VIRTUAL LARYNGOSCOPY

Marvin P. Fried MD[1], Vik M. Moharir MD[1],

Hiroshi Shinmoto MD[2], Abdalmajeid M. Alyassin PhD[3], William E. Lorensen MS[3],

Liangge Hsu MD[4], Ferenc A. Jolesz MD[5], Ron Kikinis MD[5]

[1] Department of Otology and Laryngology, Harvard Medical School; Joint Center for Otolaryngology , Beth Israel Deaconess Medical Center and Brigham and Women's Hospital, Boston, MA 02115.

[2] Department of Radiology, Tokyo Metropolitan Hiroo Hospital, Tokyo, Japan.

[3] General Electric Corporate Research and Development Center, Schenectady, NY 12301.

[4] Division of Neuroradiology, Department of Radiology, Harvard Medical School, Brigham and Women's Hospital, Boston, MA 02115.

[5] Surgical Planning Laboratory, Division of MRI and Image Guided Therapy Program, Department of Radiology, Harvard Medical School, Brigham and Women's Hospital, Boston, MA 02115.

This work has been accepted for presentation at The American Laryngological Association Annual Meeting, on May 9-10, 1998.

This work is supported in part by grants from The Partner's Center for Innovative Minimally Invasive Therapy; Brigham and Women's Hospital; Sun Microsystems; General Electric; International Business Machine; Pharmacia and Upjohn; Carl Zeiss, Inc.; Thinking Machines, Inc.; The National Institutes of Health; The Witaker Foundation; Department of Radiology, Brigham and Women's Hospital and Harvard Medical School

NIH Grants: R01 CA46627-08, P01 CA67165-01A1, P01 AG04953-14

Corresponding Author:

Marvin P. Fried, MD
333 Longwood Avenue
Boston, MA 02115
Phone: (617) 713-2000
Fax: (617) 734-2682

Abstract

Virtual endoscopy enables computer-generated 3D visualization of a cavity by reconstructing two-dimensional CT or MR data. The technique has been used experimentally to study the colon, bronchi, ear, and other locations. Here, virtual laryngoscopies were created from the cross-sectional image data of three patients. The patients represented: a normal airway, a squamous cell carcinoma of the glottic fold, and a posterior glottic stenosis. These reconstructions included extra-luminal anatomy which is not typical of current virtual endoscopic techniques. The two-dimensional CT and MR images of the patients underwent post-processing for 3D reconstruction. The resulting models were imported into an experimental virtual endoscopy program for

1. airway lumen generation
2. interactive viewing

Though they could not be used for biopsy, the virtual laryngoscopies provided, in a non-invasive fashion, good simulation of endoscopy. Virtual endoscopy also gave the added benefits of the ability to assess the transmural extent of disease and view the airway distal to areas of luminal compromise. This technology may well provide clinical benefit in preoperative planning, staging, and intra-procedural guidance for head and neck pathology and merits further study.

Key Words: Virtual Laryngoscopy; Three-dimensional; Head and Neck; Larynx; Computer

Introduction

Endoscopy is used diagnostically for detailed three-dimensional (3D) evaluation of a lumen or cavity. Some disadvantages of endoscopic examinations, including those of the larynx, are that they require sedation, one can not assess beyond areas that prevent passage of the endoscope, and viewing is limited strictly to the lumen, restricting transmural evaluation of lesions. There is also a risk of viscus perforation in procedures such as esophagoscopy. Virtual endoscopy provides 3D anatomical information by reconstructing two-dimensional CT and MR data, overcoming the drawbacks of endoscopy. The colon, bronchi, ear, and other locations **(1-6)** have served as the locations for initial assessment of virtual endoscopy. The advantage of 3D visualization of the larynx makes this a desirable area for virtual endoscopy despite the fact that it cannot be used for biopsy. The benefits of virtual laryngoscopy should be particularly helpful during assessment of the difficult airway or when neoplasia, infection, inflammation, and congenital defects compromise the lumen.

Current methods of virtual endoscopy are limited in their 3D display of extra-luminal anatomy. For example, during virtual broncoscopy, blood vessels and the lung parenchyma are often not seen. The lack of a global context and physical clues during viewing may lead to confusion of the patient’s anatomy **(7)**. We address this problem by incorporating into our virtual endoscopic technique a method of 3D anatomical reconstruction which can use merged CT and MR images. In this paper, we describe our virtual endoscopic technique, augmented by 3D anatomical reconstruction, and discuss our initial results with virtual laryngoscopy.

