Computer-assisted planning and navigation in plastic surgery: a descriptive study in a preliminary cohort.
PURIFICACIÓN GACTO-SÁNCHEZ, TOMÁS GÓMEZ-CÍA, CRISTINA SUÁREZ-MEJÍAS, DOMINGO SICILIA-CASTRO, MANUEL PÉREZ, CARLOS PARRA, SANDRA LEAL, JOSE MARÍA DE LA HIGUERA.
Virgen del Rocío University Hospitals
Sevilla University
Avd/Manuel Siurot s/n. 41013 Sevilla
SPAIN
e-mail: purigacto@gmail.com

Abstract:- Training in surgery is often done by a learning-by-doing technique with a direct involvement in surgical intervention on cadavers, animals and, in the final stage, directly inside the operating room (OR) [1]. Traditional methods of learning have helped generations of surgeons to familiarize themselves with human anatomy. Nevertheless, even texts with the highest level of accuracy and image quality are limited by the two-dimensional nature of printed material, which cannot impart three-dimensional (3D) views. Video material is similarly limited as to deliver a 3D experience. Another restriction of most traditional methods for the study of anatomy relates to the lack of interactivity and feedback.

Although surgical planning systems have been adopted a long time ago for special purposes, most of them are intended for surgical planning and training of endoscopic and laparoscopic intervention, and are heavily based upon complex and custom tools. Different studies demonstrated that the training of potentially hazardous procedures could result in a reduction of surgical morbidity and risks [1]. In this study we present a 3D software application for virtual reality navigation in plastic surgery called VirSSPA. VirSSPA software reconstructions have been used in our centre since the year 2007 for a wide number of reconstructive procedures [2,3]. We consider it has become an extremely valuable tool for the teaching of plastic surgery to residents and interested physicians, as well as for planning complex operations.

Key-Words:- Computer assisted surgery, virtual reality systems, learning, computer simulation.

1. Introduction

Traditional methods of learning have helped generations of surgeons to familiarize themselves with surgical anatomy. Nevertheless, even texts with the highest level of accuracy and image quality are limited by the two-dimensional nature of printed material, which cannot impart three-dimensional (3D) views. Video material is similarly limited as to deliver a 3D experience. Another restriction of most traditional methods for the study of anatomy relates to the lack of interactivity and feedback. As a supplement to the knowledge gained from books and observation, cadaver dissections can play an important role in mastering anatomy. Unfortunately, however, their limited availability and high cost severely conditions this alternative in most teaching institutions. Even when cadavers are available, learning from cadaver dissection may be limited by poorly delineated anatomical structures and altered dissection planes due to chemical preservatives as well as by the relatively brief time spent in the dissection laboratories.

Although surgical planning systems have been adopted a long time ago for special purposes, most of them are intended for surgical planning and training of endoscopic and laparoscopic intervention, and are heavily based upon complex and custom tools. Different studies demonstrated that the training of potentially hazardous procedures could result in a reduction of surgical morbidity and risks [1].

The 3D complex interplay of soft tissue, vessels and bony elements makes
difficult the mastery of surgical anatomy, and conventional methods to learn this anatomy often involve a steep learning curve. Computerized models and virtual reality applications are being used to facilitate teaching in a number of other complex anatomical regions, such as the human temporal bone and pelvic floor [4-6]. In this study we present our experience with a 3D virtual reality model applied to our plastic surgery environment. VirSSPA software reconstructions have been used in our centre since the year 2007 for a wide number of reconstructive procedures [2,3]. We consider it has become an extremely valuable tool for the teaching of plastic surgery to residents and interested physicians, as well as for planning complex operations.

2. Problem Formulation

A prospective study of 160 patients undergoing preoperative imaging with computed tomography angiography (CTA) and VirSSPA 3D virtual reality model for different reconstructive and plastic surgery procedures was undertaken from December 2007 to September 2009. VirSSPA software reconstructions have been used in our centre since the year 2007 for a wide number of patients undergoing complex operations where a preoperative imaging for surgical planning was required. Patients included in the study were referred for CTA scanning at a single institution. Institutional ethics approval was obtained and all patients gave verbal and written informed consent. The radiological techniques were performed by the same radiology team.

CTA studies were obtained by means of a 16-detector-row CT scanner (General Electric LightSpeed 16, The General Electric Company, Fairfield, CT, USA). CT scans were performed using the following parameters; 0.37-s gantry rotation speed, 0.63 mm collimator width slice thickness and 1.37 helical detector pitch. X-ray tube voltage was 120 kV and tube current was 250–300 mA. All scanning took place after IV administration of 100 mL of nonionic iodinated contrast medium at a concentration of 350 mg I/mL (Omnipaque 350, GE Healthcare, Barcelona, España). The contrast material was mechanically injected (Stellant Medrad, Indianola, USA) at a rate of 4 mL/s through an 18-gauge IV catheter inserted into an antecubital vein. The scanning delay was approximately 30 seconds. Bolus tracking was done with the region of interest (ROI) on different places, depending on the area to be reconstructed. Scanning was initiated approximately 10 s after the ROI reached 100 Hounsfield units.

