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A Hepatic Cells Simulation for Medical Education in World Wide Web

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Abstract: - The enormous expansion of the World Wide Web and the recent advances in computer sciences have radically changed the traditional educational methods. In such a network-centric mode of education the presence of teachers and students in the same place or even at the same time is no longer prerequisite. These developments have also affected the education and training of medical students. Moreover, the combination of virtual reality with Internet technologies has enabled the development of advanced web-based medical simulations that can help students acquire the required experience and skills in a safe, realistic environment. This paper aims to survey the last advances on medical simulations on World Wide Web, as well as to demonstrate a new Web-based medical simulation called “Hepatic Cells Simulation”, which has been developed for being used as an educational tool for medical students and doctors. The simulation represents in 3D space the cellular structure of liver, as well as the deformation of hepatic cells resulting in the flow of bile in the blood (a pathological condition which is called Jaundice). This innovative application permits the active participation of students in the educational procedure enabling medical students not only to study the cellular structure of liver but also to interact with the simulation by changing the pressure applied on hepatic cells and performing actions that are not possible in real life.

Key-Words: - Simulation, Medicine, Virtual Reality, Web, Education, Modeling

1 Introduction

The training of new doctors traditionally involves observation, practicing on animals or cadavers as well as practicing on real patients. The recent advances on computer technologies as well as those on virtual reality technologies enable the development of advanced medical simulators.

The use of medical simulations permits practice without danger to patient and without limits on the number of times that each student can practice. Furthermore, medical simulations provide a training environment for the study and practice on a variety of pathologies even on rare or unusual cases without waiting for a patient with a specific disease. Another advantage of medical simulators is that they enable actions that are not possible in real life (e.g. navigation through the anatomy or use of unreal tools etc). Finally, simulators consist also an effective tool for the evaluation of students’ performance.

Therefore, medical simulators are considered nowadays as an integral part of the education and training of medical students. Especially in the training of new surgeons, a large number of simulators are used as valuable educational tools. The existing simulators can be broadly classified in three categories [1]. The first category includes needle-based simulations. These simulations concern the manipulation of small medical instruments such as needles, guide-wires and catheters (e.g. the Immersion CathSim Vascular Access Simulator [2]). Minimally Invasive Surgeries (MIS) is another category of medical simulations. Generally, MIS involves the insertion of instruments into the human body from small incisions. Simulations of laparoscopic and endoscopic operations belong mainly to this category (e.g. the LASSO project [3]). The final category comprises of open surgery simulations [4][5], where large incisions in the human body are required.

However, the majority of medical simulations used for the training of new doctors require dedicated, powerful and sometimes expensive graphical workstations [6]. The advent of the World Wide Web and its broad use open new possibilities to the training of doctors. The main advantages of training via web are low cost (on the value of a PC) and free accessibility, which enables the dissemination of knowledge. Especially, the combination of virtual reality with Internet technologies offers to new doctors and students a new environment in which they can safely practice many times, using their own PCs, on specific procedures before performing them on real patients.

This paper aims to present a survey on the last advances on medical simulations on World Wide Web as well as to present a new Web-based medical simulation called "Hepatic Cells Simulation", which has been developed for being used as an educational tool for the training of students at medical school. More specifically, in Section 2, some of the last advances on Web-based medical simulations are described, while in Section 3 the Hepatic Cells Simulation is presented. Finally, Section 4 outlines the conclusions of this study.

2 Web-based Medical Simulations

The last decade there is a growing interest in using the web as a new platform for educational simulations [7]. As Federico noted "*we are in the midst of a paradigm shift in education and training from classroom centric to network centric*" [8]. This means that students are able to participate in the educational process from any place (even from their home) having as much time as they really need to study the educational material and thus to adapt the educational process to their personal needs. Medicine has also been affected by this trend. The use of VRML in conjunction with Java programming language permits the development of interactive medical simulations, which can be distributed via web to all internet users with only requirement the existence of a conventional PC.

As Brodlie et al [6] refer, the use of medical simulations via World Wide Web provides significant advantages. First of all, Web provides free accessibility and enables simulations to run from any place in the world. Furthermore, the applications require only a simple VRML browser without any other special software. In addition, in case of powerful computations, users can share the power of a remote server while a large number of users can use the simulator at the same time. Finally, a family of applications with a consistent methodology can be used for different surgical procedures.

