A Virtual Reality Simulator for Bone Marrow Harvest for Transplant

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Abstract. *Despite the proposal of the first electronic based virtual reality in the 1960s, only recently low cost technology has been available for general and effective implementations. One of the main advantages of virtual reality is the user interaction and immersion on computer based simulations. This interaction and immersion can be very effective in some critical training missions such as surgery training. We are developing a virtual reality simulator for bone marrow harvest that integrates interactive stereo visualization and force feedback techniques. The main objective is to offer a low cost VR-based system to boost current adopted training methodologies for bone marrow transplant procedures, enhancing the real clinical procedures with direct benefits to patients. This paper discusses some medical aspects of this clinical procedure from the physician and patient point of view, describes the proposed systems and its implementation, and finally considers the impact of the use of VR-based systems on such applications.*

Keywords: *bone marrow, transplant, surgery simulation, Virtual Reality.*

1. Introduction

Bone marrow transplant, despite commonly held perceptions, is not a usual surgery. Basically, the bone marrow transplant consists of an infusion of healthy cells, capable of generating identical copies of themselves and producing blood cells. This process is completed by an intravenous reinfusion. The most complicated part of the bone marrow transplant is the process of harvesting the donor bone marrow. This invasive procedure is relatively simple, but the success of the procedure will depend on the physician's dexterity and his ability to manipulate the needle. For some procedures, like bone marrow harvest, the training is not always simple and not only requires the use of cadavers or animals, but also the supervision of a tutor on real procedures.

Virtual reality has been used with significant results in many critical mission medical applications, which demands intense decision making from physicians and mistakes are not allowed. The use of virtual reality techniques are beneficial in cases where a mistake could have a physical or emotional impact on the patient by helping to simulate procedures and surgical training. The possibility of producing a sense of touch, pressure and force for the physician is the main advantage using this technology, improving its medical performance.

In this project, we are proposing a virtual reality system for medical training in bone marrow harvest from children. This system should generate the force, pressure and touch sensation involved in the bone marrow harvest proceeding, giving to the physician the conditions to learn and improve this practice. The bone marrow harvest is a blind procedure, since physicians cannot see the internal patient anatomy. In our case we are providing a training tool which incorporate stereoscopic view of the human part of interest.

Our goal is to support the teaching and training of the operators in this modality, providing competence to novice physicians, better quality for patient’s attendance and better rehabilitation for bone marrow donors.

This project has been developed in joint cooperation with the Instituto da Criança (Children’s Institute) of Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo and counts on physicians experience and abilities to describe the bone marrow harvest procedure and test the proposed system.

2. Motivation and Related Work

Despite it seems to be a simple transplant apparently, the bone marrow transplant is a high precision invasive procedure. The Instituto da Criança realize on average 15 procedures every year. Currently the only training procedure available for novice surgeons is training with guinea pigs; real procedure observation and further supervision by trained surgeons in real procedures.

Surgical simulations for medical training using virtual reality technology are being a research topic for many medical modalities [Basdogan00]. However, we do not found in the literature references related particularly to the bone marrow transplant.

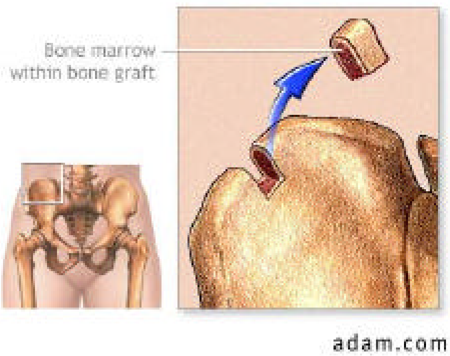
The Auckland University in New Zealand in cooperation with the MCGill University in Canada developed a simulation system for ocular surgery [Sagar94]. The system is based on finite element analysis for the modeling of the eye surface and its respective deformation of the ocular surface. The simulation is part of a robotic system for ocular microsurgery and the surgeon can control the robotic system in the same manner as a conventional surgery but with a higher precision. The Georgia Institute of Technology and the Medical College of Georgia developed a visual and tactile force feedback system for eye surgery simulation [Peifer99]. In this system, the Virtual Reality environment represents the eye and all surgical instruments, and the eye is deformed according the manipulation of the virtual instruments.

Another interesting virtual medical simulator that takes advantage from the tactile force-feedback is the prostate cancer diagnosis virtual simulator developed by the University of New Jersey [Burdea99]. This diagnosis is made by rectal palpation without visual feedback. To implement this system a ring with tactile feedback was developed to provide the touching feeling of the prostate surface. The system simulates different diagnosis situations, and it's capable of measuring totals exam time and hit rate of successful diagnosis.

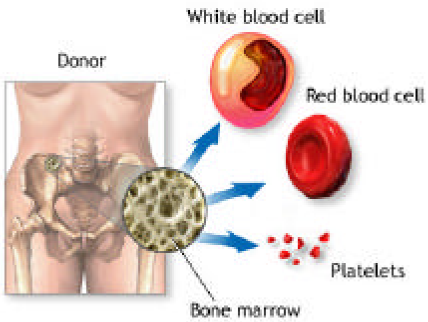
3. Bone Marrow Transplant

The bone marrow is a soft fatty tissue that is found inside bones that produces blood cells. The bone marrow from chest, skull, hip, ribs and spine, contain cells that can generate all family of blood cells of the human body. These cells [Figure 01b] includes the white cells (leukocyte) which protect the body against infections and the red cells (erythrocytes) which transport oxygen and remove the impurity from organs and tissues, and finally the platelets which act in the blood coagulation.

Some references [Roitt92] indicate that 95% of the total blood cells production into the human body is originated from the bone marrow and the rest in the liver and spleen. Some of the produced cells originated in the bone marrow are introduced directly in the blood, while some migrate to peripheral tissues to become lymphocytes. All blood cells had maturation stages and all mature blood cells are originated from key cells in the bone marrow.



a)



b)

Figure 01 – a) Bone Marrow from the Hip (Iliac Crest). b) Bone Marrow and Blood Cells (both pictures obtained from www.adam.com).

The bone marrow transplant is a relatively new medical procedure to treat recently considered incurable diseases. The first success transplant was made in 1968, and since then has been a current procedure for patients with leukemia, aplastic anemia, lymphomas, multiple myelomas, disturbs in the immunology system and in some solid tumors such as the breast cancer and ovarian cancer [Oncolink]. Bone marrow transplants prolong the life of patients who might otherwise die. As with all major organ transplants, however, it is difficult to find bone marrow donors, and the cost of the transplant is relatively high. The hospitalization period is three to six weeks. During this time, patients are isolated and under strict monitoring because of the increased risk of infection. It takes about six months to a year for the immune system to fully recover from this procedure.

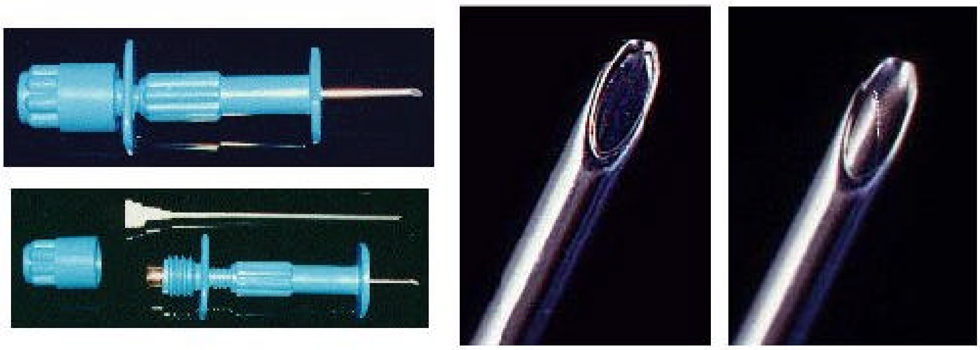


Figure 02 - The Illinois Syringe for Bone Marrow Harvest.

The process to extract he bone marrow is made through many material aspirations from the iliac crest (Figure 01a) bone marrow (sometimes it includes the sternum bone also) from the donator under general anesthesia. The extraction is made through serial aspirations from the bone marrow using a thick needle and syringe (Figure 02); the total amount of material to be collected is around 200 ml. The bone marrow is filtered, treated, and transplanted immediately, sometimes it's frozen and stored for later use (Figure 03). The procedure is a blind procedure without any visual feedback except the external view of the donor, the physician need to feel the skin and bone levels traspassed by the needle to the bone marrow and then start the material aspiration. The patient will receive the bone marrow on a procedure very similar to a blood transfusion.

