Computer Assisted Planning of Surgical Procedures

Ron Kikinis, M.D.(1), Harvey Cline, Ph.D.(2), David Altobelli, M.D.,D.M.D.(3,4), Michael Halle, M.S.(5), William Lorensen, M.S.(2), Brahm Rhodes, Ph.D.(1), Ferenc Jolesz, M.D.(1)

Affiliations: Department of Radiology, Harvard Medical School and Brigham and Women's Hospital (1), General Electric Corporate Research and Development Center, Schenctady, N.Y. (2), Craniofacial Surgery, Harvard Medical School and Brigham and Women's Hospital (3), Dental School of Harvard Medical School (4), Spatial Imaging Group, Media Lab, Massachusetts Institute of Technology (5).

ABSTRACT

A system for computer-assisted planning of surgical procedures has been developped. Its components are a workstation with hardware accelerated 3D rendering board, a software environment and a set of procedures. Data sets from over 41 patients have been analyzed so far. We found a potential for improving the surgeons understanding of the anatomical situation he was going to face and for reducing the time spent during surgery to understand the altered anatomy.

I : INTRODUCTION

The requirements for computer assisted-planning of surgical procedures in a clinical environment are: availability of the hardware and data; robust but user-friendly software that works on both MRI and CT data and can be used by doctors or technicians; efficient segmentation of clinically relevant structures; and the ability to manipulate interactively the visualized structures for the simulation of surgical procedures. It is our goal to develop a user-friendly environment that consists of a combination of hardware, software, and know-how that fulfills these requirements.

II : APPROACH

A : Patients

Three different anatomical areas have been included: the brain, the head and neck, and the kidneys. The main motivation for patient inclusion was that the information provided by the unprocessed conventional images was insufficient for surgical planning. Over 41 cases have been analyzed so far (15 neurosurgical, 20 craniofacial and 6 kidneys).

B : MR /CT acquisition

In general, radiologist prefer highly anisotropic data sets with excellent in-slice resolution and poor out-of-slice resolution. Using available signal to noise, we have defined protocols modifying the slice thickness while leaving the in-slice resolution intact. This step is essential for the practicability in a clinical environment.

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C : Supervised/Automated Segmentation

The image processing consisted of multiple steps. It was modified according to the data available and the structures targeted. The end result of the process was a label map where every targeted structure had a different label. Mostly automated procedures were used and were completed by manual segmentation if necessary. Typically, segmentation consisted of application of a noise reduction filter, followed by a supervised multivariate analysis to generate a primary label map which was subsequently edited using a combination of erosion, dilation and connectivity in order to generate a mask of the intracranial cavity [1-5].

D : 3D Visualization: Computer Software/Hardware

The results of the segmentation were visualized using the dividing cubes surface rendering algorithm. The programs were written in C on a Unix/X windows platform. A hardware accelerator board supporting the dividing cubes algorithm allows the manipulation of multiple objects interactively. Each object has a matrix attached to it that allows one to determine all the available visualization parameters including: rotation, translation, scale, and range. A virtual "camera" can be rotated into an arbitrary position for the visualization of a scene. A virtual surgical knife is available allowing one to define a polygonal prism with determinable depth along the view ray. Each of the fractions (inside or outside of the prism) can be converted into a separate object.

III : RESULTS

A : Data Acquisitio

Using the modified protocols, we were able to obtain image data suited for both clinical conventional reading and generation of 3D reconstructions from both MR and CT. This is important, because in clinical practice the available scanner time is very limited a (35 min patient slot) and accordingly acquisition of separate additional sequences is difficult or impossible.

B : Patients

1 : Neurosurgery

3D reconstructions from 15 patients have been used for the preoperative planning. The neurosurgeons are interested in evaluating the relation of the target structure to surrounding critical structures such as cranial nerves, vessels, white matter tracts and nuclei. The ability to selectively cut structures proved to be essential in the planning of craniotomies.

2 : Craniofacial Surgery

The challenge in craniofacial surgery is to identify the distorted structures and to reposition them into a physiological position. In children there is the additional challenge of taking future growth into account. Over 20 patients have been planned. Based on the clinical impression, two-dimensional analysis, and interactive visualization of the three-dimensional computer generated surfaces, osteotomies were designed in three dimensions. The skin and bones were subdivided interactively in simulation of surgery. Each of these object lists (e.g. the Le Fort I osteotomy segment) was then manipulated by multiple parameters. Functions include scaling, translation (x,y,z), rotation (angle, rotation, and elevation), center of rotation, color, mirror reflection, embedment of grid patterns, and range boundaries. To estimate the best position for a an anatomic unit, normative data from cephalometric, and anthropological data bases were used for initial positioning. The entire procedure, often containing multiple object lists (all of the osteotomy segments and overlying skin patches) is controlled by script files which allow subtle position changes to be easily modified, and with viewing from multiple vantage points. Finally, a planning conference was held at the computer workstation where further input and modifications were made. The data was then transferred to video tape or to color prints for use in the operating room.

3 : Kidney Surgery

Planning was performed in cases with planned partial nephrectomy. The question raised was the relation of small tumors to surrounding kidney strucures such as the pelvis of the kidney and the vessels. In addition, the relative position of the tumor to the kidney surface was of interest in small tumors, that might not be seen from outside.

IV : DISCUSSION

A : Tools to be developed

The next significant increase in functionality of the system will be to implement a 3D pointing device and to port the whole setup into the operating room. For this purpose, we are currently extending the hospital network into the OR.

B : Clinical Significance

We have found that it is possible to use 3D reconstructions to enhance significantly the surgical planning process. The interactivity enables the surgeons to have a much better understanding of the anatomy and pathology. The evaluation of the clinical significance is still preliminary but there is a distinct potential to reduce the time the surgeon has to spend during surgery to understand the altered anatomical situation. The ability to measure interactively on the 3D reconstructions allows more elaborate surgical plans in craniofacial surgery.

V : REFERENCES

[1] Cline HE, Lorensen WE, Kikinis R, et al.: 3-D Segmentation of MR Images of the Head using Probability and Connectivity. J Comput Assist Tomogr 1990;14(6):1037-1045.

[2] Gerig G, Kuoni W, Kikinis R, et al.: Medical Imaging and Computer Vision: An Integrated Approach for Diagnosis and Planning. 11th DAGM Symposium Mustererkennung 1989, Hamburg, FRG, Oct 2-4 1989;Fachberichte IFB 219, Springer Berlin:425-433.

[3] Gerig G, Kikinis R, Jolesz FA: Image Processing of Routine Spin-Echo MR Images to enhance Vascular structures: Comparison with MR Angiography. Nato Advanced Workshop in Travemuende, June 1990. Proceedings: 3D Imaging in Medicine, Hoehne, K.H., Fuchs, H. Pizer, S.M.: Nato ASI Series, F: Computer and System Sciences Vol. 60, Springer, 1990 1990;60:121-132.

[4] Kikinis R, Jolesz FA, Gerig G, et al.: 3D Morphometric and Morphologic Information Derived From Clinical Brain MR Images. Nato Advanced Workshop in Travemuende, June 1990. Proccedings in Hoehne, K.H., Fuchs, H., Pizer, S.M.: 3D Imaging in Medicine. Nato ASI Series F: Computer and Systems Sciences, Vol 60, Springer 1990 1990;60:441-454.

[5] Lin W, Kikinis R, Haacke EM: A Full Automatic Display of 3D Bone Structure from MR Imaging. Presented at the Annual Meeting of the Society of Magnetic Resonance Imaging, held in April 1991, Chicago, Il 1991;.