore, it begins to become a common and desirable solution in training process [18].

Quite common are also training methods that use the Human Patient Simulation. Benefits arising from the use of various types of simulators is the ability to accelerate understanding and learning of skills in comparison to traditional instructional methods [19].

Related to the above mentioned techniques of competence development are techniques based on the Augmented Reality (AR). The essence of the AR technology is to complement the surrounding world with artificial elements (see section 3.2). As a rule, these are elements in the form of virtual models, also acoustic additives, smells and other impacts on the human sensory system and musculoskeletal system.

Improving the competencies of medical staff with use of the AR technology has been applied previously in the fields of minimally invasive surgery. In the field of ultrasonography the AR technology has been used in trainings on placement and positioning of the injection needles inside the tissue [20]. Many application cases are recorded in laparoscopy. Here the advantage of trainings based on the AR technology is the possibility of using real surgical laparoscopic instruments giving the impression of the surgery reality, including the resistance and tactile sensations [21, 22], and the ability to create multiple variants of training scenarios through unrestricted visualization of anatomic images [23].

The research show the advantage of the augmented reality technology over the virtual reality, taking into consideration first of all the opportunity to create conditions of physical reality of a training position and tactile interaction during surgical operations [21, 24]. Use of the AR technology as a hybrid system gives the combination of features characteristic for a physical simulator, i.e.: interactivity and realism, and for a virtual simulator, i.e.: objectivity of the correctness assessment of activities and individualized training [25].

In addition to training applications, there is research undertaken over the use of AR technology in clinical practice [26, 27, 28].

3.4 The case of the AR technology application in improving competencies of the surgical staff in the field of total knee arthroplasty

3.4.1 Purpose, subject and scope of the research

For the research the following practical purpose has been formulated: development and testing of the manner of using the AR technology for training in the scope of teaching, improvement and consolidation of the technical competencies of surgical staff.

Tab. 3.1 Scope of the research
Source: Own work

Stage of the research	Methods
Identification and analysis of the course of total knee arthroplasty.	Photographic and video recording of the surgery, interview, analysis of instruction manual.
Identification and cataloguing of surgical instruments, including analysis of their assembly and disassembly.	Photographic recording of instruments, video recording of produced assembly and disassembly of instruments, interview, analysis of instrument catalogue.
Creation of computer 3D geometric models of surgical instruments and selected elements of the human anatomy.	3D geometric modelling.
Development of computer animation instruction	3D computer animation.
Preparation of training materials for the AR technology implementation.	AR labelling with photo codes.
Development of the training.	Scenario methods.

The subject of training is learning how to use surgical instruments used in the total knee replacement surgery. The learning process can be divided into three main stages:

- Learning of terminology and design of instruments.
- Learning how to assembly and disassembly the instruments.
- Learning to use the instrument during surgery.

The article focuses on the third stage of the process, i.e. use of the instrument during the procedure in the scope of fixing the instrument to the tibia and preparation to align the bone.

Development of a training using AR technology has been forced by the specified scope of studies presented in the tab. 3.1.

3.4.2 Specification of the augmented reality technology

As already mentioned, the Augmented Reality technology is a hybrid technology, i.e. allows for perception of information from two sources: from the real and virtual worlds. On the real image recorded by a video camera there are imposed additional information, hereinafter referred to as the related information [29]. The related information are provided by triggers in the form of special tags, such as photo codes. The principle of operation of the AR technology is illustrated in the fig. 3.1.

