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REVIEW

Optical coherence tomography applications in otolaryngology

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KEYWORDS

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Abstract

Optical coherence tomography is a novel imaging technique providing high-resolution bidimensional images of tissue microstructures. Several studies have been published on the use of this technique in different fields of medicine, particularly ophthalmology. There are very few studies in the field of otolaryngology. This paper presents various applications of optical coherence tomography in the different sub-specialties of otolaryngology, as well as the benefits of this technique over traditional diagnostic methods.

PALABRAS CLAVE

Tomografía de coherencia óptica; Otorrinolaringología; Biopsia

Aplicaciones de la tomografía de coherencia óptica en otorrinolaringología

Resumen

La tomografía de coherencia óptica es una técnica de imagen innovadora con la cual se pueden obtener imágenes en dos dimensiones de alta resolución sobre la microestructura de los tejidos. Hoy día hay varios estudios sobre el uso de esta técnica en distintas ramas de la medicina, sobre todo en oftalmología. Sn embargo, poco se ha estudiado en la otorrinolaringología. En este trabajo presentamos los diferentes usos de la tomografía de coherencia óptica en los distintos campos de la otorrinolaringología, así como sus beneficios sobre métodos convencionales de diagnóstico.

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Introduction

Basic principles

Optical coherence tomography (OCT) imaging is a relatively new diagnostic imaging technique in which cross-sectional or topographic high resolution images of biological tissues are obtained.¹ OCT operates in a manner similar to ultrasound, but uses near infrared light instead of sound to discriminate intrinsic differences in tissue structures. It works by projecting a signal of low coherence light on tissue, which is then reflected and measures the magnitude and phase of light from tissues of different depths. The majority of current OCT devices used in clinical trials have an axial resolution of 10 μ m and a penetration of up to 2 mm in most tissues.^{2,3} This technique has the ability to provide high-resolution images in turbid media, such as living tissue, and gives us the opportunity to characterize both the normal and the pathological microanatomy.⁴

Basic fundamentals

The basic principle on which OCT works can be seen in Figure 1. Using a Michelson interferometer, a light source, transmitted by a superluminescent diode, is transmitted through a beam splitter and is divided into a reference beam and a sample beam. The reference beam is reflected unchanged through a mirror and the sample beam is dispersed by the different layers of tissue. The beams are then united again in the beam splitter and are emitted to a photo detector, through which they are digitized and processed by a computer.

Medical uses

The clinical applications in which OCT has been most successful are those situations in which it is necessary to



Figure 1 Diagram of a system of optical coherence tomography with a Michelson interferometer. BS indicates beam splitter; PD, photodetector; RB, reference beam; SB, sample beam; SD, superluminescent diode. obtain information about the microstructure of tissues, but the risk and morbidity of a biopsy makes them prohibitive. The earliest medical uses were in ophthalmology, where OCT still has a major importance.⁵ OCT is used to obtain images of the retina to document microscopic pathological changes of the macula,^{6,7} in order to study the thickness of the cornea⁸ and to monitor corneal incisions in cataract surgery.⁹ Another early medical use of OCT was in dermatology,¹⁰ where its main function is to characterize skin tumours and inflammatory processes without the need to obtain a biopsy.¹¹

In cardiology OCT has been used to analyze the microstructure of coronary arteries, ¹² as well as to assess their occlusion. ¹³ In pneumology, it is used to obtain images of the pleura and the lung when there is suspicion of malignant tumour. ¹⁴ In gastroenterology, it is used to study the morphology of the gastrointestinal tract ¹⁵ and to diagnose and monitor premalignant injuries. ¹⁶ In urology, it is used to describe the tissue of the urinary tract without the need to use biopsies¹⁷ and to characterize different and inflammatory neoplastic processes. ^{2,18} OCT also been used in neurology, ¹⁹ primarily for the diagnosis of multiple sclerosis. ²⁰

OCT in otorhinolaryngology

Laryngology

Early diagnosis of laryngeal cancer is critical for its effective treatment. While clinical examination can identify premalignant lesions by direct laryngoscopy with optic fibre, sometimes it cannot obtain reliable information and it is impossible to determine the severity of dysplasia without obtaining a biopsy.²¹ That is why OCT is a promising diagnostic technique in laryngology, since it could reduce the need for biopsies thus avoiding their associated morbidity.