Sections were obtained in a single breath hold. The approximate time of acquisition was 10-12 seconds. The entire procedure took less than 10 min and was, therefore, very well tolerated by the patient. The volumetric data acquired was then used to reconstruct images with a slice width of 0.63 mm and a reconstruction interval of 0.8 mm. The resulting complete set of reconstructed images was automatically transferred to a computer workstation, which generated multiplanar reformatted images and 3D volume rendered images. Data were stored as a DICOM-compatible (Digital Imaging and Communications in Medicine) file onto a CD-ROM to be loaded into a personal computer with VirSSPA software.

The 3D reconstruction of the region of interest for further surgery is then analysed. Vessels caliber, course and anatomic relationships are evaluated. Using these 3D images, points of interest can be marked on a grid and printed on a transparent template scale (1:1) to allow their transposition onto the skin of the patient to locate precisely those points prior to surgery [3,7].

Among the VirSSPA 3D reconstructions for planning surgical procedures in our unit virtual reality models of free flaps in microvascular reconstruction have been used for the forearm and hand in patients with electrical burn injury. The 3D virtual reality application was also used in congenital craniofacial and thoracic malformations (Fig. 1), nasal septum perforations (Fig. 2), post-traumatic nasal deformities, hand surgery, preoperative simulations of cutaneous tumour excisions, vascular malformations, microsurgical breast reconstructions due to breast cancer and even to simulate experimental composite tissue transplantation models.
Figure 1. Congenital deformity of the anterior wall of the chest called Pectus excavatum, in which several ribs and the sternum grow abnormally. This produces a caved-in or sunken appearance of the chest. The defect is filled in and measured in orange in order to produce a resin template by rapid prototyping for surgical reconstruction.

Figure 2. A nasal septum perforation is a medical condition in which the nasal septum, the cartilaginous membrane dividing the nostrils, develops a hole or fissure. A perforated septum can result in breathing noises and may lead to recurrent nose bleeds. Perforation can be surgically closed. To help in this process presurgical planning is essential to evaluate the morphology and dimensions of the hole.

Another application of VirSSPA virtual reality model is accurate restoration of facial symmetry after complex facial trauma or oncologic surgery. VirSSPA presurgical planning software allows the surgeon to import two-dimensional computed tomography (CT) data and generate a precise 3D virtual representation of the skull (Fig. 3).

Figure 3. Congenital malformation of I and II branchial arches resulting in facial asymmetry. Simulated osseous and cutaneous defect reconstruction marked in blue.

The proposed surgical repair can then be performed in a virtual environment prior to the actual procedure. Stereolithographic (hard copy) models can be fabricated from the virtual model to assist with surgical planning and intraoperative repair.

The virtual data can also be imported into an intraoperative navigation system which is used to guide the movement of bone segments and application of hardware. Plastic surgeons at our hospital have applied computer-aided and image-guided technology to many areas of facial reconstruction.

3. Problem Solution
Today most surgeons review radiologic studies (such as CT and magnetic resonance, MR, imaging scans) to construct a mental 3D model before surgical intervention; we see radiology, but we treat anatomy. The Smart Operating Room is currently being developed where instead of having vital information posted at inconvenient locations around the operating room, vital signs, radiologic studies, and laboratory studies can be called into your visual field with voice commands [8]. The technology can take us even further by allowing surgical
practice on palpable 3D simulations of either standardized or patient-specific datasets [9]. For example, a surgeon preparing for soft-tissue reconstruction can perform the planning phase on a 3D image of the patient, then rehearse several different flap possibilities to establish the most favorable outcome before entering the operating room. Some simulators provide only graphic representations with no useful information about the physical properties of tissue or the true feasibility of manipulation.

Plastic surgeons at Stanford and the M. D. Anderson Cancer Center had been working with computer scientists and engineers to take specific data for skull and breast reconstruction in order to develop planning systems for reconstructive surgery that utilize tissue mechanics and medical imaging [10]. These programs may be used to plan the best osteotomy for a specific patient or to calculate the distraction axis. They can assist intraoperative navigation, including planning cutting trajectories, measuring depth and orientation at each point, and determining the position, orientation, and deformation of bones. Taking preoperative planning one step further, some groups have generated models to allow better understanding of postoperative function, such as Zhao et al.’s computer assisted craniofacial surgery planning system, which helps predict the aesthetic outcome of surgery as well as the functional improvements, such as bite force alteration [11]. These applications are particularly useful in areas where precision and alignment are critical, such as in craniofacial surgery or in preparation of a limb for prosthesis [12].

Neurosurgery was the first to use computer-aided surgery in the form of stereotactic surgery. CT scans and MR images are used to precisely locate the position of lesions during surgical planning and execution. Computer simulation has been used for visualizing and planning procedures and for rehearsing complex surgical interventions, such as frontal orbital advancement and resection of malignant liver lesions [13]. Stanford uses patient specific data to create an interactive 3D simulation for preoperative planning in craniofacial surgery. Several systems have been designed using finite element mesh to aid plastic surgeons in planning procedures because of the need to stretch and reshape the patient’s skin while minimizing distortion of the surrounding tissue. Among these systems are the computer-aided plastic surgery system and a similar system designed by Lee to generate computer-synthesized facial expressions [14]. Kawabata et al. [15] also used finite element mesh to improve tissue representation and analyze the effects of Z-plasty and facial soft-tissue movement.