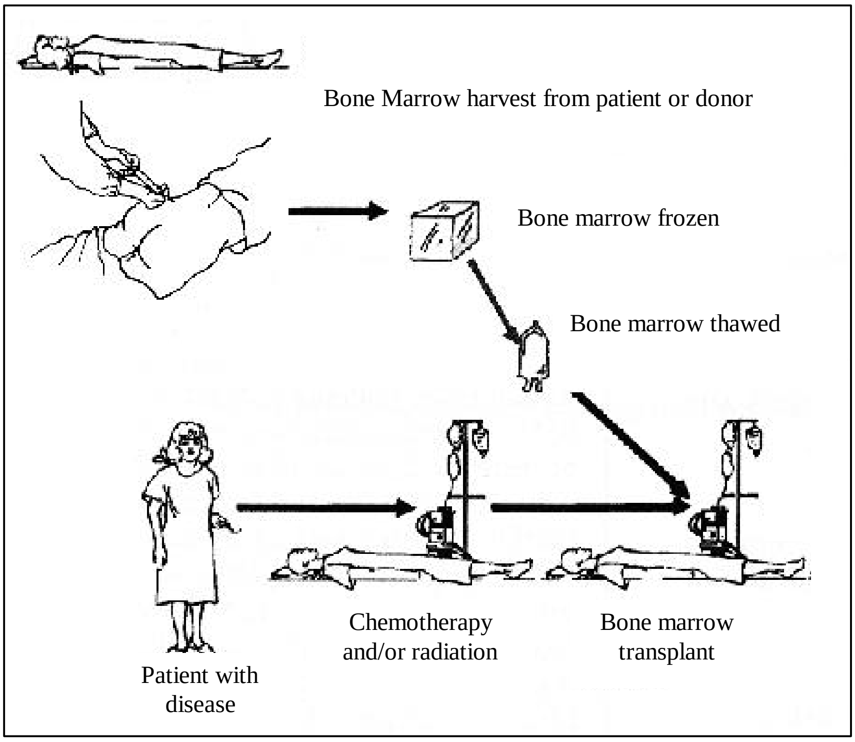


Figure 03 - Flowchart with Stages of the Bone Marrow Transplant.

The whole procedure apparently is quite simple, but from the physician point of view it demands great ability, which will offer a better recovery to the donator and less pos-harvesting pain.

4. The System Platform

The proposed system is based on a “fish tank” [Pimentel95] like semi-immersive virtual reality system where two surgeons (the tutor and the trainee) can share the same stereoscopic view of the bone marrow harvest procedure simulation. A high end PC Pentium III 600Mhz platform with and AGP 3Dlabs Oxygen GVX1 board including a time-multiplexed Stereo Graphics Crystal Eyes shutter glasses [Stereo97] and a Phantom Desktop haptic device composes our simulator [Sensable00]. Figure 04 shows the current available platform to the tests.

The haptic senses motion in 6 degrees of freedom providing realistic sense of touch. The trainee can feel the point of the virtual needle in all axes, and track its orientation (pitch, roll and yaw) like when manipulating a real needle. This device is attached to the PC parallel port.

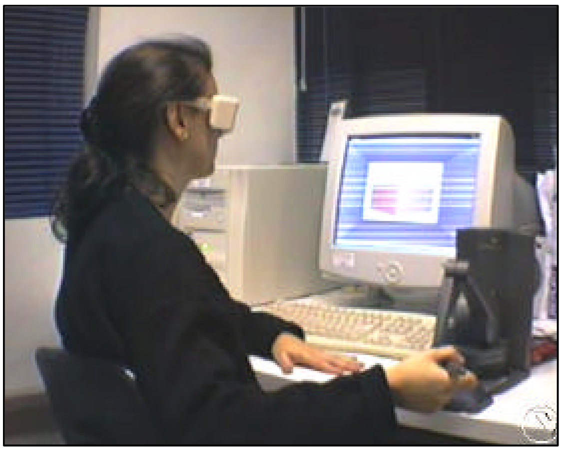


Figure 04 - System Platform

The system runs on a Windows NT workstation and was developed on C++, OpenGL and the Ghost API [Sensable00, Sensable99].

5. The Simulator

The simulator consists in a force feedback virtual interactive model of tissue layers from the pelvis region and its hardness and texture characteristics. Figure 05 describes these tissue layers.

The simulator objective is the training of novice physicians in the process of harvesting the bone marrow. Using a virtual syringe with a tactile feedback (simulated in the Phantom Desktop) the physician can penetrate thought the several tissue layers feeling the transitions among tissues, as well as feeling the texture associated to each layer.