Study Design

Patient Profile

In order to give a variety of clinical conditions, three cases were chosen retrospectively for virtual laryngoscopy. Patient one, KS, (Figure 1 and Figure 2) is a 56 year old female with no laryngeal or airway pathology. Patient two, GY, (Figures 3-5) is a 58 year old male with a T3 N3 M0 squamous cell carcinoma involving the left area of the vocal fold, with paraglottic extension. Patient three, SH, (Figures 6-8) is a 39 year old female with posterior laryngeal glottic stenosis.

Materials and Methods

Data Acquisition

Patient one underwent a helical CT scan with 3 mm thick axial images. Patient two underwent CT and MR imaging. CT consisted of 5 mm thick consecutive axial images, while MR was acquired with 1.5 cm thick axial SPGR images. Patient three underwent a helical CT scan with 2 mm thick axial images.

Image Processing

All three patients underwent 3D reconstruction of their anatomy. Patient one had the following structures reconstructed: vocal folds, thyroid cartilage, arytenoid cartilage, epiglottis, and the cuneiform tubercle. For patient two, the following structures were assembled: epiglottis, tumor, left jugular vein, left common carotid artery, vertebral column, hyoid bone, and mandible. Lastly, patient three had the following anatomic entities reconstructed: hyoid bone, thyroid cartilage, vocal folds, epiglottis, arytenoid cartilages, and intra-arytenoid web.

The 3D reconstruction method employed has been developed at The Surgical Planning Laboratory

(SPL) of Brigham and Women's Hospital: The CT and MR images were *transferred* to computer workstations at the SPL using internal network communication. The images underwent *filtering* for reduction of unwanted signal **(8)**. *Registration*, or merging, of CT and MR images came next for patient two. The matrix of the CT images was reduced from 512 to 256 in order to match the MR data. The actual combining then took place based on maximization of mutual information between aligned CT and MR images **(9)**. The rest of the steps utilized this combined data, allowing information from the two different radiological modalities to be incorporated into the final picture. *Segmentation* consisted of isolating and outlining each desired anatomic component in the two-dimensional radiological data **(10)**. This involved an automatic and a manual component and was the rate limiting step of the entire reconstruction process. After an individual anatomic component was segmented, the slices were stacked together to get a 3D anatomic structure **(11-13)**. In a viewing program, the individual structures were *integrated* to create a 3D model of the patient anatomy.

The completed 3D models were imported into an experimental virtual endoscopy program **(14)** (VESA, General Electric Corporate Research and Development Center, Schenectady, NY). Inclusion of the models in the virtual endoscopy program was feasible because both use the visualization tool kit (VTK) format for displaying 3D images **(15)**. The virtual endoscopy program then created the airway lumen of each patient, starting at the oropharynx and ending at the trachea. Lastly, a virtual laryngoscopy path was generated, also by the program, by marking start and end points on the axial CT images.

Results

The virtual laryngoscopies were run on a computer workstation (Ultrasparc with Creator 3D graphics, Sun Microsystems, Mountain View, CA). The virtual endoscopy program allowed for display of multiple images: a camera view, a global or external view, and a view of the related CT or MR slice. The camera and global views could be enlarged or reduced, rotated 360 degrees in any axis, and translocated in the vertical or horizontal plane. The camera lens could face any direction and have a view angle from 1-180 degrees. Any anatomic structure could be added or deleted. The individual anatomic components could be rendered transparent and have their color and light intensity controlled.

The virtual endoscopy of patient one (Figures 1 and Figures 2) starts in the oropharynx. The camera faces inferiorly as it descends the airway. It moves past the arytenoid cartilage and vocal folds and into the trachea. Rendering the airway lumen transparent shows and thyroid cartilage. While in the trachea, turning the camera in the cephalic direction gives an inferior view of the laryngeal structures. The virtual endoscopy screen gives the camera location in a global context as well as the related cross-sectional CT slice.