Nevertheless, there is a question whether the development of web-based simulations with sufficient realism and speed to enable real time interactions is possible. Within WebSET (Web-based Standard Educational Tools) project [9], medical simulations were developed for neurosurgery, lumbar puncture and laparoscopy procedures showing that World Wide Web can provide an effective virtual environment within which training can be enhanced by 3D simulation and interaction [10]. Specifically, a neurosurgery procedure developed within WebSET project concerned the simulation of ventricular catheterization, where students acquire an appreciation of the ventricular system in the brain and learn how to cannulate it in an emergency. On the other hand, the lumbar puncture simulation involved the insertion of a needle between vertebrae in the lower back directly into the spinal cord to take a sample of spinal fluid for various tests. In the laparoscopic operation a verres needle inserts into the abdominal cavity to inflate the cavity by pumping carbon dioxide into it.

Another application of web-based medical simulation is the one used by the Department of Neurosurgery in the Leeds General Infirmary to train surgeons in the treatment of trigeminal neuralgia [11]. A well-recognized treatment for trigeminal neuralgia is percutaneous rhizotomy procedure. This procedure involves the insertion of a needle into the patient's face and guiding it towards the foramen ovale, which is punctured to allow access to the nerve causing the pain. The simulation provides an alternative exercise for trainees in which they practice before performing the operation on real patients.

In the next section we present a novel web-based medical simulation, which is called Hepatic Cells Simulation and aims to simulate a pathological condition, which leads to a disease that is called Jaundice.

3 The Hepatic Cells Simulation

The bile in the human liver flows within long tube-like structures that are called bile ducts. Blockage of bile ducts due to pathological reasons (e.g. cancer) prevents bile from being transported to the intestine and bile accumulates in blood. In such a condition, which is called Jaundice, human skin and eyes become yellow from the accumulated bile in blood. In this section we demonstrate the simulation application for this pathological condition, which we have developed for being used as a Web-based educational tool for the training of students at medical school.

The simulation represents in 3D space a portion of the cellular structure of liver, as well as the deformation of hepatic cells resulting in the flow of bile in the blood. Cells are represented as surfaces in order to decrease the computational requirements. The deformation of hepatic cells is caused due to the increasing pressure applied on their walls. It is the first time that such a pathological condition is simulated, enabling so medical students not only to study the cellular structure of liver but also to interact with the simulation by changing the pressure applied on hepatic cells and performing actions that are not possible in real life.

3.1 The 3D Model

The 3D model was initially developed in 3D Studio Max and then exported in VRML, where further adjustments and modifications were carried out. The modeling of all cells was performed under the guidance and supervision of expert doctors. Hepatic cells were modeled as cubic structures with a cavity along their four successive faces. Joining hepatic cells to form blocks (like walls) these cavities on their surface create long tube structures that are called bile ducts. Within these ducts, human bile flows i.e. the bile flows around each hepatic cell. In our simulation the bile is modeled as a yellow cylindrical-like structure.

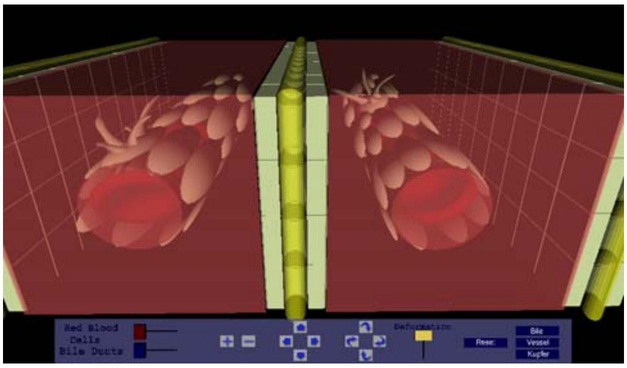

Fig.1. Hepatic Cells Simulation

The simulation aims to present just a characteristic portion of the cellular structure of the liver and therefore three blocks of hepatic cells have been modeled as it is shown in Figure 1. Among these blocks there are two blood vessels. The cellular structure of these blood vessels is presented as well in this simulation. Blood vessels consist of ellipsoid cells of various sizes and some special cells, which are called Kupfer cells.

Kupfer cell is one of the most important types of cells since it is highly phagocytic. Kupfer cells perform a number of functions. However, the most important is their ability to endocytose and remove from the blood potentially harmful materials and particulate matter such as bacterial endotoxins, micro-organisms, immune-complexes and tumour cells. Their modeling requires smooth curvatures due to their complex structure and thus a large number of polygons is needed. In web-based applications, memory requirements and fast access via web should be seriously considered. Therefore, a compromise between realism and speed is required. To keep the number of polygons low in order to increase the speed of the simulation only two Kupfer cells (one in each vessel) were indicatively modeled (in fact there are many Kupfer cells in each vessel).

The blood flows within the blood vessels and it is a mixture of red blood cells and plasma. A number of red blood cells were modeled as discs with their centers pushed inwards. Figure 2 shows red blood cells moving through blood vessels.

