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Optical Coherence Tomography–Enhanced Microlaryngoscopy: Preliminary Report of a Noncontact Optical Coherence Tomography System Integrated With a Surgical Microscope

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Abstract

Objectives—Optical coherence tomography (OCT) is a new imaging modality that uses near-infrared light to produce cross-sectional images of tissue with a resolution approaching that of light microscopy. We have previously reported use of OCT imaging of the vocal folds (VFs) during direct laryngoscopy with a probe held in contact or near-contact with the VFs. This aim of this study was to develop and evaluate a novel OCT system integrated with a surgical microscope to allow hands-free OCT imaging of the VFs, which could be performed simultaneously with microscopic visualization.

Methods—We performed a prospective evaluation of a new method of acquiring OCT images of the VFs.

Results—An OCT system was successfully integrated with a surgical microscope to permit noncontact OCT imaging of the VFs of 10 patients. With this novel device we were able to identify VF epithelium and lamina propria; however, the resolution was reduced compared to that achieved with the standard contact or near-contact OCT.

Conclusions—Optical coherence tomography is able to produce high-resolution images of vocal fold mucosa to a maximum depth of 1.6 mm. It may be used in the diagnosis of VF lesions, particularly early squamous cell carcinoma, in which OCT can show disruption of the basement membrane. Mounting the OCT device directly onto the operating microscope allows hands-free noncontact OCT imaging and simultaneous conventional microscopic visualization of the VFs. However, the lateral resolution of the OCT microscope system is 50 μm, in contrast to the conventional handheld probe system (10 μm). Although such images at this resolution are still

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useful clinically, improved resolution would enhance the system's performance, potentially enabling real-time OCT-guided microsurgery of the larynx.

Keywords

laryngeal imaging; laryngoscopy; larynx; optical coherence tomography; vocal cord; vocal fold

INTRODUCTION

Optical coherence tomography (OCT) is a new imaging modality that combines low coherence light and interferometry to produce cross-sectional images of tissue structures. It is analogous to ultrasound with the exception that broadband near-infrared light (wavelength, 1,310 nm), rather than sound, is used to create cross-sectional images of tissue, with a resolution (approximately 7 μm) approaching that of light microscopy.[1]

Our group has previously reported our experience with OCT imaging using a handheld probe held in contact or near-contact with the mucosal surface under examination in 1) normal larynges[2]; 2) laryngeal cancer[3]; 3) the oral cavity and oropharynx[4]; 4) the nasal cavity[5]; and 5) the pediatric[6] and neonatal[7] airways. The contact or near-contact OCT system has obtained excellent images, which have provided detailed information on the layered structure of the mucosa from various sites of the upper aerodigestive tract (UADT) in a noninvasive manner. The major drawback of OCT imaging is that its maximum depth of penetration is only 1.6 mm at present, although this is sufficient to visualize the full thickness of the normal epithelium and superficial lamina propria (SLP) of the human vocal fold. The line of demarcation between these two layers represents the basement membrane, the disruption of which is diagnostic for malignancy.[3,8] Other investigators have used a similar handheld probe OCT system to image the vocal folds.[9–13]

Although OCT imaging using a handheld probe has successfully imaged benign and malignant lesions, some disadvantages have been noted, particularly when it was used in conjunction with laryngeal microsurgery. Motion artifact may occur, owing to the movement of the probe tip, which is amplified by any tremor the operating physician may have. During imaging, the probe may obscure visualization of the operative field, owing to the restricted diameter of a surgical laryngoscope. Most importantly, the presence of the probe within the lumen of the laryngoscope interferes with the use of microlaryngeal instruments, compromising the ability to perform bimanual surgery on the larynx with simultaneous OCT imaging. Often, the surgeon must remove the OCT probe from the field and then introduce the surgical instruments into the laryngoscope; this step prolongs surgery and limits the potential benefit of OCT in imaging any disorders.

This aim of this study was to design, construct, and evaluate a novel OCT imaging system — one that is integrated with a surgical microscope — to allow hands-free OCT imaging of the vocal folds to be performed simultaneously with conventional microscopic visualization.

MATERIALS AND METHODS

OCT Equipment

Details of the time-domain OCT device used in this study have been described previously[14,15] and are reviewed briefly for this report. The optical pathways for both the OCT device and the microscope are illustrated in schematic form in Fig 1.

The OCT system consists of 1) an interface device that houses the scanning system and 2) a workstation containing the interferometer, the low coherence light source (central wavelength λ, 1,310 nm, JDS Uniphase, San Jose, California),[16] the aiming beam generator, detectors, and other optical and signal processing hardware needed for image reconstruction, display, and recording.

The interface device is the novel part of the OCT system, and this replaces the handheld probe used in our previous studies[2–4] to allow noncontact OCT imaging at a distance of 40 cm from the target tissues. The interface device is an acrylic housing (a in Fig 2) that attaches to the operating microscope via the lens mounting ring. The device has an input for the fiber from the interferometer (b in Fig 2), a lens (c in Fig 2) that is moved to adjust the focal length of the OCT beam, a mirror (d in Fig 2) mounted on a galvanometer that allows scanning in the coronal plane, and a second fixed mirror that redirects the path of the light (e in Fig 2). A gimbaled micromanipulator (f in Fig 2) controls the aiming beam for the OCT signal.

Images are generated by raster-scanning the beam on the tissue by use of the galvanometer-mounted mirror. The region of interest scanned with this system is 1.6 mm deep and 6 mm wide. The axial resolution of the imaging system is approximately 7 μm, and is determined by the coherence length of the light source. The lateral resolution of OCT is diffraction-limited, and is 50 μm at a distance of 40 cm from the fiber terminus (b in Fig 2). In contrast, the lateral resolution is 10 μm for the handheld OCT probe system.

This new system was extensively tested by imaging the vocal folds of excised pig larynges before being used with human subjects.

Subjects

This study was performed with the approval of the Human Subjects Institutional Review Board at the University of California, Irvine (UCI). Informed consent was obtained from each patient before imaging.

Optical coherence tomography imaging with the new device was performed in 10 patients who were undergoing upper airway endoscopy under general anesthesia at the UCI Medical Center. The study population consisted of 5 patients with a diagnosis of squamous cell carcinoma (SCC) of the larynx; 1 patient with carcinoma in situ of the glottis, 1 patient with mild dysplasia of the vocal folds, 2 patients with SCC of the oropharynx and clinically normal vocal folds, and 1 patient with Reinke’s edema. In the patients with SCC of the larynx, the subsites involved were supraglottic in 1 (a T3 lesion), glottic in 3 (1 each of T2,

T3, and T4 lesions), and subglottic in 1 (a T3 lesion). The majority of the subjects were male (6 of 10). The mean age of the subjects was 54 years (range, 44 to 75 years).

