VIRTUAL SIMULATION AS A LEARNING METHOD IN INTERVENTIONAL RADIOLOGY

VIRTUALNA SIMULACIJA KAO MODEL UČENJA U INTERVENTNOJ RADIOLOGIJI

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INTRODUCTION

Thanks to the implementation of new technologies as well as rapid advancement of imaging diagnostic methods, radiology has made more progress than any other discipline of medicine in the last few decades.

Interventional radiology implies minimal invasive procedures aimed at making diagnosis and/or treating certain vascular or non-vascular diseases. The principle is based on percutaneous (direct through the skin) guiding of instruments through the blood vessels (vascular procedures) or other paths (non-vascular procedures), under guidance of imaging methods [1–3]. Compared to open surgical procedures, the big advantages of this procedure are smaller skin incisions, lower risk for the patient, lower complication rate, less pain, local

SUMMARY

INTRODUCTION. Radiology is the fastest growing discipline of medicine thanks to the implementation of new technologies and very rapid development of imaging diagnostic procedures in the last few decades. On the other hand, the development of imaging diagnostic procedures has put aside the traditional gaining of experience by working on real patients, and the need for other alternatives of learning interventional radiology procedures has emerged. A new method of virtual approach was added as an excellent alternative to the currently known methods of training on physical models and animals. Virtual reality represents a computer-generated reconstruction of anatomical environment with tactile interactions and it enables operators not only to learn on their own mistakes without compromising the patient's safety, but also to enhance their knowledge and experience.

DISCUSSION.

It is true that studies published so far on the validity of endovascular simulators have shown certain improvement of operator's technical skills and reduction in time needed for the procedure, but on the other hand, it is still a question whether these skills are transferable to the real patients in the angio room. Conclusion. With further improvement of technology, shortcomings of virtual approach to interventional procedures learning will be less significant and this procedure is likely to become the only method of learning in the near future.

KEY WORDS: Computer Simulation; Radiology, Interventional; Endovascular Procedures; Diagnostic Imaging; Teaching Materials

SAŽETAK

Uvod. Radiologija je medicinska disciplina koje se razvijala velikom brzinom u poslednjih nekoliko decenija zahvaljujući razvoju novih tehnologija i imidžing dijagnostičkih metoda. Razvojem novih imidžing dijagnostičkih procedura tradicionalno sticanje iskusta u invazivnom vaskularnom pristupu bolesniku u okviru interventne radiologije znatno se smanjilo. Pored rada na fizičkim modelima i životinjama, virtualni pristup učenju se nameće kao odlična alternativa učenju interventnih procedura.

Discusija. Do sada objavljene studije o validnosti simulatora endovaskularnih procedura ukazuju na znatno poboljšanje veština operatora kao i skraćenje trajanja procedure, uz još uvek upitnu realnost i prenosivost ovih veština na realne pacijente u angio sali. Zaključak. Još većim napredovanjem tehnologije nedostaci virtualnog načina učenja interventnih procedura biće sve manji i moguće je da će u bliskoj budućnosti postati jedini način učenja interventnih procedura.

Ključne reči: Kompjuterska simulacija; Interventna radiologija; Endovaskularne procedure; Dijagnostički imidžing; Način učenja interventnih procedura

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anesthesia, shorter hospital stay as well as lower treatment costs [4–9]. Not only must an interventional radiologist possess vast clinical and diagnostic knowledge but he must also master practical medical skills which include the application of interventional material (instruments) on the patients in the angio room in the real time [4]. Traditionally, these interventional skills are developed by working on patients under supervision of an experienced doctor [4,6]. However, the problem is that this “one to one” learning method is not a daily routine in many hospitals any more [4,10]. Rapid development of non-invasive medical imaging methods has considerably reduced invasive diagnostics work, mostly in the field of digital subtraction angiography. Therefore, an interventional radiologist has less opportunity to work with real patients. What makes the whole situation even worse is the fact that teaching residents and young radiologists is time-consuming for the “mentor” doctors and that leads to the increase in patient care costs. Regulations on daily maximal allowed work for doctors (at least in European Union) also narrow the possibility of training. The fact that gaining experience through making own mistakes is a very important and inseparable part of training makes it easy to see that it is necessary to introduce a different approach in training young interventional radiologists [4,9,11–13]. The need for other alternative methods for interventional radiology training, which emerged in the mid ’90s, resulted in the application of physical models, animals and virtual approach as teaching methods [10]. So far, each of these approaches has shown its limitations in certain aspects.