In one of the first works published, where OCT was used to obtain images of the larynx, it showed a good correlation between the images obtained and the histopathological sections, and it clearly showed the normal structure and alterations in tissue.²² Figure 2 shows the normal anatomy of the vocal cords. In subsequent studies, OCT images were obtained which successfully demonstrated the different structures of the vocal cords, as well as different types of lesions, benign and malignant, corroborated histologically. These results demonstrate the potential usefulness of OCT in the diagnosis, control and treatment plan for different laryngopathies.²³⁻²⁹

The use of OCT has been specifically described in patients undergoing direct laryngoscopy, during which images were taken of the areas of interest.^{26-28,30} One of these studies describes how to clearly identify the infiltration of the basal membrane by laryngeal cancer, as well as the transition zones at the margins of the tumour.²⁶ Figure 3 shows that the tumour has invaded the basal membrane. In another comparative study, images were obtained from patients without disease and patients with benign disease. It accurately describes various microstructures, such as blood vessels, glands, cysts, and the average epithelial thickness of the different sites of the larynx.²⁷ Finally, one group concluded that the use of microlaryngoscopy along with OCT



Figure 2 Optical coherence tomography (OCT) of the normal anatomy of the vocal cords. BM indicates basal membrane; LP, lamina propria; SSE, stratified squamous epithelium. B. OCT of the vocal cords showing normal anatomy.

is more sensitive than microlaryngoscopy alone, as it obtains an accurate diagnosis in 89% of cases compared with 80% using microlaryngoscopy alone.³⁰ In another study, OCT was used incorporating a microscope (Figure 4) for its use during direct laryngoscopy without using the hands, which allows taking images while viewing under a microscope. Although this represents a functional advantage and although the images are of clinical use, the resolution is inferior to that of images obtained with a traditional probe.³¹

Another use of OCT in laryngology has been as a means of surgical control during laser surgery for laryngeal carcinoma in early stage, where the use of OCT has provided factual information about structural changes in the tissue; thus enabling a more accurate determination of the area to be removed for diagnostic purposes or to obtain disease-free tumour margins.³² The usefulness of OCT has also been reported in obtaining images from different sites of the larynx, with the patient awake, using a probe which is inserted through the nose and contacts the area of interest.³³ In 2 studies, the OCT is incorporated to a rigid laryngoscope for its use in the clinic. However, the images obtained do not have the same resolution.^{34,35}

The studies on animals have focused on observing the microscopic changes that occur after various types of injuries. One study used CO_2 laser in order to determine changes in the vocal cords in a porcine model. The images were correlated with the histological findings, and concluded that OCT can be used to determine the depth of a lesion.³⁶ This was corroborated by another study which analyzed the



Figure 3 A. Optical coherence tomography (OCT) of the larynx showing the infiltration of tumour (T) through the basal membrane (BM) and thickened stratified squamous epithelium (SSE). B. This OCT image shows that the basal membrane (BM) is compromised and the tumour (T) has infiltrated beyond the basal membrane.



Figure 4 Interface device for optical coherence tomography (OCT) mounted on a surgical microscope. a, acrylic cube; b, input of light fibre of the OCT; c, movable lens; d, movable mirror mounted on a galvanometer; e, fixed mirror; f, micromanipulator.



Figure 5 Images with optical coherence tomography (OCT) showing the tympanic membrane. A. Normal tympanic membrane. B. Tympanic membrane with tympanosclerosis (arrow). C. Tympanic membrane with perforation (arrow).

lesions of the larynx by different chemical means through OCT and histology.³⁷ Moreover, different types of subglottic injuries have also been studied and it has been concluded that OCT can differentiate satisfactorily between oedema and increased collagen deposition at microscopic level.³⁸

Otology

Initial studies with OCT were designed to obtain images ex vivo of rat cochlea, which clearly identified the bony margins of the membranous labyrinth, the scala vestibuli, medial and tympanic as well as the basilar and Peissner membranes. Obtaining images in vivo in human beings may present some difficulties.^{39,40} In another study in pigs, images were obtained after exposing the cochlea, which were compared with corresponding histologic sections. In this work, it was concluded that it is possible to successfully visualize cochlear microanatomy in pigs, and the possibility was suggested of using OCT to visualize the microanatomy of the inner ear in vivo, preserving its integrity.³

In another study with temporal bones from cadavers, images were obtained of the tympanic membrane and the middle ear, where relevant structures could be delineated, although the images obtained through the tympanic membrane were not as clear due to lack of transparency of the tympanic membrane. The authors indicate that further studies are needed to differentiate abnormalities and alterations of the middle ear.^{21,41} With respect to the inner ear, a study took place to determine the usefulness of OCT in cochlear implants. It was shown that the cochlear spaces can be clearly delineated, and it was suggested that OCT can be used to monitor and guide the placement of cochlear implants.⁴² Figure 5 shows the tympanic membrane in normal conditions and in pathological processes.

Rhinology, oral cavity, and paediatric otolaryngology

The literature concerning OCT in these areas is scarce. In rhinology, the first report of the use of OCT was to see structural changes in the nasal septum, before and after septoplasty with Nd-YAG laser. Minor structural changes were found when comparing with conventional septoplasty.⁴³ In another study, use OCT was used to produce images of the nasal mucosa, which identified the different layers and their microstructures. Smilarly, images were obtained in



Figure 6 Images with optical coherence tomography (OCT) of the mucosa of the nasal septum in normal conditions. BM indicates basal membrane; LP, Iamina propria; PCE, pseudostratified columnar epithelium; SG, seromucinous gland.

patients following medical treatment with decongestants, which showed substantial changes in the architecture of the nasal mucosa, as well as loss of seromucinous glands.⁴⁴ Figure 6 shows the normal microanatomy of the nasal septum obtained with OCT.

In one of the first works in the oral cavity, diagnostic imaging with OCT was performed on various structures within the oral cavity with possible cancer and premalignant lesions. Several changes were observable in the oral mucosa, which were compared. The authors concluded that, through this system, we have the ability to diagnose cancer and premalignant injuries.⁴⁵ In a subsequent study, in which images were taken of the same areas, the identification of microstructures, such as papillae, glands, ducts and blood vessels was additionally described; moreover, a larger variety of pathological processes, such as mature scars, granulation tissue, mucous cysts, leukoplakia, and invasive cancer, were studied and compared with histologic cuts.⁴⁶ OCT provides a great advantage in the diagnosis of lesions of the oral cavity without the need for taking biopsies. Until 2007 all studies on OCT in otolaryngology had been conducted in adult humans, cadavers or animal models, but none in paediatric patients. Currently, there are 2 references on the use of OCT in the airways of paediatric patients. The first was carried out with children aged 1 to 17 years, where images were obtained from the oral cavity, oropharynx, hypopharynx, and larynx, with both normal and pathological anatomies; it concluded that OCT is safe and reliable in this group of patients.⁴⁷ The last study was conducted in newborn patients requiring ventilatory support. Smilarly, it was possible to identify the different structures of the neonatal airway; it was concluded that OCT in newborns is a potential non-invasive method for monitoring neonatal airways.⁴⁸

Conclusions

OCT is a non-invasive method to obtain high-resolution images of various tissues of the human body in vivo. Today, the number of works performed with OCT in otolaryngology is limited, and the few works there are, focus mainly on the study of laryngology. The main advantage of using OCT in laryngology is that it has the capacity to provide in vivo images of the microstructures of the vocal cords with a higher level of detail than any other imaging modality. Another of its functions during surgery may be to guide biopsies and to corroborate surgical margins, without the need to send specimens to the laboratory.

OCT has a great potential for the diagnosis of premalignant and malignant lesions, although it is still in experimental stages and, therefore, it is still not advisable to replace the histological diagnosis by the diagnosis with OCT. The most important criterion in OCT for the diagnosis of malignancy is the degree of infiltration of the basal membrane. However, one problem of this method is its penetration capacity so that, in tumours with large volumes, the use of OCT is limited. Currently, we recommend using OCT to identify more superficial lesions with atypical appearance, where the degree of invasion is not known.

The advantages of using this diagnostic method is that it can produce images of living tissues at high resolution, quickly and directly, without having to prepare the patient or the tissue in any way and, above all, without having to take biopsies, which represents an enormous advantage in areas like the inner ear. Also, this technique does not emit any radiation which is harmful to the patient, which presents a great advantage, especially for paediatric patients.

Conflict of interests

The authors have indicated there is no conflict of interests.

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