Acquisition of OCT Images

For each subject, the larynx was exposed with surgical laryngoscopes and suspension. Endoscopic photographs were taken. Biopsies or surgical excisions were performed when indicated clinically after OCT imaging had been performed.

The operating microscope with a 400-mm lens was positioned to provide optimal visualization of the vocal folds through the lumen of the laryngoscope. The OCT aiming beam was used to select the region of the vocal folds for examination. Images were then acquired en face, in the coronal plane, and displayed continuously on a monitor. The focal length of the scanner system was adjusted by hand to focus the OCT beam on the tissue surface. The position of the microscope was also adjusted so that the angle at which the OCT signal encountered the vocal folds was as close to 90° as possible to maximize the detection of backscattered light. As soon as an image of the vocal fold had been obtained (indicating that the focal length was correct), scanning was performed over a 6-mm range at a frame rate of 1 Hz. The images on the monitor were used to adjust the position of the microscope (and thus the OCT beam). Images were acquired with surgical laryngoscopes of various sizes (A, B, and C Kleinsasser Operating Laryngoscopes, and the Distending Operating Pharyngo-Laryngoscope, Karl Storz Endoscopy America, Inc, Culver City, California) in order to maximize the light delivered and detected.

Images were captured continuously and recorded for further detailed analysis. All still images in this study were 1.6 mm deep by 6 mm wide. By convention, increased backscatter of OCT light is depicted as white signal intensity on grayscale imaging.

Image Analysis

Optical coherence tomography videos, still OCT images, and conventional endoscopic photographs were reviewed by 4 of the authors (D.E.V., J.M.R, W.B.A., B.J.F.W.) on 2 occasions after operation, each separated by at least 2 weeks.

Overall image quality and the presence or absence of a definable border between the epithelium and the SLP, representing the basement membrane, were noted. The image quality for each subject was rated on a 1 to 4 scale as follows: 1 (poor) = unable to interpret adequately; 2 (adequate) = able to discern tissues and planes but limited depth of penetration, or other artifact (eg, blood) compromising the image data; 3 (good) = good signal penetration, able to distinguish subsurface structures with minimal artifact; 4 (excellent) = outstanding imaging detail and signal penetration with minimal to no artifact.

An overall score for the quality of each image was determined by averaging and rounding to the closest whole number the grades assigned to each image by the 4 observers. Two average scores were obtained as each observer graded the images twice. Intraob-server reliability of the ratings of image quality was assessed for each observer with the weighted kappa coefficient (*x*w), which was determined with MedCalc (MedCalc Software, Mariakerke, Belgium). The kappa coefficient tests reliability by estimating the proportion of

agreement and correcting for chance agreement. Interpretable values range from 0 (less agreement than expected by chance) to +1 (complete agreement, or perfect reliability). As the rating categories graded levels of quality, *x*w values were used to adjust for the different levels of disagreement.[17] The interpretation of *x*w values is varied. We used a commonly accepted description of strength or reliability (see Table[18]).

RESULTS

Images were obtained for all 10 subjects with the OCT microscope system. Image acquisition required approximately 15 minutes per subject with the OCT microscope, compared to approximately 5 minutes per subject with our handheld OCT probe system.[2] Images of normal or nearly normal vocal folds were obtained in each case, but images could not be obtained in areas of exophytic SCC, especially if the lesions were friable and bleeding.

The image quality ratings were as follows for both assessments: poor for 5 images, adequate for 2, good for 3, and excellent for none. In 8 of the 10 subjects, the average image quality scores were in agreement. Intraobserver reliability was fair for 1 of the observers, moderate for 1, good for 1, and very good for 1. The *x*w values for each of the observers ranged from 0.32 to 0.90.

Most of the OCT examinations were adequate or good, and no examinations received an excellent score. The image quality was inferior to that obtained with the standard handheld probe system. The demarcation between the epithelium and the SLP, representing the basement membrane, was visualized in 5 of the 10 subjects (those in the adequate and good groups). Early images obtained with this system were generally of poorer quality than those obtained later in the series. Figure 3 is illustrative and depicts a normal vocal fold in which the epithelium cannot be clearly delineated from the SLP.

Improved image quality was evident in later studies. Figure 4 shows the vocal folds of a 48-year-old male smoker who presented with hoarseness. Bilateral vocal fold irregularities were observed on laryngoscopy. The dot (green aiming beam spot) on the left vocal fold is the aiming beam of the OCT system. The entire lesion was imaged with OCT. The epithelial layer is of normal thickness,[2] and the basement membrane (the junction between the epithelium and the SLP) is intact. The left vocal fold lesion was excised, and the entire specimen was submitted for histologic examination, which revealed mild dysplasia and acute inflammation. The OCT image and the photograph of the histologic findings are representative of the lesion. The anterior commissure of the same patient is depicted in Fig 5. The epithelium of the most anterior portions of both vocal folds is clearly defined, and the area of the basement membrane is marked with arrows.

The potential clinical value of visualizing an intact basement membrane is illustrated in Fig 6, which depicts an irregular lesion on the right posterior vocal fold of a nonsmoking 47-year-old woman. The OCT imaging did not include the portions of the lesion on the undersurface of the vocal fold, as this system (like a conventional microscope) images the glottis en face from above. A representative OCT image shows a thickened epithelium with

the boundary between the epithelium and the SLP clearly intact, indicating that the integrity of the basement membrane is likely preserved. The OCT images suggest that this is not an invasive lesion. The entire lesion was excised transorally with a carbon dioxide laser in a piecemeal fashion with frozen section control.[19] Pathologic examination of all tissue excised found carcinoma in situ, with no evidence of basement membrane disruption.

DISCUSSION

It should be emphasized that although individual frames were selected to illustrate this report, in practice OCT imaging is performed in real time at 1 Hz, providing a time series of images that are analogous to viewing an ultrasound study. Significant amounts of information may be gained from analysis of a time series of images. Therefore, OCT imaging is much less prone to sampling errors than is histology, as every region of interest can be scanned multiple times quite rapidly. This is particularly true for cutting-edge laboratory systems that can acquire images at near-video rates.