Many available products operate with only graphic representation and do not utilize information about tissue properties. Computer graphic-rendering techniques are better suited to procedures involving bony versus soft-tissue manipulation. The algorithms are less complicated because the interaction between two solid structures (such as an airplane and a building or bone and bone) is mathematically simpler than illustrating an interaction between a surgical instrument and skin, which has variable mechanical properties for stretch, indentation, and shearing. As addressed earlier, the issue of fidelity to small or thin structures again arises with computer-assisted surgery. The utility of computer-assisted planning and computer-assisted surgery in daily practice depends on the fidelity of the simulator. For example, the Microscope-Assisted Guided Intervention augmented reality system is being developed to show the location of blood vessels within the brain for neurosurgery. The utility is great, but accuracy is within 1 mm, a small but significant distance in neuroanatomy. Augmented reality will also need to overcome the propensity of the eyes to adjust to visual clues from real structures, drawing the superimposed image closer. The above examples illustrate the need for communication among surgeons, engineers, and computer scientists to ensure tools are developed that address specific operating room needs.

Fast and suitable answers are required for knowledge management in sanitary organizations. Continuous learning in medical specialties allows for better capabilities to approach new situations. Educational strategies emerge as important issues among the technical tools sanitary professionals are equipped with. However,
the vast amount of scientific information available for the decision making process transforms information selection in a difficult task for medical professionals. Decision making helping systems are the easiest way to bring medical knowledge and practice together. Numerous attempts have been made in that direction but results are poor and limited. We present here the idea that is taking place in our hospital in order to develop a knowledge management system applied to surgical procedures.

Before this integral system was developed VirSSPA project began in 2005 in Virgen del Rocio University Hospitals. Its main objectives the design and implementation of a virtual reality tool for preoperative planning of surgical procedures called VirSSPA. This tool enables the user to treat radiological images in DICOM format and to generate the 3D image of the selected tissue through segmentation algorithms based in growing seeds and thresholds together with the Marching Cubes reconstruction methodology [16]. Once the 3D models have been generated by the application the user is able to plan and to proceed with the surgical operation in a virtual way.

We consider that the learning of the VirSSPA technique is not difficult, and it could be readily mastered by any motivated surgeon. However, there is a short learning curve associated with equipment set-up, software application, and interpretation of scan data. The learning curve is suitably brief and it takes approximately 40 min to create the 3D images. The various data are stored in a CD, which can be used and managed easily with a standard computer and reviewed as often as necessary. The images are then loaded onto the intra-hospital imaging system, allowing full visualization of the 3D model from any angle on the computer in the operating theater. Despite the learning curve involved, the ability of surgeons to perform “virtual surgery” with 3D images preoperatively provides a very attractive alternative to standard CTA techniques. Another potential attraction of our approach is that MR data might also be used for this purpose in a similar way [3].

Potential improvements could be made in order to achieve more accurate data exporting the 3D results from the workstation. Improvements could include automatic registration of the pre-op CTA volume images and laser-guided markings on the patient live.

The conversion of more superficial structures into phantom images makes possible for the viewer to grasp the 3D relationship of superficial and deeper structures. This technique is also well tolerated by patients because it is rather simple and speedy. Main disadvantages are the cost and the fact that the examination does involve both ionizing radiation as well as the injection of iodinated contrast medium. However, the effective dose of radiation used in this study was 5.6 mSv [3], which is lower than that used for an opaque enema and almost equivalent to that administered by a staging CT scan of the abdomen.

As an extension of the VirSSPA project the development of a virtual reality integrated system to improve knowledge management in the hospital surgical environment is being considered. This system will allow surgical practice information to be preserved and used retrospectively. The documental database generated will be a useful tool to share information between medical professionals. Moreover it will establish protocols to facilitate and optimize surgical practice resulting in a correct knowledge management.

4. Conclusion

The improvements obtained with VirSSPA software can be summarized as follows:

• The system aids the teaching of more junior trainees in the art of assessing patients and performing different surgical procedures.

• It provides a very attractive alternative to standard CTA techniques. Another potential attraction of our approach is that MR data might also be used for this purpose in a similar way.

• Our virtual reality model changes the usual procedure for planning and performing surgery showing clearly the potential for improved outcomes. This could result in reduced amount of stress for the surgeon as
well as in decreased operative time and risks for the patient.

Likely, other exciting virtual reality applications may derive from these principles for future use in reconstructive plastic surgery. We hope that our project will contribute to the many steps that need to be taken worldwide towards such end.

Acknowledgements

The modular software programming tools used in this study were developed at Alcalá Innova and Reina Mercedes Foundation in collaboration with the Sevilla School of Engineering, Spain. The VirSSPA project is being developed and financed by the Andalusian Department of Health, Spain.

References: