Evaluating Virtual Endoscopy for Clinical Use

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Virtual endoscopy is a term used to describe computer simulated endoscopy procedures derived from high resolution images of patient anatomy. By simulating the endoscopic examination, the patient is spared the discomfort and possible complications of an actual examination. The physician also has more flexibility in a virtual endoscopic examination of 3D patient data in comparison to a real endoscopic examination. Virtual endoscopy removes the physical and physiologic constraints of real endoscopy and can create views that are not possible in an actual endoscopic examination. This may enhance the performance of actual endoscopic examinations. Virtual endoscopy may also be used to perform "numerical biopsies"; anatomic measurements such as size, distance, shape, and density. Virtual endoscopy allows the physician to comprehensively explore the patient anatomy using an intuitive and interactive interface. There are currently two technical approaches to performing virtual endoscopy: perspective volume rendering and surface rendering of polygonal models. Perspective volume rendering uses traditional volumetric rendering algorithms to create visualizations directly from the volumetric dataset. Polygonal models require a preprocessing step to convert the segmented volume information into a polygonal surface that may be displayed at real time frame rates. Both paradigms have inherent strengths and weaknesses. We illustrate and compare the methods on actual patient data, including simulated endoscopic examinations of the airways, colon and esophagus. Preliminary results in virtual endoscopy show promise and will continue to be an area of active research leading to useful clinical applications. Copyright © 1997 by W.B. Saunders Company

KEY WORDS: virtual endoscopy, surgery planning, volume rendering, surface rendering.

THE TERM VIRTUAL endoscopy describes several techniques to create visualizations from 3D medical image scans similar to those produced by current minimally invasive endoscopic procedures. Virtual endoscopy holds significant promise to supplant some real endoscopic examinations and become a standard screening practice for real endoscopy. Many of the serious complications associated with real endoscopy may be avoided by using virtual endoscopy. Risk of infection or perforation of the anatomy being examined will be eliminated. Endoscopic examinations are also expensive, time consuming procedures with thousands of examinations being performed each year. Virtual endoscopy may augment

or replace at least some of these procedures with a noninvasive, efficient examination.

Several approaches to virtual endoscopy are being explored in the biomedical imaging field. We compare two methods for virtual endoscopy: perspective volume rendering and polygonal modeling techniques. We present an evaluation of several factors important to the clinical use of virtual endoscopy.

MATERIALS AND METHODS

Virtual endoscopy techniques currently fall into two general 3D display methodologies: perspective volume rendering and surface rendering.

Perspective Volume Rendering

Volume rendering is the process of creating 2D visualizations of a 3D volume image by casting rays through the volume from a user selected eye position. As each ray travels through the volume, each voxel it intersects is considered. If the voxel parameters meet the ray stopping conditions, an output pixel is colored or shaded for display according to a model appropriate for the surface encountered. Volume rendering algorithms can show the texture of anatomic surfaces. Several shading models are available^{1,2} including voxel value, depth shading, depth gradient, and voxel gradient. The rays may also continue through the volume to provide projection images including maximum intensity, summed voxel, and surface thickness. Each voxel may be assigned a relative opacity value to create transparent renderings.

Surface Rendering

To display anatomic surfaces, a polygonal model may be created from the anatomy to be examined. This process is known as tiling. Several well known algorithms exist for transforming image surface data to geometric data.³ All of the tiling algorithms require an appropriate iso-surface to be extracted from the volume data. The volume data are processed to create a geometric representation in the form of polygons.

Current display systems offer a variety of options for rendering parameters and features. The physician can control color, shading, texture and transparency, as well as the rendering algorithm used (shaded, texture mapped, wire-frame, hidden

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line, etc). Stereo 3D display of the virtual endoscopy visualizations may be achieved using a head mounted display or special goggles.

RESULTS

Airway Endoscopy

Patient data for a virtual endoscopic examination of the esophagus and bronchial tree was acquired at 0.26 mm in-plane resolution and 1 mm slice thickness on a helical computed tomography (CT) scanner. The data were then tri-linearly interpolated to 0.26 mm cubic voxels and reduced from 16 bits to 8 bits, for a volume size of $512 \times 512 \times 103$ (25 Mb). The tumor in the lung and the airway surfaces were segmented and tiled.

Fig 1. Patient-specific airway endoscopy. (A) Small airway; (B) trachea model.

Perspective volume rendering (see Fig 1A) allows visualizations of airways that are difficult to tile and model correctly due to their small size. Modeling produces similar visualization, but with different resolution and quality (see Fig 1B).

Colon Endoscopy

The colon data were extracted from the Visible Human Male from the National Library of Medicine⁴ CT dataset with 1 mm cubic voxels. The skin surface and colon were segmented and models created of both surfaces. Figure 2A is an endoscopic visualization of the colon from the models. Figure 2B is a navigational guide showing an anterior to posterior view of the trunk model from the Visible Human. The camera position is indicated by the bright sphere located inside the transparent colon. Figure 2C shows a perspective volume rendering of the Visible Human Male colon.