Optical coherence tomography is a nascent imaging modality. Since the initial report by Dr Fujimoto's group,[1] OCT has undergone relatively slow adoption, except in the field of ophthalmology.[20] The use of OCT in the head and neck is an obvious choice, because most disease in this area originates from the thin mucosal surfaces of the UADT. Of all the mucosal sites of the UADT, we believe that the larynx especially would benefit from the application of this new imaging technology, as the ability to noninvasively image the layered microstructure of the vocal folds would enhance the ability to both diagnose and treat laryngeal disorders. Currently, image resolution is reaching its fundamental limits in terms of the optics, and therefore current research in this area of biophotonics is concentrating on instrumentation and delivery technologies, to facilitate new clinical applications.

In this report we have focused on the preliminary evaluation of a novel OCT system, in which the OCT scanner has been integrated with a surgical microscope to permit noncontact OCT imaging of the vocal folds, and attempted to define the potential advantages and limitations of such a device.

Vocal fold images were obtained in all subjects examined by integrated OCT and surgical microscopy. However, we observed significant differences in image quality within the subject group, and image quality was, as expected, inferior to that obtained with a standard handheld probe system (Fig 7). Only 50% of the studies were rated as of either adequate or good quality. The good-quality images were encouraging, with high-intensity signal patterns clearly demonstrating the layered structure of the vocal fold. In images rated as adequate, the basement membrane (as defined by the junction between the epithelium and the SLP) was identified in each case; this ability has important implications for the diagnosis of microinvasive malignant lesions. Unfortunately, we were unable to obtain adequate images from lesions that were particularly bulky or were bleeding. The irregular surface of these bulky lesions affected image quality, as the OCT beam was not incident on the tissue surface at right angles (see below). Furthermore, these larger lesions were often friable, and as blood absorbs the light from the system, less signal is backscattered, with the result of darker

images of inferior quality. However, this limitation may not prove to be especially significant, as OCT would probably not add much information to the evaluation of these more advanced lesions, because, first, the diagnosis is usually not in question, and second, because conservative treatment is not indicated for these lesions. We believe that the preferred indications for OCT imaging would be 1) the evaluation of smaller epithelial lesions of indeterminate appearance to assess for signs of invasion through the basement membrane (eg, white lesions)[3]; 2) the evaluation of lesions of the SLP (such as cysts, nodules, and scars)[10]; and 3) the guidance of surgical excision of early laryngeal cancers, to ensure that the lesion is excised completely while also allowing maximum preservation of normal tissue.[12] As the device described in the current study is integrated with a surgical microscope, it has particular potential to permit assessment of excision margins, similar to the current role of histologic frozen sections. However, OCT could render its assessments instantly and in real time — potential advantages over frozen sections.

Improvement of the quality of images, especially in the subjects in whom OCT yielded images of little clinical value, is crucial. The quality of images obtained by OCT is determined by the amount of incident light that is backscattered and depends on factors such as the optical properties of the tissue under examination, the geometry of the instrument, and the optical path length. The most important technical factor limiting the performance of this OCT system is the distance between the terminus of the OCT fiber (b in Fig 2) and the tissue surface. In the present system, light must travel approximately 40 cm to the tissue surface, backscatter, and then retrace the same optical pathway to the fiber terminus. The amount of backscattered light that can be collected is therefore limited by the small numerical aperture intrinsic to surgical microscope systems. As the intensity of light collected decreases, the image quality deteriorates. The handheld OCT probe system gives images superior to those from the OCT microscope system because the probe is held immediately adjacent to the tissue surface, and thus has a large numerical aperture. In contrast, the OCT microscope system described in this report has the longest focal length of any system reported to date. The maximum lateral resolution of this system (50 μm) is much less than that of our handheld probe system (7 μm), but even at this resolution important anatomic features, such as the boundary between the epithelium and the SLP, can be resolved, and therefore the information provided by the microscope OCT system remains clinically useful. Fortunately, axial resolution (into the depth of the tissue) does not depend upon these geometric concerns, and does not change with optical design. Axial image resolution is more important in the assessment of epithelial lesions, because the depth of a lesion and its relation to the basement membrane are the most crucial characteristics of these lesions. However, the depth of penetration of OCT (which is independent of its axial resolution) is still limited to a maximum of 1.6 mm, which will restrict clinical utility (see below for further discussion).

The image quality was worse when the OCT imaging was performed through surgical laryngoscopes of a smaller diameter. The smaller lumen limits the amount of light that can be directed onto the tissue surface (and thus less light is reflected back to the OCT system). Where possible, OCT was performed through the largest-bore laryngoscope that could be introduced safely, such as the Distending Operating Pharyngo-Laryngoscope (Karl Storz Endoscopy America, Inc), which resulted in improved image quality. This finding was

expected, given that image quality is proportional to the amount of backscattered light collected.

The inability to obtain good images of bulky and irregular lesions (all SCC in this series) was also expected, and again, relates to fundamental technical limitations of OCT. The forward scattering of coherent photons into the tissue is greatest when the beam is incident on the tissue at a right angle. Likewise, the backscattered optical signal is also greatest at 90°. The microscope (or the surface of the tissue) must be adjusted to minimize deviation from the perpendicular. Maintaining incident light at right angles to markedly exophytic lesions is difficult, if not impossible. Optical coherence tomography is better suited to flatter lesions, such as those suspicious for early cancer.

The main advantage of OCT is that it acquires real-time cross-sectional images of tissue noninvasively. Preservation of tissue is most important in dealing with glottic lesions, as unnecessary or excessive tissue biopsy or resection may result in soft tissue deficits and/or vocal fold scarring, both of which may have significant effects on postoperative voice quality.[21] As a preoperative imaging modality, OCT may help to avoid these complications by providing the clinician supplemental information about the structure and extent of a lesion before a biopsy (which may then become unnecessary).[10] As an intraoperative imaging modality, OCT may help to decrease the sampling error associated with biopsies by directing the surgeon to the most abnormal areas of the vocal fold epithelium for biopsy. Optical coherence tomography may also facilitate the preservation of tissue by distinguishing between normal and pathologic vocal fold mucosae during operation, and thus guiding the microsurgical treatment of vocal fold lesions in real time.

