Chapter 11

The Virtual Reality Technique in Simulation Surgery - A Mandibular Fracture Model

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We describe in this chapter a surgical simulation system based on the virtual reality (VR) technique for fractures of the mandible. The equipment used consisted of a Silicon Graphics IRIS-4D/VGXT workstation with a 60-inch rear projection screen viewed through liquid crystal shutter glasses, a pair of data gloves and a 3 dimensional Polhemus sensor. The skull data consisted of 2,800 polygons, and the data for the face consisted of 1,640 polygons. The data were displayed by Gouroud shading. Additional data to check interference and the data for texture mapping were prepared. The operator was guided by a sound navigation system and could rotate, move and reposition the bone fragments by the action of the data gloves under 3 dimensional visualization.

Two surgical simulation methods have been reported, namely, computer graphic images and 3 dimensional models. The computer graphic images have the advantage of offering repeatability, while 3 dimensional models offer tactile operation and true 3 dimensional information.

Simulation surgery utilizing the techniques of virtual reality combines the advantages of both methods. The sense of depth is truly 3 dimensional, and unlimited trial-and-error is possible. Some problems still exist such as the speed limitations of processing data, the screen resolution, the accuracy and degree of sensitivity of the data gloves, accurate representation of changes in soft tissue, and so on. It is hoped that these will be eliminated with the development of computer technology.

11.1: Introduction

Computer aided surgery has become popular in many clinical fields in recent years. The authors put simulation surgery into practice in the field of plastic and reconstructive surgery using a surgical planning system based on 3 dimensional computed tomography (3DCT) data, using the techniques of computer graphics and laser lithography models. Simulation surgery has proved useful in many aspects of plastic and reconstructive surgery including preoperative diagnosis, determination of the surgical procedure, postoperative evaluation and prognosis, medical education of the medical students and doctors, and in the process of obtaining informed consent from the patients and their families. The present study reports on the clinical application of a "virtual surgery" system, using so called virtual reality technique, in repair of a fracture of the mandible. Although the system is now only in the prototype stage, the authors confidently believe that this system represents a meaningful step forward in the future of clinical and surgical management, with benefits to both clinician, students and patient.

11.2: Materials and Methods

11.2.1: Apparatus

The apparatus consists of (Figures 1, 2): a workstation, (Silicon Graphics IRIS-4D/VGXT CPU/FPU R3000A/R3010A, 32 Mb RAM, 1 Gb hard disk drive, Silicon Graphics, Inc, Mountain View, California, USA); a 60-inch rear projection screen (Victor, Tokyo, Japan); liquid crystal shut-
11.2.2: 3D Data of Skull and Face

The 3D data used are a ready-made set of data of a skull and face in the CuBISM format (skull-5,572 polygons and face-1,640 polygons, Viewpoint Data Labs, Orem, USA). The data are not CT data, but data obtained by tracing a dry skull using a 3D digitizer. The skull data were reduced to 2,800 polygons and converted to the original format of Solidray (Solidray, Yokohama, Japan). Two fracture lines were created in the mandible, thereby giving fracture fragments. The data were displayed by Gouroud shading, using the Silicon Graphic's Graphic Library. A set of interference data was prepared with a limited capacity of about 300 polygons, to check only on the correct interface of the two segments. Two types of facial display, male
and female, were prepared for the texture mapping from photographs of models and modified using Adobe Photoshop (Adobe Systems, Mountain View, USA) on a Macintosh computer. These modified data were patched on the 3D facial data by CuBISM software (Pixy and N. K. Exa, Tokyo, Japan) under the consideration whereby elements of the texture data corresponded to the landmark points of the facial data.

11.2.3: Operative Procedure

The object of this simulation system is a case of fracture of the mandible (Figures 3, 4). The system was developed for the use of medical practitioners and medical students, in addition to applications involving education of the general public. The operator is guided through a procedure by a sound feedback system. At the beginning of the simulation, the video display shows a start-up image. The operator puts on the liquid crystal shutter glasses, the left-and right-hand data gloves, and sits on the chair in front of the screen. The simulation is started when the operator touches the 'start' button on the screen using the right-hand data glove. The screen displays 3D images of both a male and a female. After selection of either the male or female 'patient' image, the screen displays the surgical field. Anterior and posterior motion of the skull and face (with exception of the fracture fragment) is controlled by the left data glove, as well as clockwise and counterclockwise rotation. The right data glove is used for grasping and moving the fracture segment. By bending the fingers of the data glove, the fragment is grasped; while maintaining the 'grip' of the fragment, the operator can move and rotate the fragment around by corresponding motion of the
right-hand glove. When the fragment touches the mandible, a sound is generated: This sound is used as a substitute for tactile feedback which is not available in the current system. After repositioning the fragment, two-plate fixation is required to complete the procedure.