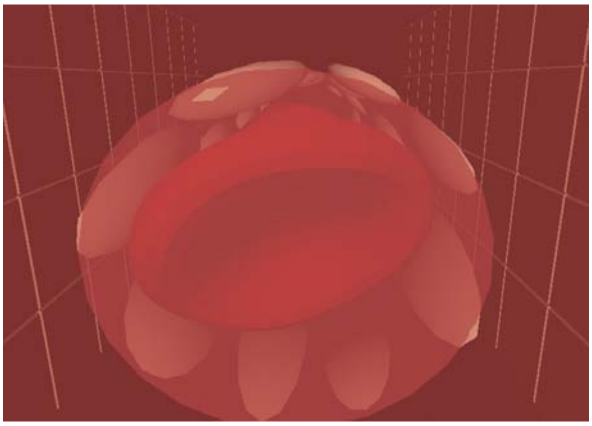

Fig.2 Red blood cells moving through blood vessels

3.2 User Interaction

The simulation supports multiple functions in order to enable medical students to explore the 3D model. Since some medical students are not familiar with VRML browsers and 3D technologies in general, the simulator provides a user-friendly navigation system. Working on this direction, we aim to address a general problem of 3D environments, which is the fact that many non-familiar users are not able to manipulate 3D environments and as a result they stop using them. The navigation system of the simulator enables the viewer to zoom in or out as well as to move in any direction he wishes (up, down, left, right). Moreover, it enables the rotation of the model around any arbitrary axis enabling thus the viewer to examine the model from different views. In order to facilitate the navigation, the simulator provides special options with which the user can be directly moved to specific positions in the 3D virtual world in order to study the model from close. Specifically, the simulator enables close views of bile ducts, red blood cells and Kupfer cells, as well as it enables direct return to the initial position.

Another advantage of the simulation is that it enables actions that are not possible in real life. These actions concern the adjustment of objects' transparency. The simulator is equipped with two special components, which enable the user to:

- *change the transparency of hepatic cells*: This action enables the study of the bile ducts' network.
- *change the transparency of blood vessels' cells*: This action enables the user to study how red blood cells move through blood vessels.

Finally the most important part of this application is the simulation of the deformation of hepatic cells. The deformation of hepatic cells is caused due to the increased pressure of bile on the cells' walls. The medical student can use a special controller to increase the pressure and consequently increase the degree of deformation of cells. As the cells are being deformed the bile flows in the blood. This condition is simulated by changing gradually the color of blood from deep red to yellow. For modeling the deformation, a Java Applet containing a new algorithm called Dynamic ChainMail [12][13], which have been developed especially for web-based simulations, was used. The algorithm enables fast and realistic deformations of surfaces using simple geometrical calculations. For the simulation presented in this paper the deformation of only a part of hepatic cells was required. When deformation has finished the blood has a yellow color, which means that the patient suffers from Jaundice. Hence, the progress of the pathological condition in the simulation is determined by the student themselves. This is especially important as students are not any more simple passive observers of the educational process but they actively participate acquiring knowledge through the interaction with the virtual model.

4 Conclusion

World Wide Web enables the connection of a huge number of different networks and computers around the world and so the distribution of information. This significant feature of Web in conjunction with the high potentialities of virtual reality permit the development of various types of applications of web-based simulations. Especially in medicine, where the importance of simulations in the education of students is already known and recognized by the scientific community, web offers new opportunities.

Medical web-based simulations, in contrast with conventional simulations that run on dedicated workstations at universities or research institutes, provide free accessibility to all students and enable practicing from remote places (e.g. students can practice even from their home). Students can safely and repeatedly practice in a virtual environment on specific procedures, using just a conventional PC, before applying them to real patients.

The hepatic cells simulation presented in this paper was developed to be used as an educational tool for the training of students, while it adopts all the above advantages of web-based medical simulations. The simulation supports multiple functions in order to enable medical students to explore the 3D model and perceive better the cellular structure of human liver. Students can navigate among cells or even change the transparency of specific objects (i.e. cells) to study interior parts. However, the main advantage of the simulation is that it enables real-time interaction with the user. Students are not any more simple observers but they acquire an active role within the educational process modifying the 3D model (i.e. causing the gradual deformation of a hepatic cell) and determining, in fact, the next step of the pathological condition. Furthermore, students can repeat the simulation as many times as needed to study the progress of the pathological condition, adapting so the educational process to their personal needs.

This active participation of students in combination with the advantages provided by Web applications provides a new base for the educational process. Future advances on computer and communication technologies are expected to allow the development of more complex medical simulations that will combine real time interaction and high levels of realism.

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