As discussed previously, determining the integrity of the basement membrane (seen indirectly in OCT images as the interface between the epithelium and the SLP) is crucial to this technology's ability to diagnose invasive carcinoma.[2,3] Armstrong et al[3] demonstrated that in the larynx OCT is able to clearly identify disruption of the basement membrane by invasive carcinoma, and is also able to identify transition zones between normal epithelium and carcinoma. However, in using OCT imaging to determine whether an epithelial vocal fold lesion is malignant on the basis of basement membrane integrity, there are two technical limitations that are common to both the standard handheld probe system and the microscope system. First, false positives may occur in benign epithelial lesions in which the thickness of the lesion exceeds the maximum OCT signal depth penetration (approximately 1.6 mm).[2] In such cases, the basement membrane zone will not be identified even if one is present. For example, a benign lesion, such as a papilloma, that is greater than 1.6 mm in depth will have the same appearance as a carcinoma on OCT. Although false positives are obviously undesirable, in the case of suspected malignant disease, it is safer to classify a lesion as malignant when it is not than to characterize a malignant lesion incorrectly as benign. Furthermore, we believe that the utility of OCT is greatest in thinner lesions at the periphery of thicker tumors (where resection margins may be clinically difficult to determine)[12] or in evaluation of lesions of the SLP, in which the overlying epithelium is normal and therefore very thin.[10]

The second limitation of OCT relates to image resolution. The OCT systems used most commonly at present cannot resolve cellular features (such as cellular maturation) and subcellular structures (such as nuclear pleomorphism) and therefore cannot determine whether an epithelium is dysplastic. This issue is discussed in detail in an earlier report from our group.[3] Fortunately, recent developments in OCT technology using broadband femtosecond light sources have improved axial resolution from 7 μm (that of a standard handheld system) to 1 to 5 μm, which does allow imaging on a cellular level, including the characterization of some intracellular structures, such as the nucleus.[22] Given the progress in this technology to date, these ultrahigh-resolution OCT systems will eventually be incorporated into clinical devices that may be able to differentiate among benign, premalignant (dysplastic), and malignant lesions by determining both the cytologic and the histologic characteristics of a lesion in situ and in real time. The aim of the current article is to report on the preliminary experience with a prototype of a new OCT device integrated with a surgical microscope, and not to define the accuracy of the diagnostic capability of OCT in general, which has yet to be determined. An evaluation such as this should be undertaken with the most reliable and powerful OCT system available, which, at the present time, is the handheld contact or near-contact system.

The major operational challenge with the OCT microscope system is aligning the OCT beam and adjusting the focal length of the system so that the light is focused precisely on the target tissues. This is not a trivial task. Because most investigational OCT systems use invisible near-infrared light, a visible aiming beam is necessary. However, owing to the different wavelengths of the laser used for the aiming beam and for the OCT beam, the two beams are not necessarily coincident on the target tissue. This makes aiming the OCT beam difficult. Furthermore, whereas in conventional surgical microscopy, changes in the distance from the microscope objective to the target tissue of several millimeters have little impact on image quality, OCT imaging is exquisitely sensitive to geometry, as images are only obtained in a thin plane that is 1.6 mm deep. To compensate for this sensitivity, we designed our prototype device to incorporate a moveable lens in the optical pathway to allow adjustments in the focal length. The position of the lens was adjusted during imaging and monitored in real time. In contrast, imaging the vocal folds with a handheld OCT probe does not require this maneuver, as the focal length is fixed and lies just outside the protective casing of the probe tip.[2] The major reason that the examinations in the current study took longer than those previously undertaken with the handheld probe was the extra time spent aiming and focusing the OCT beam on the target tissue.

Optical coherence tomography imaging has several potential advantages for use in laryngeal surgery. First, the diagnosis of many epithelial vocal fold lesions, such as leukoplakia, is often uncertain without resorting to the gold standard of diagnosis — biopsy with histologic examination. The main disadvantage of a biopsy is the potential for scarring that may lead to persistent dysphonia, which has especially significant implications if a neoplastic process is excluded and no further ablative treatment is required. Optical coherence tomography has the potential to diagnose lesions in situ, in real time, and in a noninvasive manner. Second, in performing a biopsy on a vocal fold with an extensive area of abnormality, there is the potential for sampling error, possibly resulting in failure to diagnose important disorders such as SCC. Optical coherence tomography may be used to reduce this error, by alerting

the clinician to areas of a lesion in which the basement membrane cannot be identified, either owing to a thick lesion (of any cause) or secondary to disruption of the basement membrane by an invasive carcinoma. Third, the surgical treatment of vocal fold lesions may be improved by the use of OCT. For example, during the resection of an early glottic cancer, which is commonly undertaken by a transoral laser technique,[19,23] discrimination between normal tissue and invasive carcinoma may be difficult even with the operative microscope. As OCT can provide detailed information about tissue structure in real time, the use of this imaging technology may help to guide surgery, delineate tumor boundaries, and direct surgery toward regions of concern. Overall, this may lead to superior oncological resection and maximal preservation of normal tissue to optimize postoperative laryngeal function. Shakhov et al[12] used a handheld probe OCT system to monitor laser excision of early laryngeal cancers, and concluded that OCT localized the lesions more precisely both before and during operation. It is important to note that the current OCT systems in use for medical applications are not able to accurately identify areas of dysplasia in an epithelium unless the dysplastic epithelium is thicker than normal. However, the new generation of ultrahigh-resolution OCT systems (with an axial resolution of 1 to 2 μm) will be able to image individual cells and even subcellular structures,[22] and thus would be able to detect dysplastic epithelium.

CONCLUSIONS

Optical coherence tomography is a new optical imaging modality able to produce cross-sectional images of tissue to a depth of 1.6 mm, and with a resolution approaching that of light microscopy (approximately 7 μm). We have developed a novel system that combines OCT with surgical microscopy. With this system, hands-free noncontact OCT imaging of normal or near-normal vocal folds was successfully performed simultaneously with microscopic visualization. This preliminary experience has identified the advantages and limitations of the OCT microscope system. We believe that the potential benefits of a microscope-integrated OCT system will be 1) to improve the diagnosis of laryngeal lesions in a noninvasive manner and 2) to allow the endoscopic treatment of laryngeal lesions to be undertaken with greater accuracy than it can be when the procedure is performed with conventional microscopic visualization alone.

Further refinements are required before this system can be used clinically. However, given the advancements in OCT technology to date, including the development of new ultrahigh-resolution OCT systems, and given the dramatic decrease in the costs of OCT system components spurred by demand from the defense and telecommunication industries, OCT is poised to become an important part of the armamentarium for the diagnosis and treatment of mucosal lesions of the UADT.