The virtual laryngoscopy of patient two (Figures 3-5) begins in the oropharynx. The camera looks down toward the epiglottis, beyond which the tumor protrudes into the larynx. The transparent airway lumen and the global view allow for appreciation of the transmural extent of the tumor. In addition, a patent left common carotid artery and compressed jugular vein can be seen. The resected gross pathology specimen confirmed the virtual laryngoscopy findings of extension out of the limits of the larynx and occlusion of the jugular vein.

The virtual endoscopy of patient three (Figures 6-8) begins in the oropharynx. It looks down toward the vocal folds. The area of stenosis is visualized in both the camera and global views. During endoscopy we could not view beyond the glottis; however, the virtual camera moves beyond the vocal folds and the area of stenosis without difficulty. A rertroverted view from the trachea gives another perspective on the laryngeal structures. A posterior global view, with the web removed, demonstrates a non-compromised airway distal to the stenosis.

Discussion

Physicians use a variety of imaging techniques for diagnosing, staging, preoperative planning, and monitoring of disease. Endoscopy allows for direct viewing into a cavity. In addition to being an invasive procedure and requiring sedation, endoscopy cannot be used beyond areas of luminal stenosis or obstruction and limits visualization to the interior walls of the cavity. CT and MR show tissue volume beyond the lumen and usually do not require sedation. The problem with these noninvasive techniques is that they present information in a cross-sectional two-dimensional format, which the physician must mentally reconstruct into a three dimensional picture. This at times can be difficult in areas of intricate anatomy, such as that of the head and neck **(16)**. Having three-dimensional imaging from non-invasive techniques could combine the benefits of endoscopic and radiological imaging.

Previous researchers used CT for three-dimensional reconstruction of the larynx and airway **(17-20)**. Because CT has poor soft tissue resolution, using it alone would make evaluation of head and neck tumors difficult. Dunham and Wolf digitized endoscopic images of the pediatric airway and used a computer for 3D reconstruction of the lumen. Though it allows the airway to be visualized in 3D, this method cannot be used to display extra-luminal anatomy or the transmural extent of tumors **(21)**.

Virtual endoscopy uses two-dimensional CT and MR data to create a 3D emulation of endoscopy with some important advantages. By making the lumen transparent during virtual endoscopy, the full extent of a lesion may be seen, as demonstrated by the case-study of patient two. This may enhance preoperative planning and staging of head and neck pathology. Endoscopy is limited by the physical progression of an endoscope; this presents a problem when assessing the difficult airway, such as a narrowed lumen from any cause. An example occurred during the evaluation of patient three- during the endoscopic exam, we could not view beyond the stenosis. Virtual endoscopy allowed for visualization beyond the lesion without difficulty.

A technical challenge to current methods of virtual endoscopy is the limitation of anatomic detail. Our approach to virtual endoscopy incorporates a method of 3D anatomical reconstruction to better delineate patient anatomy. This new technique allows for anatomic rendition of even the smallest of structures, such as the vocal folds and arytenoid cartilages. Combined MR and CT data allows for visualization of soft tissue, cartilage, and bone. This should be particularly helpful when evaluating tumors and their extension. As demonstrated by the second case-study, the intricate relationship of the tumor with its surrounding viscera, such as the occluded jugular vein and patent carotid artery, could be delineated. The simultaneous display of the global view and related CT or MR slice further improved the understanding of the location of the virtual camera in relation to its extra-luminal spatial context.

It is important to stress virtual endoscopy, unlike traditional endoscopy, cannot be used for biopsy. However, combing the two techniques by integrating and displaying virtual endoscopy during endoscopic procedures may have a synergistic effect. This could allow for biopsy of the margins of lesions, improving delineation of the extent of pathology **(16, 22)**. The neurosurgical team of our institution is already using this technology for intra-procedural guidance **(23)**, and in the near future, we hope to do so as well.

We did encounter some challenges that must be overcome before expanded application of our method of virtual laryngoscopy. The 3D anatomic rendition is only as good as the two-dimensional CT and MR images from which it is constructed. The luminal views are inferior in detail to their endoscopic counterparts. Currently it takes several hours for completion of a single virtual endoscopy, not including the steep learning curve that exists. If 3D anatomic reconstruction is not incorporated, virtual endoscopy of the lumen and limited structures takes approximately 1-2 hours, with less of a learning curve for the individual doing the reconstruction. The current cost for incorporating 3D reconstruction to virtual endoscopy needs reduction. Finally the key question remains: what role should virtual laryngoscopy, with or without 3D reconstruction, play in the clinical setting? This can only be answered with further study and clinical correlation.