11.2.4: Evaluation Function
The system evaluates the results of the operation and assigns one of 4 grades: A (excellent); B (good); C (fair); and D (poor). In grade A to C, the appearance of soft tissue over the area of interest and the face as a whole is simulated and displayed. To enable this, the distance for multiple points between the face surface and the nearest bone surface is calculated under normal conditions, and the calculations are repeated following repositioning of the fracture fragments. The elasticity of the soft tissue is not considered in this system yet. Differences in the calculated data result in the altered appearance of the facial tissue.

11.2.5: 3D Visualization Method
The 3D visualization system is based on the time division method using liquid crystal shutter glasses (Figure 5). The right-and left-hand pictures in the video frame buffer are compressed to half size in the vertical plane. A simultaneous pulse changer alters the frequency of the simultaneous pulses of the picture from 60Hz to 120Hz, with the result that the half-size picture appears full-sized in the vertical plane, and left and right-images are shown alternately on the screens. This results in a true full sized 3D image without flicker, but at only half the available resolution.

11.3: Results
The 3D data used in the skull and face are ready-made library data. In the very early stages of development of the virtual surgery system the authors tried using 3DCT data, but this approach was unsuccessful, due to the impossibility of achieving real time movement because of the large amount of 'data crunching' involved. The resolution obtained by the system is therefore unfortunately lower than the crisp resolution associated with 3DCT images,
which offer a resolution based on 500,000 polygons compared to the 2,800 available in the authors' system. The refresh rate of the screen is from 8 to 10 Hz at a data loading of 2,800 polygons for the skull and about 300 polygons for the interference data in this system, using the Silicon Graphics VGXT workstation. The processing time increases in proportion to the numbers of polygons. The rate of data processing is governed by the device input and output such as the data gloves - 20%; the interference check - 40%; and the time taken for drawing the skull

### 11.4: Discussion

Two surgical simulation methods based on 3DCT data have been reported, namely, computer graphic images displayed with shading on a video display and life-sized 3D detailed models produced by laser lithography or on a milling machine. The computer graphic images have the advantage of offering repeated attempts at simulation methods with instant replay, but with the inherent disadvantage of only giving a flat screen 2D screen representation of 3D data. Solid models offer real size, tactile operation and true 3D information, but can only be used once thus not allowing any trial-and-error experimentation with procedures. Simulation surgery utilizing the techniques of virtual reality combines the advantages of both methods. In our system, rather than the total immersion head mounted display containing two separate video screens, a large back-projection video image is viewed through the liquid crystal goggles. The sense of depth is truly 3 dimensional, and unlimited trial-and-error is possible. The combination of these offers a true state-of-art simulated surgical experience. This system, however, is not always realistic in this early prototype stage. The repositioning and movement of the fracture fragments are done by 'grasping' and moving them directly with the data gloves. Ideally, the operation should be simulated with surgical instruments such as bone holding forceps. As the capabilities of computers improve, these refinements will be able to be designed into the program.

As for the facial display, the elasticity of the soft tissue is not considered. The size of the display of the skull depends on the size of the screen and is thus not truly life-sized. Even with the recent rapid and continuous development of computer architecture, software and hardware, problems still exist such as the speed limitations in processing huge amounts of data, the screen resolution, the accuracy and degree of sen-
sitivity of the data gloves, accurate representation of changes in soft tissue, and so on. It is hoped that these will gradually be eliminated with the development of appropriate hard-and software.

In conclusion and despite the problems outlined above simulation surgery using virtual reality, what we call "virtual surgery", could be argued to have the following advantages:

✔ Pre-and postoperative evaluation of the condition of the patient from the true 3D aspects of the virtual reality visualization
✔ Selection of the most appropriate operative procedure and the solution of any problems arising from it using simulation surgery
✔ Improvement of the surgical result and the overall safety of the procedure
✔ Cutting down on the days required for admission and actual time for operation
✔ Reduction of the surgical fee and associate costs.

Virtual surgery offers an ideal, flexible and comprehensive educational tool for training and teaching medical students, improving the experience of young doctors, and honing the already extensive skills of the experienced surgeon. It is additionally useful for the process of educating patients and their families, illustrating the pre-, intra- and postoperative stages of a procedure and obtaining informed consent.

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