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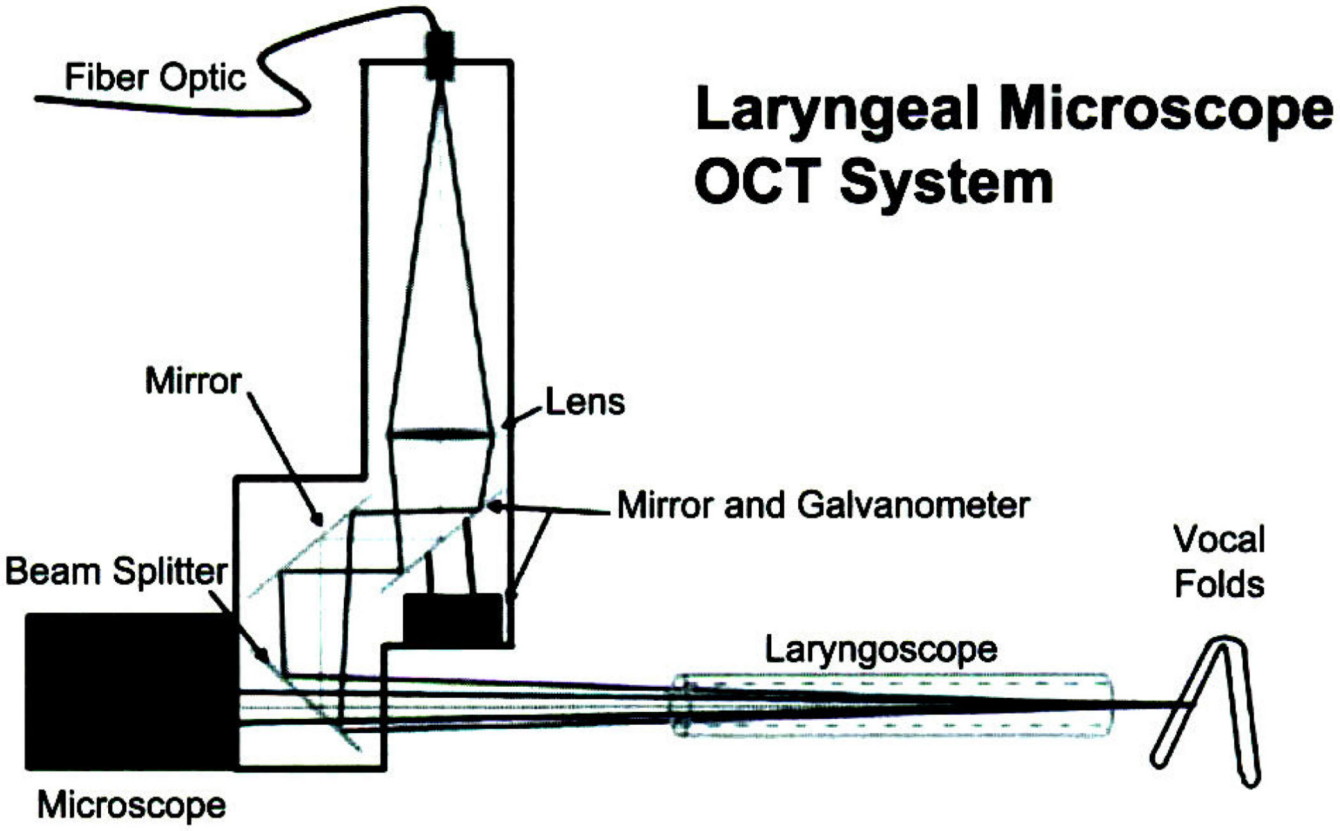

Fig. 1.
Pathways of normal light and optical coherence tomography (OCT) beam in OCT microscope system.