Conclusion

A new approach to virtual endoscopy now exists by adding 3D anatomical reconstruction. It provided good representation of the laryngeal and neck anatomy of the three patients that severed as the initial study group. Though it cannot be used for biopsy, virtual laryngoscopy carries potential for improving preoperative planning, staging, and intra-procedural guidance for head and neck pathology. However, prior to expanded implementation, improvements need to be made in time and cost factors. In addition, a study with a larger patient population, needs to be done to compare virtual laryngoscopy with intraoperative findings.

References

1. Vining DJ, Shifrin RY, Grishaw EK, et al. Virtual Colonoscopy (abstr.). Radiology 1994;193:446.

2. Vining DJ, Padhani AR, Wood S, et al. Virtual Broncoscopy: a new perspective for viewing the tracheobronchial tree (abstr). Radiology 1993;189:438.

3. Frankenthaler R, Moharir VM, Kikinis R, et al. Virtual Otoscopy. Otolaryn Clinics of North America; In Press. Due April 1998.

4. Satava RM, Simon IB. Endoscopy for the year 2000. Gasterointest Endosc Clin N Am 1993;4:397-407.

5. Jolesz FA, Lorensen WE, Shinmoto H, et al. Interactive Virtual Endoscopy. AJR 1997;169:1229-35.

6. Geiger B, Kikinis R. Simulation of endoscopy. In: Ayache N, ed. Lecture Notes in Computer Science- Proceedings from The First International Conference on Computer Vision, Virtual Reality, and Robotics in Medicine, in Nice, France 1995;905:277-281.

7. Summers RM. Navigational aids for real-time virtual broncoscopy. Am J Roentgenol 1997;168:1165-70.

8. Gerig G, Kubler O, Kikinis R, Jolesz FA. Nonlinear Anisotropic Filtering of MRI Data. IEEE Trans Med Imaging 1992;11/2:221-232.

9. Wells W, Viola P, Kikinis R. Multi-Modal Volume Registration by Maximization of Mutual Information. Medical Image Analysis 1996;1:35-51.

10. Wells WM, Grimson WE, Kikinis R, Jolesz FA. Adaptive Segmentation of MRI Data. IEEE Transcriptions on Medical Imaging 1996;15:429-442.

11. Lorensen W, Cline H. Marching Cubes: A high resolution 3D surface construction algorithm. Computer Graphics 1987;21:163-189.

12. Schroeder W, Zarge J, Lorensen W. Decimation of Triangle Meshes. Computer Graphics 1992;26:65-70.

13. Taubin G, Curve and Surface Smoothing without Shrinkage. IBM Research Report RC-19536; 1994.

14. Alyassin AM and Lorensen WE. Virtual Endoscopy Software Applications on a PC. Proceeding from the 6th Annual Conference on Medicine meets Virtual Reality in San Diego 1998:84;89.

15. Schroeder W, Martin K, Lorensen W. The Visualization Toolkit. 2nd ed./ Prentice-Hall, New Jersey, 1997.

16. Jolesz FA. 1996 RSNA Eugene P. Pendergrass New Horizons Lecture: Image-guided procedures and the operating room of the future. Radiology 1997;204:601-12.

17. Silverman PM, Zeiberg AS, Sessions RB, Troost TR, Zeman RK. Three-dimensional Imaging of the Hypopharynx and Larynx by means of Helical (Spiral) Computer Tomography- Comparison of Radiological and Otolaryngological Evaluation. Ann Otol Rinol Larngol 1995;104:425-431.

18. Zinreich SJ, Mattox DE, Kennedy DW, et al. 3D CT for cranial facial and laryngeal surgery. Laryngoscope 1988;98:1212-9.

19. Metes A, Hoffstein V, Direnfeld V, Chapnick JS, Zamel N. Three-dimensional CT reconstruction and volume measurements of the pharyngeal airway before and after maxillofacial surgery in obstructive sleep apnea. Journal of Otolaryngology 1993;22:261-4.

20. Yumoto E, Sanuki T, Hyodo M, et al. Three-Dimensional Endoscopic Mode for obervation of Laryngeal Structures by Helical Computed Tomography. Laryngoscope 1997;107:1530-7.