Simple physical models, which are likely to get deformed, could be punctured with needles under ultrasound guidance or could be used for wires and catheter insertion. These models have the authentic human anatomy, and they do the following under fluoroscopic guidance: they use special blood circulation pumps, mimic blood flow and allow contrast agent application. It is true that these models are anatomically correct, but on the other hand, they are expensive and can be damaged after repeated needle punctures. In addition, it is difficult to reproduce a pathological condition, that being a limiting factor for a great number of situations young radiologists can find themselves in and so miss the opportunity to learn some skills from them [11].

Training on animals provides real physiology and “touch” but; however, their anatomy is different from human anatomy for one thing, and for another, pathological conditions are difficult to be reproduced. In addition, animals are expensive to take care of and they raise many other ethical issues, especially in the western countries [11,14].

The third option of endovascular procedures training is virtual reality. Virtual reality refers to computer generated presentation of real anatomical environment with or without feedback information and tactile interaction [7,14]. A medical simulator is defined as a device that tries to present multiple problems in medicine authentically [15]. A simulator giving feedback information achieves a higher degree of reality. The trainees are expected to react to simulated problems as if they were in the real angio room. Most simulators have similar characteristics of technology – signals and consequences are very close to reality, capability of simulating complex situations, changing the format for individual or interactive work, limitations in technology (e.g. inability of simulators to learn), and high expenses [15]. Simulation provides dynamic and efficient supplement to medical education in a safe environment with no risks for the patient [9]. It gives an operator a possibility to promote individual work, makes training easier, memorizes case details for objective evaluation, and allows mistakes with no consequences [16]. At the same time, this way of learning raises no ethical questions and reduces the cost of education. Virtual simulators have recently experienced a great transformation, developing from an idea to a practical approach, mostly thanks to the progress of technology that has made all these things possible.

In medicine there are laparoscopic simulators, endotracheal intubation simulators, colonoscopy simulators and simulators for endovascular interventions [4,8].

The aim of endovascular simulators is to improve psychomotor skills of the trainees by constant repetition of the procedure, i.e. maneuvering [6]. They also bridge the gap between knowledge and experience. It is now believed that if this learning tool is used more frequently, the patients will trust their doctors more. Virtual simulation can be used to test new instruments about to be launched in market. In addition, there is a possibility of connecting the simulator devices with internet for remote observation, teleconference or training [17]. A virtual reality simulator for interventional radiology represents an integrated software and hardware of endovascular simulation [15]. It consists of a haptic device, computer processor with simulation software, two screens with two-dimensional (2D) and three-dimensional (3D) display [9,13,14,17] (Figure 1 and 2). A haptic device is designed to be a virtual patient with simulated approach through the common femoral artery. There is a primary (one femoral artery approach) and secondary (left and right common femoral artery approach) haptic device. Besides the common artery approach, there are separated controls for stent positioning, balloon dilation, contrast agent injection [9,13–16]. Some simulators are equipped with a device for practicing puncture. A haptic device allows the user to make the catheter and wire move forward during manipulation, rotate within a virtual blood vessel, while displaying these functions.
on the screen at the same, ‘real’ time [17]. The user is thus enabled to gain manual skills. The device also provides the user with tactile information during catheterization. Information such as angulation, friction, progress of catheter is included in the algorithm that gives feedback information [5]. A screen with 2D display resembles the one used in clinical fluoroscopy. The trainee has the possibility to adjust the fluoroscopic picture, which means that there is a possibility for zooming, collimation, rotation. This can be done by pressing the pedal on the floor as in the angio room [17]. A 3D screen with display allows the users to see blood vessels in different positions and with different angulations in all three projections, and thus enables them to understand better geometric relations during catheter and wire movement within blood vessels [17] (Figure 3). The software library is connected to the haptic device with a program, and it stores different clinical cases of vascular pathology [8,17]. Simulation software uses the reconstruction of real contrast-enhanced CT scans of real patients [4,7,9]. There are modules for diagnosing and treating almost all arteries in the body, including the carotid, coronary, renal, iliac and femoral ones [7,9,17]. The module library is constantly updated with new cases, procedures and devices [13,14]. It allows the user to practice interventional radiology on a great variety of practically unlimited clinical cases. The use of these data through CT scans enables the user to deal with the "real" case before dealing with the real case on the patient [9]. All complicated parts of procedure could be repeated many times, which minimizes the possibility of making real mistakes [11].

Simulators of endovascular procedures are based on the principle of Seldinger technique. It implies the percutaneous approach, i.e. the application of hollow needle through the skin into the blood vessel and through which it is possible to place the instruments such as wires, catheters, stents, etc. This technique presents the beginning of all vascular and most of non-vascular procedures in interventional radiology [4,8]. A simulator with possibilities of practicing femoral artery puncture is made of two workstations. At the first station resembling a true femoral region, the trainees can feel the pulse, locate the femoral artery, and make the puncture with a haptic device pen that actually represents the puncture needle. Virtual surrounding is shown on the semitransparent mirror. The operator can manipulate the needle in terms of orientation, rotation, depth. This allows the safe catheterization after the proper puncture. After the puncture, light red blood appears in the middle of the virtual needle. If light red blood appears for only a short time it means that the needle is not completely in the vessel, and the appearance of dark blood means that the needle is in the vein. If an operator cannot puncture the artery in the third attempt, there is an option of ultrasound-guided needle puncture [4]. The purpose of this practice is to prevent the complications such as the perforation of punctured blood vessels. The other work-
station consists of the haptic device that already has a needle inserted through the skin of a virtual patient, and the operator must place the wire and catheter [4,7,8]. This workstation is used to practice the next steps of Seldinger technique. It implies a careful introduction of a guide wire by tactile sensation. When the guide wire is adequately placed, the needle is removed leaving the guide wire to serve as a canal for the catheter. Once the wire-catheter is safely implanted, the manipulation by an operator can be continued. All manipulations are transferred to the simulator cord that represents the position of all virtual instruments within blood vessels in the real-time. Fluoroscopy ensures virtual visual sensation. The majority of endovascular simulators have only one station. With these simulators, the screen is guided through the system of menus that allow the user to choose module, diagnostic catheter, wire, stent or balloon catheter. Simulation starts with choosing the module that can be basic or advanced one depending on the difficulty of clinical case. After the program started, the patient's anamnestic data appear first, including the risk factors. Depending on the type of diagnostics, the operator chooses from the tools on the left side of the screen. The tool menu represents the type and size of the catheters, stents, balloons, etc. A fluoroscopic signal is shown then on the right side of the screen together with the virtual tool that has been chosen [9]. The operator inserts the guide wire first and then the catheter. Real time wire monitoring is possible on both screens (2D and 3D) at the same time. As in the real angio room, the fluoroscopic monitoring is obtained by pressing the pedal on the floor while the operator is operating the instruments. The fluoroscopic monitoring represents any movement in blood vessels in the real time [4,7,17]. If the simulated case implies the presence of arterial calcifications or stenosis, the device produces tactile sensation of friction [4]. During catheterization, the screen displays the chosen instruments, the amount of contrast agent used, duration of procedure, time and radiation dose. These data are later used for the assessment of operators’ performance.

Since this program has been created to simulate possible real situations, complications often appear during the procedure. These complications include changes in electrocardiogram (ECG), pulse, respiration rate, oxygen saturation. All of these changes are shown on the left side of the screen. The complications are treated with drugs that can be chosen on the screen. The drugs offered are antihypertensives, anticoagulants or thrombolytics. ECG signals are connected with oxygen supply, which means that every action leading to lack of oxygen will create irregular ECG signal that demands a prompt therapy [13, 14]. In case of the appearance of complications, multiple cognitive decisions must be made, thus enabling the operators to apply and test their knowledge during the procedure. In addition, when the users are exposed to these long and complicated procedures, they can develop their mental capability and skills to deal with risk cases in reality [13].