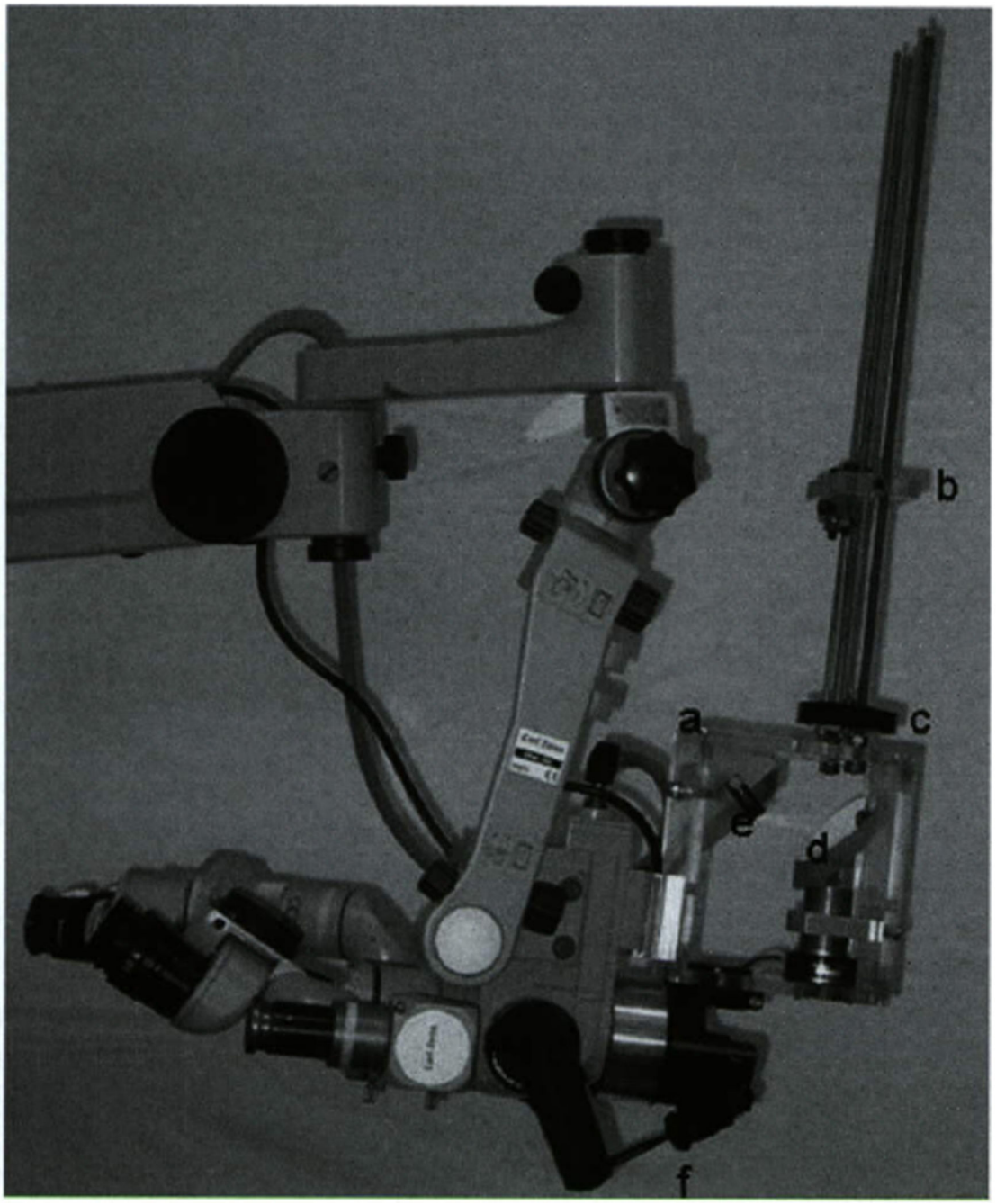

Fig. 2.

OCT interface device mounted on surgical microscope. a — acrylic cube; b — input for OCT light fiber; c — moveable lens; d — mobile mirror mounted on galvanometer; e — fixed mirror; f — micromanipulator.

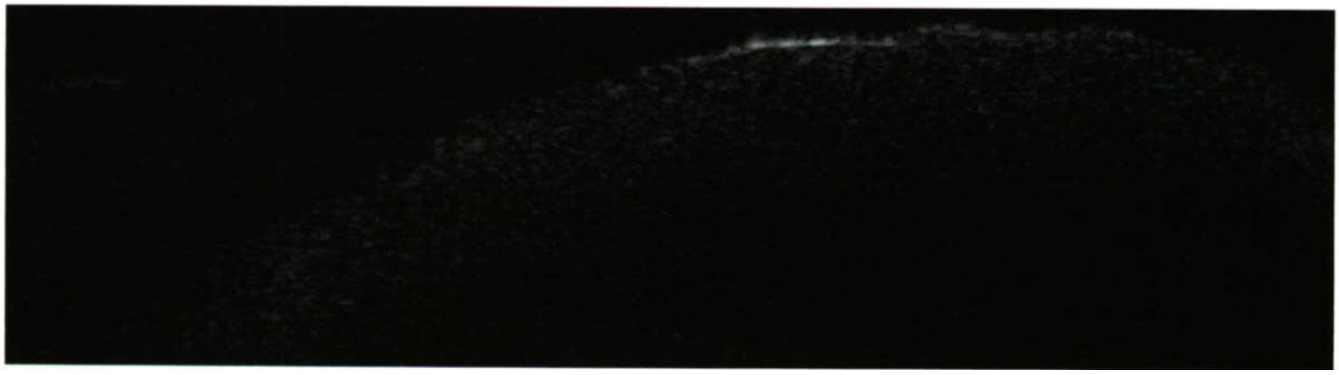

Fig. 3.
Early OCT image of vocal fold. Epithelium is not seen as layer distinct from superficial lamina propria (SLP).

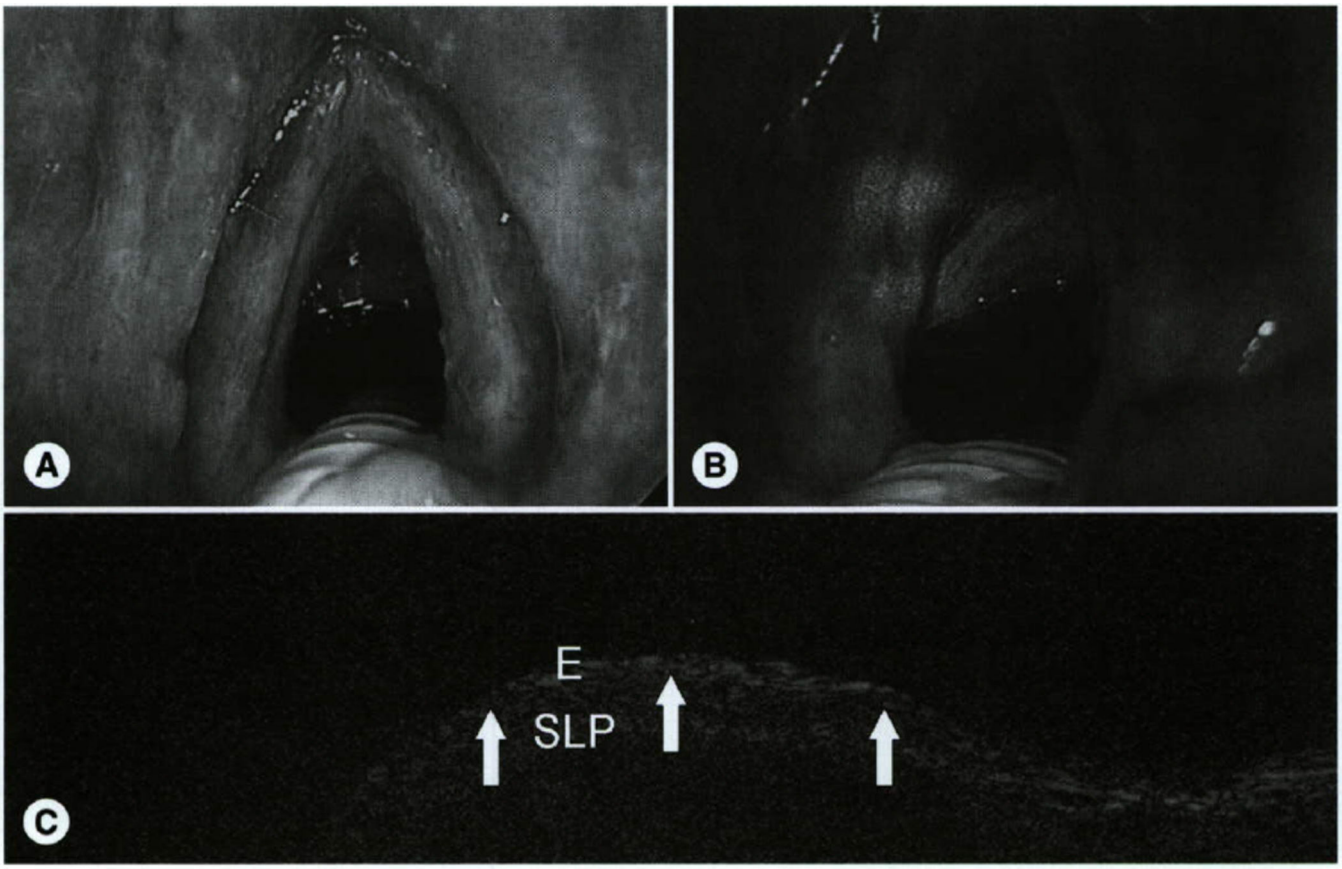

Fig. 4.

A) Endoscopic photograph of vocal folds. **B**) Endoscopic photograph demonstrates aiming beam (green) of OCT system. **C**) OCT image of left vocal fold. Demarcation between epithelium (**E**) and SLP, representing basement membrane, is marked with arrows.

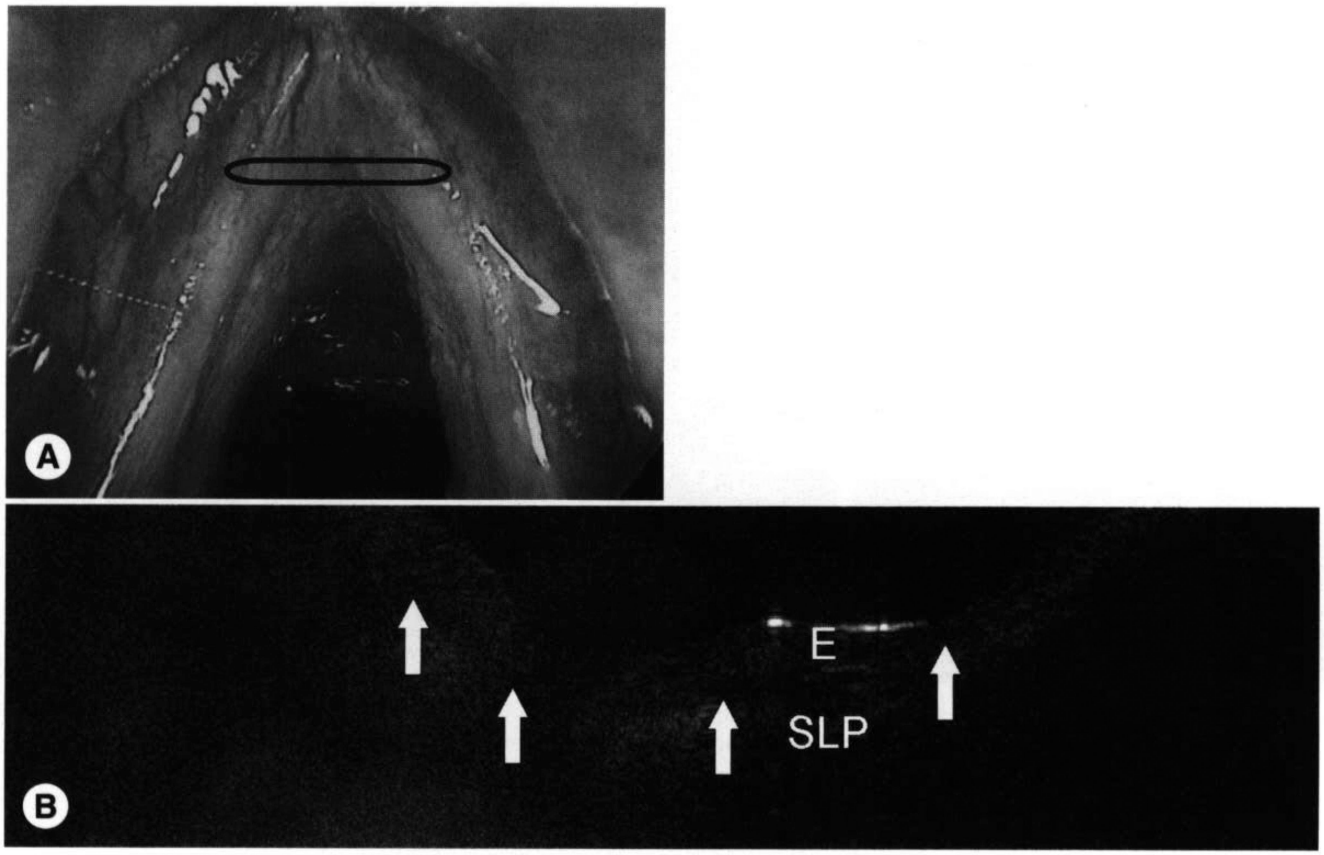

Fig. 5.

A) Endoscopic photograph of anterior commissure of larynx with area imaged by OCX marked. **B**) OCT image of anterior commissure. Demarcation between epithelium (**E**) and SLP, representing basement membrane, is marked with arrows.