21. Dunham ME, Wolf RN. Visualizing the Pediatric Airway: Three-dimensional Modeling of Endoscopic Images. Ann Otol Rinol Larngol 1996;105:12-17.

22. Fried MP, Hsu L, Topulos G, Jolesz FA. Image-guided surgery in a new magnetic resonance suite: preclinical considerations. Laryngoscope 1996;106:411-417.

23. Nakajima S, Atsumi H, Kikinis R, Moriarty TM, Mecalf DC, Jolesz FA, Black PM. Use of cortical surface vessel registration for image-guided neurosurgery. Neurosurgery 1997;40:1201-1208.

Figures and Captions

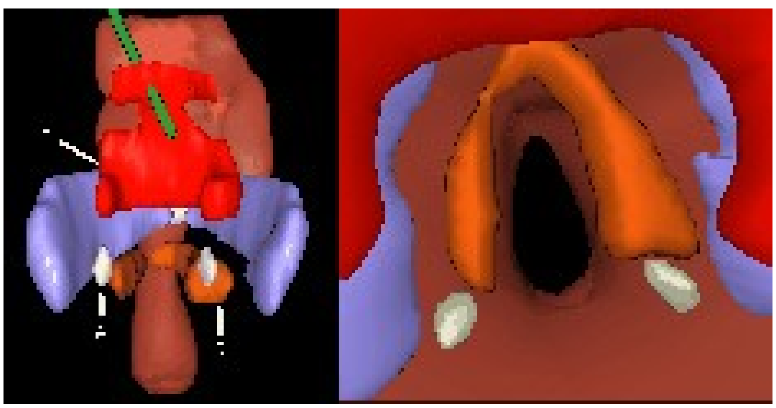

Figure 1: Patient 1. The **left** side shows a posterior global view during virtual endoscopy. The left (A) and right arytenoid cartilages are in white. The lumen has been rendered partially transparent to show the thyroid cartilage (in violet). The epiglottis is in red, along with the aryepiglottic fold and the cuneiform tubercle (B). The vocal folds (C) are rendered orange. The green line follows along to indicate the camera position during virtual endoscopy. The camera faces inferiorly to give us the view on the **right**, showing the vocal folds, arytenoid cartilages, the edge of the cuneiform tubercle, and thyroid cartilage.

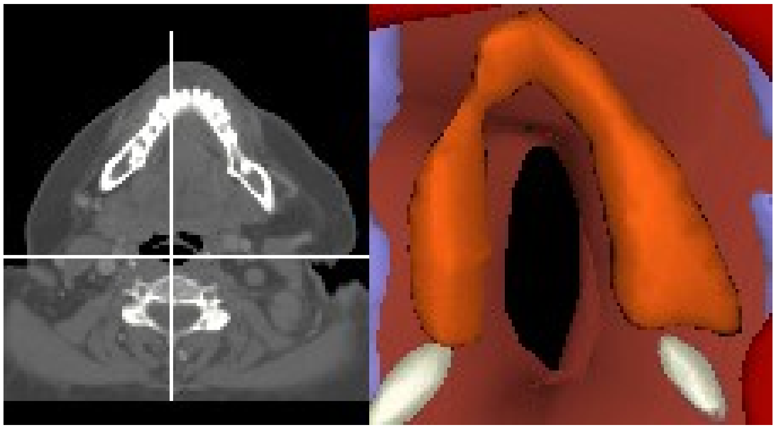

Figure 2: Patient 1. The **right** side shows a view of the larynx further along during the virtual endoscopy. The vocal folds are orange, the arytenoid cartilages in white, and the epiglottis, located along the superior and right perimeter, is in red. The lumen has been rendered partially transparent to expose the thyroid cartilage, in violet. On the **left**, instead of the global view, we see the related two-dimensional CT slice. The cross-hairs indicate the camera location, which faces inferiorly to show the camera view on the right. The related CT slices scroll along during the virtual endoscopy to continuously update the camera location.