Simulation program gives an operator the possibility to repeat certain manipulations in order to develop and maintain manual skills [4]. The number of repetitions needed to achieve the skill depends on individual capabilities of the trainees as well as the simulator training program [7]. Since there is no risk of cumulative radiation dose, the operators can practice patiently on a simulator with no risk either for themselves or for the environment [9,14]. Most of the programs have the possibility of the objective post-procedural check up, thus enabling the operators to practice on their own mistakes without compromising the patient, and to improve their knowledge [9,17]. Most of the simulators offer individual training, mentor training with “one to one” discussion, small groups (allows detailed examination and learning from each other), team work, specific training skills, pre- and postoperative training (preparation of an operator for the consultation with patients or preparation for potential stressful situations) [16].

Besides multiple advantages of training, some shortcomings have also been noticed such as mechanical failures and problems of the software that needs to be restarted [10]. As one of the greatest problems, and certainly the main reason that none of the Medical Faculties in Serbia own this device, is the high retail price and high maintenance cost. The most critical questions when designing a simulator are precision and efficacy. The simulator has to generate visual and tactile sensations close to real ones, versus the deformation that is to be shown in the real time on a graphic display. For the training itself, the feedback information is more important than a deformation. However, a virtual deformation could lead to incorrect learning [14]. The whole system of simulation uses blood vessels hierarchy, and accordingly, generates a geometric model of blood vessels. Physical modeling represents the base for the model interaction between catheter, wires and other interventional materials. These physical models can foresee the reaction of the catheter, wire, etc. [17]. Even though a virtual artery is constructed on an anatomical model described in medical literature and based on principles of physics of physiological and pathological conditions of blood vessels, it cannot be presumed whether the skills acquired on the simulator will be transferable to the procedures in real life [4].

Discussion

In order to assess the validity of virtual simulation as a method of training, simulators of endovascular procedures have been the subject of many studies. The study conducted by Aggarwal et al. was aimed at determining the reliability of simulator as a tool in the assessment of endovas-
cular skills and at assessing the possibility of improving the skills of an inexperienced operator by training provided on a simulator. The study included 20 vascular surgeons; eight of them had performed more than 50 procedures and 12 had performed less than 10 endovascular procedures. Since the aim of the study was not to test knowledge but endovascular procedures, all operators performed balloon angioplasty and implanted stents into renal arteries. The operators with experience had to repeat this procedure twice and those with no experience had to do it six times. The following was monitored: the time of procedure, amount of contrast agent and radiation dose and the 6-week training followed. In the beginning, the surgeons with more experience were much faster and used less contrast agent during the procedures. During the six-week period the group of inexperienced surgeons significantly reduced the time of procedure and amount of contrast, while neither of the groups improved the time of fluoroscopy [9]. The aim of Neequaye et al. was to find out how the skills were acquired. Their study included 20 trainees with no experience. The first group was made of 10 trainees who had performed iliac angioplasty at some time in the past and renal angioplasty twice. The other group consisted of 10 trainees and each trainee had performed renal angioplasty twice and iliac angioplasty eight times and iliac angioplasty twice. The following was monitored: fluoroscopy time, amount of contrast agent, and the effect of stenting. An instructor offered his passive help to the operators during catheterization, who were tested for their skills not the cognitive capabilities. The operators were also given a guidebook with step-by-step explanation of the intervention. After eight weeks, the first group showed significantly improvement in stenting effect as well as the amount of contrast used, while the other group showed a significant improvement in time of fluoroscopy. The other group also showed a significant better skills in accomplishing the task assigned to the first group (iliac angioplasty) than the first group did with the task assigned to the second group (renal angioplasty). This result is explained by the fact that operators go through iliac vessels during the procedure [7].

The examples of these studies show that operators can acquire psychomotor skills through repetition by virtual simulation, and that by practicing skills in one anatomic region they can improve the skills common for the endovascular procedures in other vascular region [7]. However, some issues still remain to be discussed: How much is the reality accomplished? Can the skills acquired in this way be applied to real patients?

**Conclusion**

Virtual approach in learning endovascular interventional radiology procedures is a good alternative to the current ones. Further development of technology should diminish its shortcomings, such as a high retail price and it might become the only training tool for learning interventional radiology in the near future.

**References**