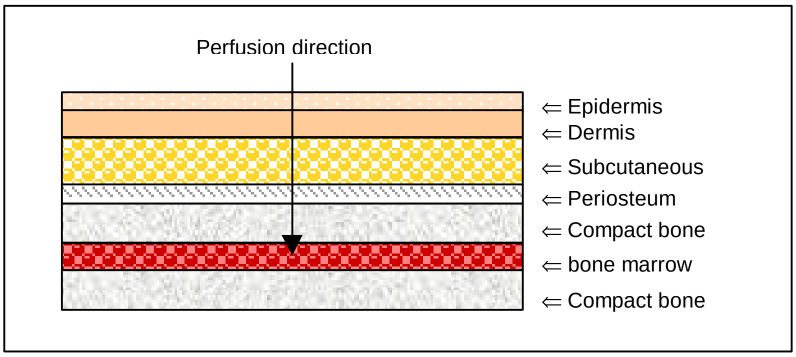


Figure 05 - The Perfusion Tissue Layers

Based on a subjective approach and based on the sensitive feelings from specialists we modeled the several physical properties of the tissues in the iliac crest in the following layers:

- Epidermis: approximately 2mm thick, elastic and slippery tissue;
- Dermis: approximately 7mm thick, elastic tissue;
- Subcutaneous: approximately 4mm thick, soft and non-resistant tissue;
- Periosteum: approximately 2mm thick, resistant, slippery, lubricated and smooth tissue.
- Compact bone: approximately 5mm thick, hard and resistant tissue;
- Bone marrow: approximately 10mm thick, soft tissue, without resistance.

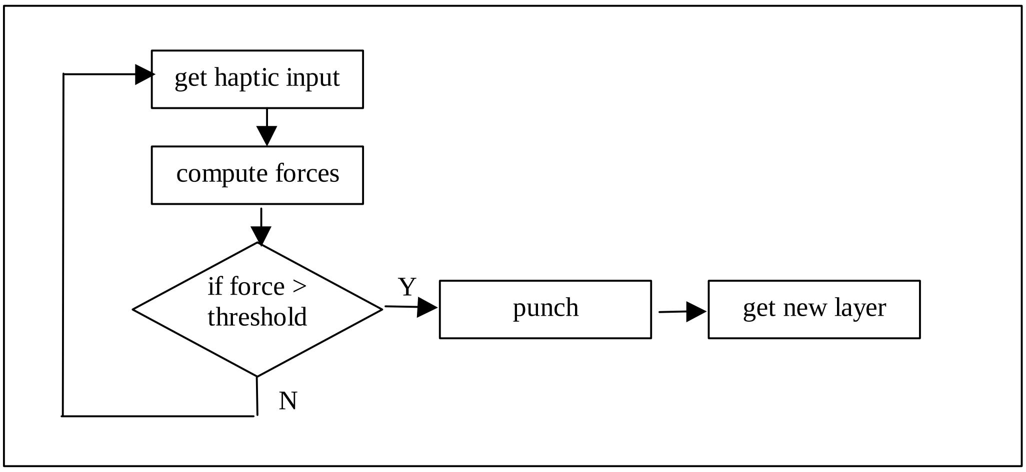


Figure 06 - State Machine for Haptic Loop

Figure 06 shows the state machine flow chart of the implemented haptic loop. Basically we implemented a loop, which tests the perfusion force for each tissue layer. The properties of each layer were applied subjectively according Figure 05.

6. Conclusion and Future Work

In this paper we proposed and implemented a basic simulator for bone marrow harvest for transplant. This simulator was implemented using the Phantom Desktop force-feedback haptic system and the Ghost API. Using the features offered by the Phantom

Desktop we modeled subjectively the tissue layers (crossed during the perfusion process) to achieve the bone marrow. Preliminary evaluation of the simulator by a physician indicates that the system has a potential use for the training of such procedures.

Further research directions are related to a better objective modeling of the tissue layers. We are also doing the modeling of the 3D anatomy of this body region of interest, in order to offer a better simulation environment to the physicians. In this case we will offer two kinds of simulations blind oriented and blindness oriented. In the blindness oriented simulations novice physician will be able to be visually assisted by a stereoscopic view of the anatomy having a better special understanding of the whole procedure. Further evaluations would be possible using the blind procedure that is closer to real procedures.

Another future research direction is related with the modeling of the 3D signature of this procedure and the level of deep perfusion of the needle in order to measure objectively the quality of the procedure. In this case we would like to store, recognize and measure the spatial procedure signature in order to compare and evaluate it with “good” procedures.

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