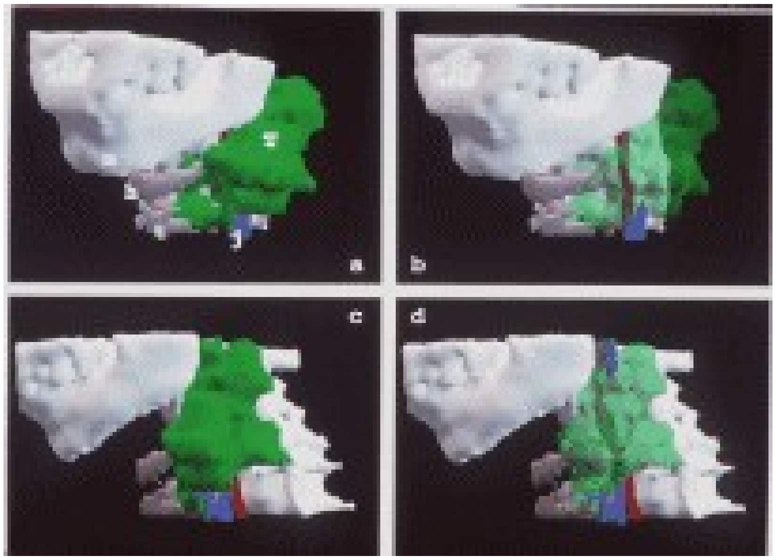

Figure 3: Patient 2: multiple global views. Figure **3a** and **3b** are the frontal-lateral views, with the tumor (T) transparent in 4b. The carotid artery, in red, is patent; the jugular vein, in blue, is compressed. Figure **3c** and **3d** are the left lateral views, with the tumor transparent in figure 4d. m=mandible; h=hyoid bone; t=thyroid cartilage; j=jugular vein.

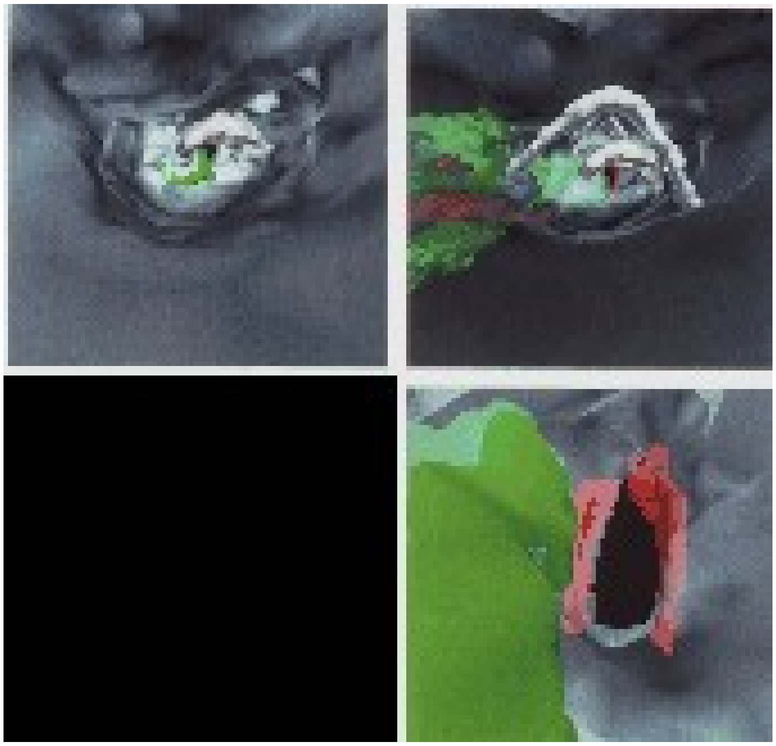

Figure 4: Patient 2. Different images during the virtual endoscopy (A= Anterior, P= Posterior). The **top left** image displays the airway with the walls opaque. The epiglottis is in off-white and the tumor in green. The **top right** figure shows the walls transparent. The transmural extent of the tumor and its relationship to surrounding structures is seen. The **bottom right** image displays the virtual camera view further down the airway with the walls made partially transparent. The vocal cords (red) and tumor are visualized.