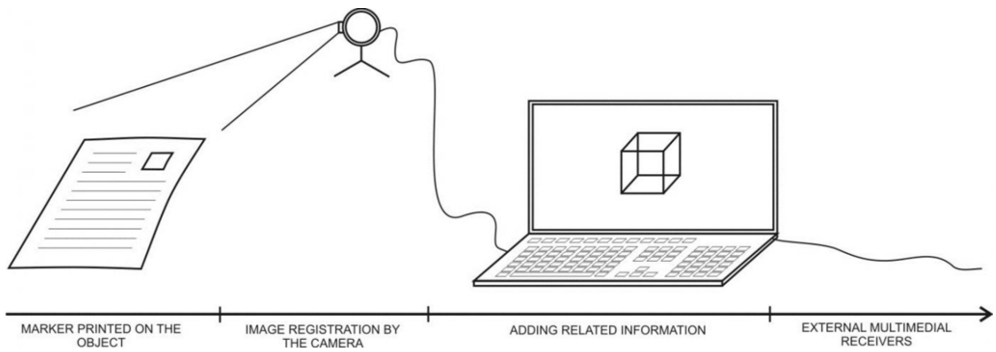


Fig. 3.1 Illustration of the AR technology operation
Source: Own work

The AR technology components are here: tags, image recording cameras, computer, audio equipment, peripherals such as projectors and monitors, specialized software and multimedia spectacles, so called AR glasses.

The tags are used for marking elements to be associated with the enhanced explanatory content (related information). The video camera is designed to register a tag and send it to a computer where the AR software recognizes the tag and releases the related information. The AR glasses, external monitors, projectors, audio sets are the intermediary devices in providing the above information to the user. For example, the information related to a traditional directory that contains a description of the surgical instrument can be the computer animated three-dimensional models of the construction and operation of instruments. Each instrument will then have assigned a separate and unique marker.

Initially, the AR technology only allowed the selection of marker from a limited group of markers provided by the manufacturer. In addition, these markers have been subject to many requirements that restricted their use. These included high lighting quality, strictly defined parameters of the marker surface (opacity, resistance to reflection), and a large size.

At present, any part of an image can be a marker. Requirements for lighting and surface have decreased significantly through the development of matrices used in digital cameras. One of the key factors continues to be the contrast between a background and a marker.

A more complex form, in comparison to the markers applied on an object, is the recognition of arrangement of real elements. This gives the possibility of preparing auxiliary or training materials even if the use of conventional markers is impossible. Its role in this case is played by the object itself, precisely speaking the characteristics of its shape.

3.4.3 Method of application of the AR technology

Knee arthroplasty is a procedure designed to remove worn surfaces of a knee joint and replace them with metal or metal-polymer implants. During this surgery the tip of the femur and tibia is removed. The suitable metal implant is selected for the femur according to the joint size, the implant exactly maps the shape of the joint surface, while to the tibia there is fixed a steel implant with polyethylene inserts. The ethene polymer, also called polyethene or polyethylene, of which there are made the abrasive linings prevents friction of the metal parts by each other. The surgery is done because of excessive wear of the osseous cartilage. The knee replacement surgery can be divided into two types:

- Partial - only part of the tibia is replaced.
- Total - tips of both bones are replaced and the kneecap is grinded.

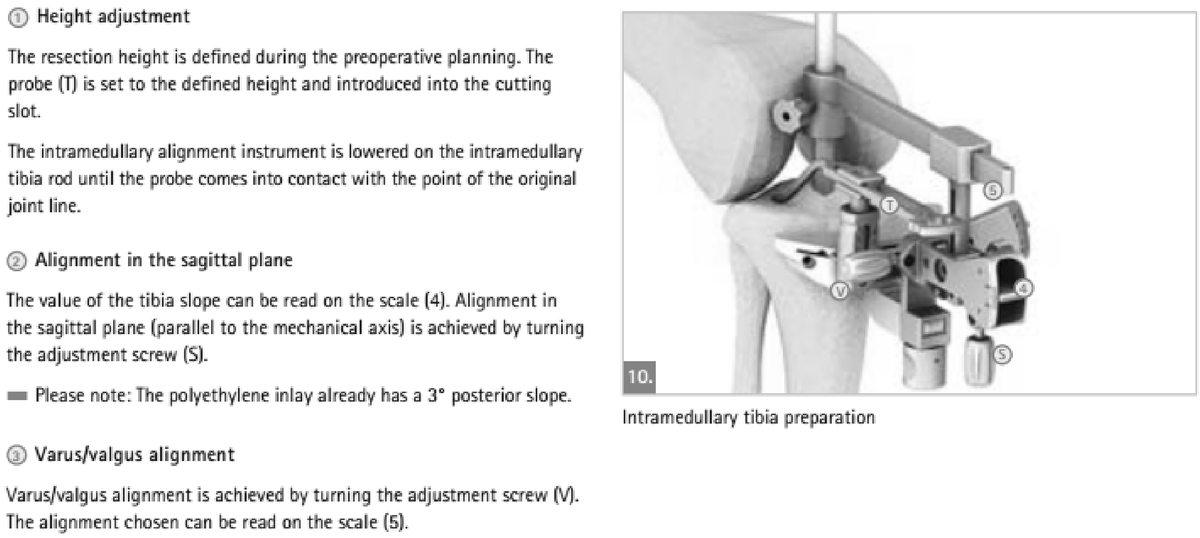
Surgery duration is approx. 1-2 hours. Hospitalization lasts 3 to 10 days, while the recovery to full fitness can take as long as 3 months. A knee joint after the arthroplasty procedure looks like in the fig. 3.2.