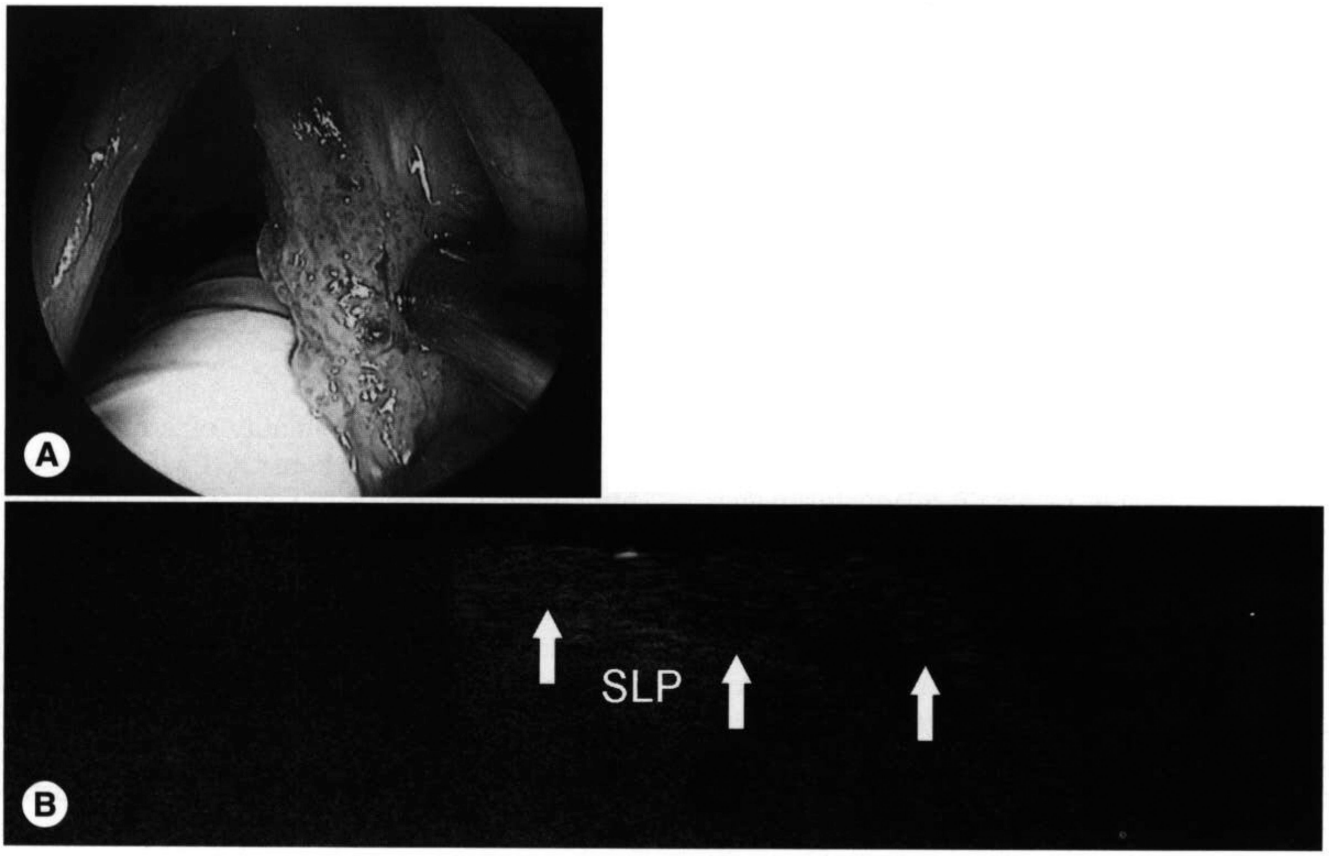

Fig. 6.

A) Endoscopic photograph of right posterior vocal fold lesion, proven to be carcinoma in situ on biopsy. **B**) OCT image of right posterior vocal fold lesion. Epithelium is thickened; however, demarcation between epithelium and SLP (marked with arrows), representing basement membrane, is intact.

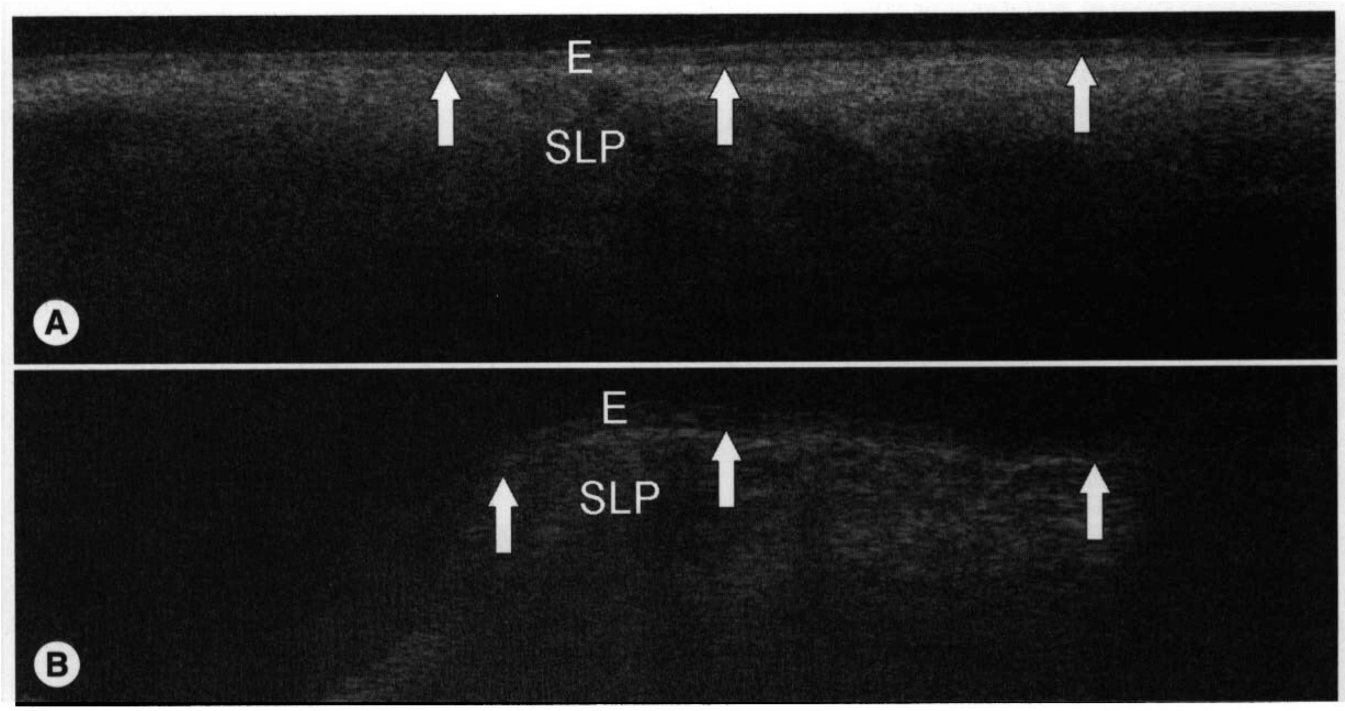

Fig. 7.

A) Image of vocal fold obtained with handheld OCT probe. **B**) Image of vocal fold obtained with microscope OCT system. Demarcation between epithelium (E) and SLP, representing basement membrane, is marked with arrows.

Table

STRENGTH OF AGREEMENT ACCORDING TO WEIGHTED KAPPA COEFFICIENT[18]

Value of Weighted Kappa Coefficient	Strength of Agreement
<0.20	Poor
0.21 to 0.40	Fair
0.41 to 0.60	Moderate
0.61 to 0.80	Good
0.81 to 1.00	Very good