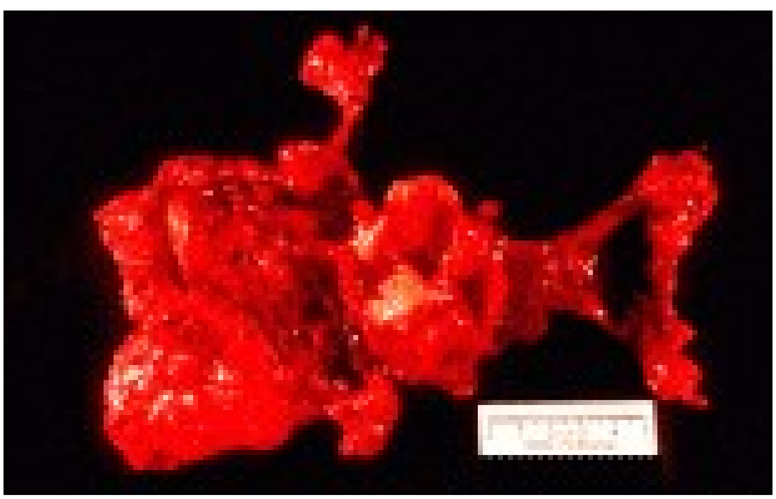

Figure 5: Patient 2- gross pathology, posterior view. The larynx and the contents of the dissected right and left sides of the neck are shown. As confirmed intraoperatively, the virtual laryngoscopy demonstrated well the findings of the extent of disease, penetration outside of the larynx, and occlusion of the left jugular vein.

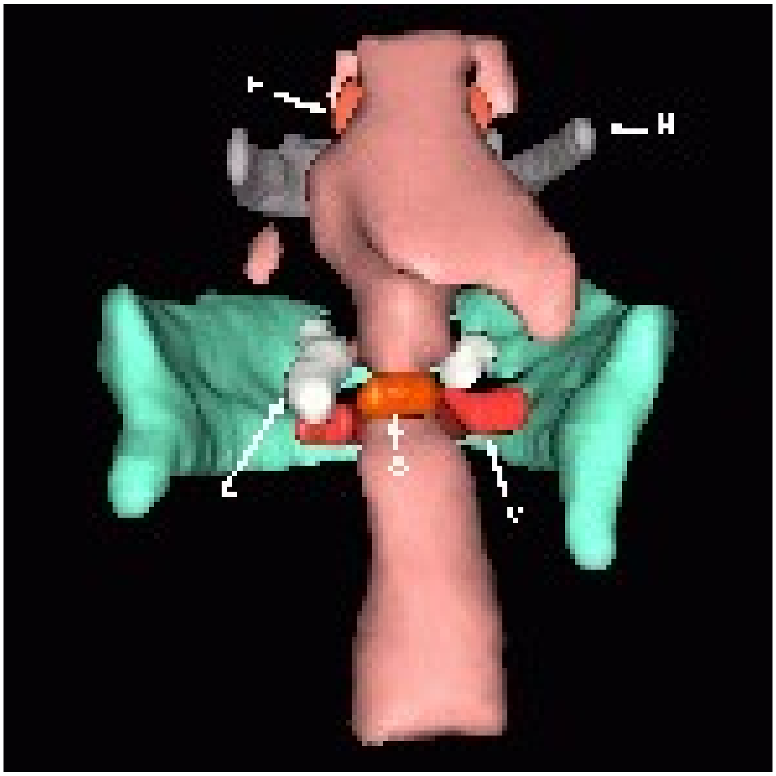

Figure 6: Patient 3. A posterior global view during the virtual laryngoscopy. The airway lumen is in peach and the thyroid cartilage is rendered light blue. A= left arytenoid cartilage; S= stenotic intra-arytenoid web; V= right vocal fold; H= hyoid bone; E= epiglottis.