Fig. 3.2 The knee joint after performed arthroplasty
Source: Aesculap® Columbus® Streamlined. Knee Arthroplasty Operating technique and Order information

To perform a knee replacement surgery there is extensive range of surgical instruments needed. Therefore, preparation of the instruments for the surgery requires practice and knowledge of complex procedures. In this paper, the B. Braun Melsungen AG instrumentation was used. A full set of specialized tools designed to perform this operation consists of a set of six boxes, in which the elements are distributed. Tool sets are sorted in order of use during the surgery. The fig. 3.3 shows a sample box of surgical instruments.

Fig. 3.3 One of the instrument boxes used in the surgery of knee arthroplasty
Source: Own work

Before and during the surgery the instruments are prepared and handled by a surgery nurse. Her responsibilities include bringing, arrangement, if necessary, assemble and provide the instruments to a surgeon conducting the procedure. After finished surgery, the nurse disassembles the tools and arranges them in appropriate places in the box.



① Height adjustment

The resection height is defined during the preoperative planning. The probe (T) is set to the defined height and introduced into the cutting slot.

The intramedullary alignment instrument is lowered on the intramedullary tibia rod until the probe comes into contact with the point of the original joint line.

② Alignment in the sagittal plane

The value of the tibia slope can be read on the scale (4). Alignment in the sagittal plane (parallel to the mechanical axis) is achieved by turning the adjustment screw (S).

▬ Please note: The polyethylene inlay already has a 3° posterior slope.

③ Varus/valgus alignment

Varus/valgus alignment is achieved by turning the adjustment screw (V). The alignment chosen can be read on the scale (5).