Esophageal Endoscopy

Figure 3A is a volume rendered view of an esophageal tumor near the stomach extending into the lung. Figure 3B shows a virtual endoscopic view down the esophagus, and Fig 3C shows the tumor infiltrating and closing off the esophagus. Rendering the esophagus transparent shows the extent of the tumor (see Figure 3D). This information may be readily obtained from the 3D CT dataset.

DISCUSSION

In an evaluation of virtual endoscopy, many subjective and objective criteria must be considered. In our study, we have concentrated on physician acceptance, exclusivity weighting, sensitivity, and specificity.

Physician acceptance requires virtual endoscopy to provide information that meets or exceeds the capabilities of real endoscopy. Virtual endoscopy must provide visualizations similar to the physician's view through the endoscope. The physician must be comfortable and familiar with the technique and possess an understanding of its capabilities and limitations.

Precise localization of tumor position is difficult to determine during a real endoscopic examination. Standard endoscopic probes are not equipped with

Fig 2. Visible human male virtual colonoscopy. (A) Colon model; (B) Colon A-P navigation guide; (C) Colon perspective volume rendering.

measurement apparatus to enable accurate determination of tumor location. Because of the elastic nature of the esophagus, the physician's measurements of tumor location can vary by as much as 2 cm. The esophagus does not move during a CT scan performed during breath holding, and thus the scan data facilitates accurate identification of tumor location.

Diagnosis of tumor involvement in surrounding structures is a crucial aspect of real endoscopic examinations of upper gastroenterology cancer patients. Currently, transesophageal ultrasound examinations are used to determine the metastatic progression of tumors. This procedure involves a second endoscopic examination of the patient. Virtual endoscopy could potentially eliminate both examinations and provide quantitative information about the tumor, including extent of involvement with surrounding structures, volume, and size.

A recent study⁵ indicates that chemotherapy combined with radiotherapy is effective in increasing long-term survival of esophageal adenocarcinoma. Tumor response studies could be significantly augmented by virtual endoscopy, coupled with powerful analysis tools such as AnalyzeAVW.⁶ Our virtual endoscopy system has been integrated into this general visualization and analysis toolkit that is already familiar to Mayo physicians. This software provides 3D segmentation, classification, registration, and visualization of the dataset. In addition, specialized analysis tools have been integrated in the toolkit for specific use in virtual endoscopy. These include capabilities for linear and angular measurements, surface area calculations, and volume estimation, each of which are calculated directly from the dataset.

CONCLUSION

Our initial results indicate that virtual endoscopy has potential to become a useful clinical tool. Virtual endoscopy can provide measurements that are not possible with real endoscopy. These measurements are reproducible and may be used to assist surgical planning. Some of the more important measurements possible are location and extent of anatomic structures and pathologies.

Because virtual endoscopy allows views to be generated from any position and orientation, with many different image quality controls, it is more

Fig 3. Use of "transparent endoscopy" for determination of tumor extent. (A) External volume rendering; (B) down esophagus; (C) esophageal tumor; (D) transparent esophagus.

flexible than real endoscopy. With virtual endoscopy, the physician also has the ability to generate views from outside of the anatomy to better delineate and understand the location and extent of a tumor. Inherently, virtual endoscopy is a noninvasive procedure. There is no risk of perforation, infection, or discomfort, and this may reduce cost.

Virtual endoscopy has some disadvantages compared with real endoscopy. The physician has no method of performing a physical biopsy. Color and texture play an important role in diagnosis during real endoscopic examinations, but in virtual endoscopy, color and texture information may not be present. If color and texture are obtained from sources other than the patient, they will not be patient-specific and thus be misleading for the

physician. If color and texture are obtained from the patient (ie, from a real examination), they will be patient-specific, but not location-specific, that is the color and texture may be from the patient, but will not be applied in the proper location.

Virtual endoscopy is a new paradigm of endoscopy. To become a clinically useful tool, its unique features and advantages compared with real endoscopy need to be validated. It must also provide information that improves outcome for patients and reduces cost.

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REFERENCES

1. Höhne KH, Bernstein R: Shading 3D-images from CT using gray-level gradients. *IEEE Transactions on Medical Imaging* 5:45-47, 1986
2. Robb RA, Barillot C: Interactive 3-D image display and analysis. *Hybrid Image and Signal Processing* 939:173-202, 1988
3. Ning P, Bloomethal J: An evaluation of implicit surface tilers. *IEEE Computer Graphics and Applications* 13:33-41, 1993
4. National Library of Medicine (U.S.) Board of Regents. Electronic imaging: Report of the board of regents. Technical Report NIH Publication 90-2197, U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health, 1990
5. Walsh TN, Noonan N, Hollywood D, et al: A comparison of multimodal therapy and surgery for esophageal adenocarcinoma. *N Engl J Med* 335:462-467, 1996
6. Robb RA: Surgery simulation with ANALYZE/AVW: A visualization workshop for 3-D display and analysis of multimodality medical images. Presented at Medicine Meets Virtual Reality II, San Diego, CA, February 1994