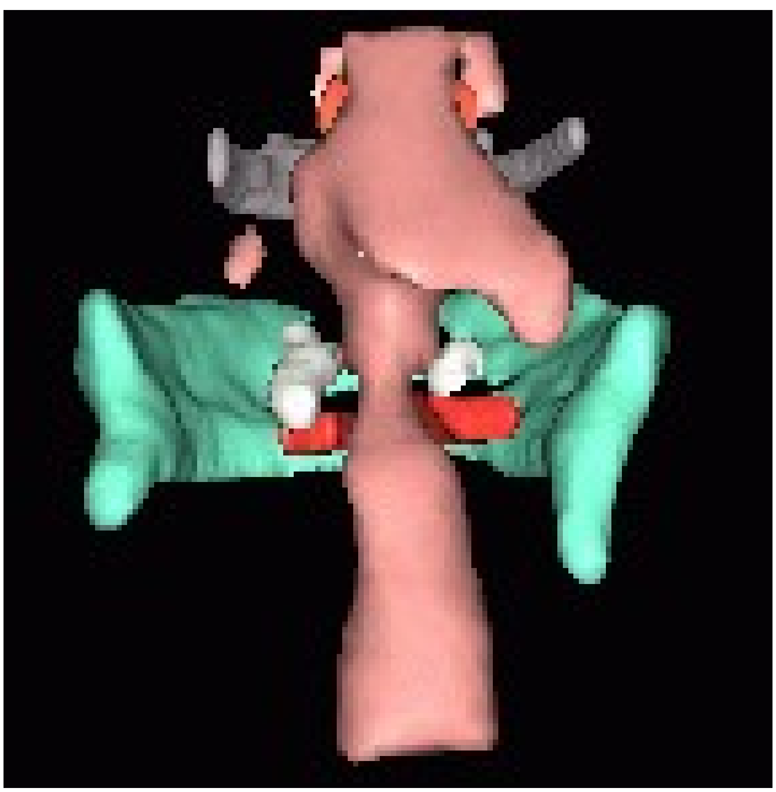

Figure 7: Patient 3. Another posterior global view during virtual laryngoscopy. The key difference

between this figure and figure 6 is that the intra-arytenoid web is rendered invisible here. The airway lumen narrowing in-between the arytenoid cartilages (white) and vocal folds (orange) is evident. Below the vocal folds, the diameter of the airway lumen expands, giving no further evidence of stenosis.

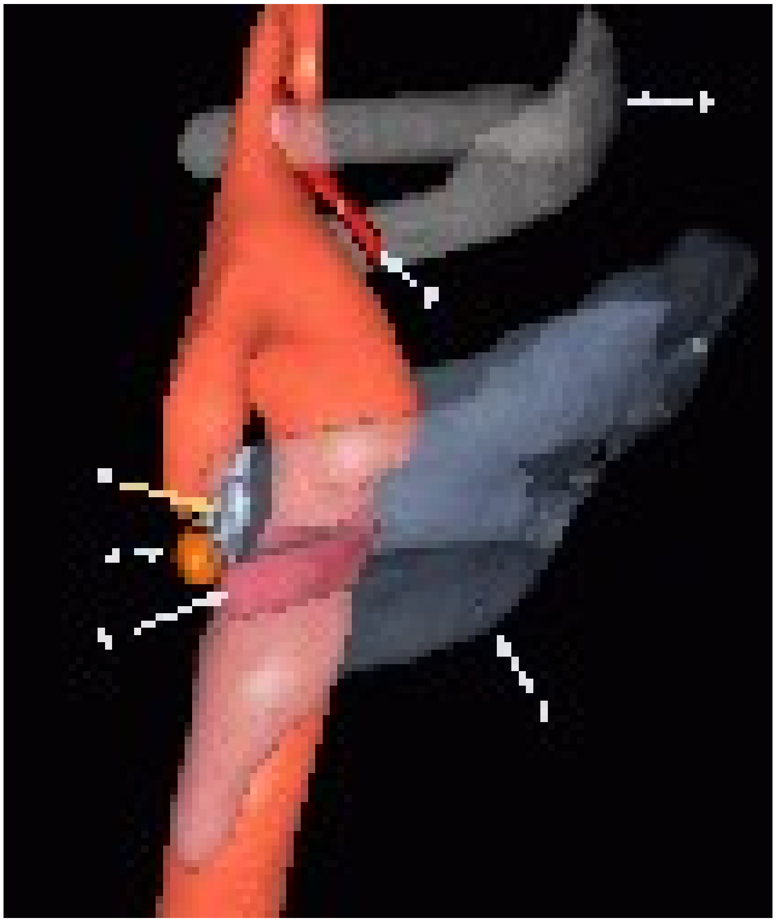

Figure 8: Patient 3. A lateral global view of the virtual endoscopy. The airway lumen, in orange, runs superior to inferior. The hyoid bone (H) and thyroid cartilage (T) have been rendered transparent. E= epiglottis; A= right arytenoid cartilage; S= stenotic intra-arytenoid web; V= vocal fold.