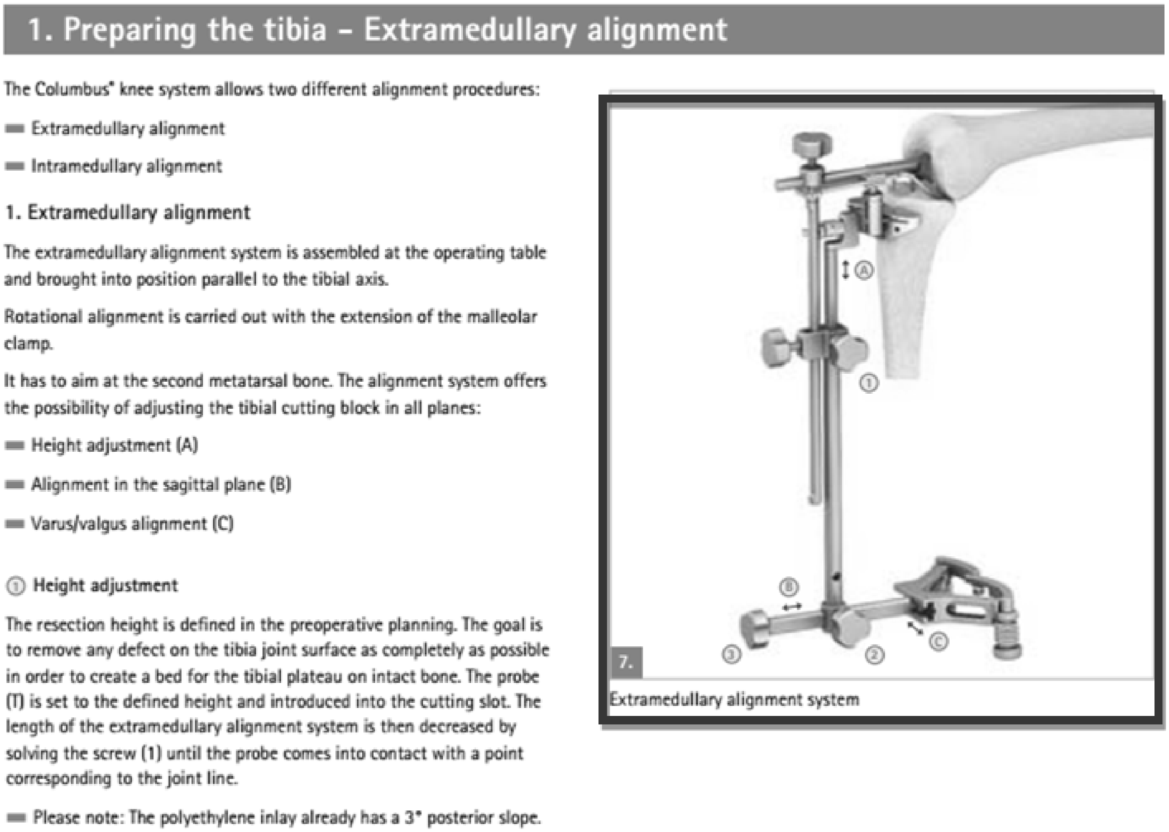
Intramedullary tibia preparation

Fig. 3.4 Part of the surgical technique instructions with use of surgical instruments in English
Source: Aesculap® Columbus® Streamlined. Knee Arthroplasty. Operating technique and Order information.

Therefore, handling of surgical instruments, consisting of many parts assembled together, requires not only medical knowledge. Medical personnel performing the knee replacement surgery must also have technical knowledge of the use and handling of tools.

Considering the complexity of instrumentation, lack of or limited opportunities for exercising activities in training conditions cause that an important element in ensuring a high level of personnel competencies are adequately prepared training materials in this area. Manufacturer of instrumentation provides instructions of surgical technique with use of the instrumentation, in English language, in the form of a workbook and posters. Part of such instruction is presented in the fig. 3.4.

The text and drawings, which in simplified and static way represent resources of information in instruction manuals, in the case of complex tasks such as handling of surgical instruments may be inadequate or extend the learning process. Due to advantages of the AR technology the mentioned traditional forms of information presentation have been enhanced with dynamic elements, such as models and computer animations showing performance of an activity and/or audio commentary.


1. Preparing the tibia - Extramedullary alignment

The Columbus® knee system allows two different alignment procedures:

- Extramedullary alignment
- Intramedullary alignment

1. Extramedullary alignment

The extramedullary alignment system is assembled at the operating table and brought into position parallel to the tibial axis.

Rotational alignment is carried out with the extension of the malleolar clamp.

It has to aim at the second metatarsal bone. The alignment system offers the possibility of adjusting the tibial cutting block in all planes:

- Height adjustment (A)
- Alignment in the sagittal plane (B)
- Varus/valgus alignment (C)

① Height adjustment

The resection height is defined in the preoperative planning. The goal is to remove any defect on the tibia joint surface as completely as possible in order to create a bed for the tibial plateau on intact bone. The probe (T) is set to the defined height and introduced into the cutting slot. The length of the extramedullary alignment system is then decreased by solving the screw (1) until the probe comes into contact with a point corresponding to the joint line.

- Please note: The polyethylene inlay already has a 3° posterior slope.

7.

Extramedullary alignment system

Fig. 3.5 A sample marker placed on a paper manual of surgical technique available in English
Source: Prepared on the basis of Aesculap ® Columbus ® Streamlined. Knee Arthroplasty. Operating technique and Order information

Fig. 3.5 shows how to "enrich" the traditional manual of the knee replacement process with dynamic models activated by the AR technology. The rectangle highlighted in red, placed on one of the manual's pages has been programmed as a marker. This, after being captured by the camera installed in the computer, becomes a trigger recalling on the screen additional multimedia resources of information. These resources are stored in a specially developed repository of training materials, located on a web server. Due to this solution, trainings can be done anywhere where Internet access is present.

View of the monitor after recording the marker by the camera is shown in the fig. 3.6. Animation available on the screen is not editable, which means that a user will not be able to intentionally or accidentally change or damage it. However, it is possible to navigate the displayed model, for example, to rotate and move. In case of lack of user's computer skills, it is possible to set an automatic start of the training immediately after computer boot.

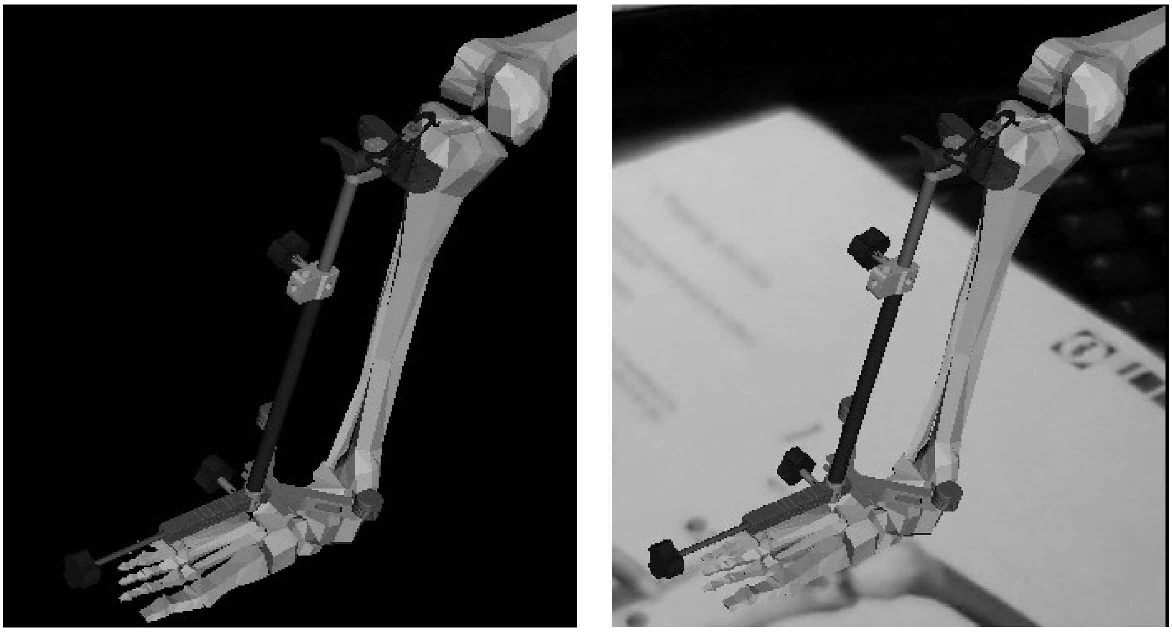


Fig. 3.6 Animation associated with the marker of fig. 3.5
Source: Own work

The presented method of training does not set any specific requirements for hardware and software. A user can use any operating system on PC, Mac or mobile devices such as PDAs or mobile phones. The possibility of using this technology on mobile devices allows for access to the materials at any time - even while performing the surgery.

3.5 Summary and conclusions

Described in the article examples of the Augmented Reality in health care indicate that the technology is certainly an effective tool to assist the process of education, improvement of competence, as well as the actual course of activities performed by surgeons. The main advantage of trainings based on AR technology is a feedback giving the impression of reality during training activities. It is both the feedback of a receptor nature (visual, audible, tactile) and somatic nature (pressure, forces), what positively distinguishes this technology from the related ones, such as Virtual Reality VR.

The indicated areas of AR technology application resulting from the review of literature refer to trainings taking place in a pre-arranged and formal way.

The authors propose a slightly different approach to the AR-based trainings, namely the approach based on common access to training that improves and consolidates skills needed to perform the operations, and which form a virtual and interactive extension of traditional teaching aids, such as a manual. This approach aims to spread the habit of continuous training (despite the obstacles identified in item 3), taking into account the convenient, pleasant and easy in receipt transfer of training information.

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