New Computer-Guided Scanner for Improving CO_2 Laser-Assisted Microincision

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ABSTRACT

Objective

The objective was to clinically test a new computer-guided scanner designed for CO_2 laser-assisted microincision. The scanner-assisted beam travels across the target as a straight or curved incision line. Line length and beam penetration can be adjusted.

Study design and setting

The studied population, 155 cases, encompassed benign lesions as well as early cancers of the larynx. Operating time was compared with that required for similar operations performed with the AcuSpot™ micromanipulator. Laser-produced coagulation thickness at the incision was measured on 41 operative specimens.

Results

The scanner-assisted incision and dissection were more accurate and required up to 30% less time than with a manually guided beam. Postoperative follow-up was straightforward. The coagulation thickness was less than 10μ for phonomicrosurgery and less than 20μ for other surgical procedures.

Conclusion

The scanner-assisted incision is more accurate than that attained manually.

Keywords:

Computer-guided scanner, CO_2 laser-assisted microsurgery, laser-produced coagulation.

INTRODUCTION

From its inception, CO_2 laser was created for surgery. [1] It emits electromagnetic energy at a wavelength of 10.6μm. This wavelength has a high coefficient of absorption for water. Soft tissues with high water content therefore strongly absorb CO_2 laser energy. [2]

The CO_2 laser induces little collateral thermal tissue interaction when compared with other wavelengths used in the medical field, e.g.: neodymium:yttrium-aluminum-garnet (Nd:YAG) laser; argon laser or potassium titanyl phosphate (KTP) laser. [1,3] Moreover, the CO_2 thermal penetration ranges in microns whereas that of other wavelengths ranges in millimeters. [2,3] These features make the CO_2 laser the surgical workhorse when tissue incision or vaporization without concomitant collateral damage is required. [4]

Pulsed waves (SharPulse™) reduce the thermal effect and consequent coagulation of the area surrounding the impact. The interpulse pauses permit the tissues to cool. The thermal reduction is even more important with superpulsed waves (SuperPulse™) where power peaks of 400-500W are delivered in millisecond pulses: the resultant average pulse power, predetermined during programming, usually ranges between 1 and 10W. [5]

In terms of laser light delivery, from the laser-arm to the target, we currently have available the AcuSpot™ micromanipulator, waveguides and the scanner.

The micromanipulator, which is attached to the operating microscope and connected to the laser-arm, yields the smallest possible beam diameter presently available, i.e. 250µ for a focal length of 400mm. This micromanipulator ensures the accurate tissue incision and dissection required for phonosurgery. [6,7,8]

The waveguide [9] makes the use of CO_2 laser possible through a flexible fiber optic delivery system, but does not provide appropriate focus. This delivery system allows working in areas that offer poor access to the linearly transmitted CO_2 laser. The regions rendered accessible include the subglottis.

By means of a computer-guided system of rotating mirrors, the scanner [10,11,12] allows the beam to sweep a given surface with extreme rapidity. This feature makes it a very effective tool when macroscopic vaporization is required. A "shaving" effect a few microns deep is achieved during each beam sweep with very little in-depth thermal penetration. The usual shape chosen for the surface is the circle. Various diameters, powers and sweep times can be set depending on the required application which can range from tumor debulking in cancer surgery to facial skin resurfacing in cosmetology. The software is known as SurgiTouch™ in surgery and SilkTouch™ in cosmetology. [13]

All these technical improvements have facilitated the use of CO_2 laser in laryngology and have made its use possible and accurate in phonomicrosurgery providing that the application criteria are strictly enforced. [6,7]

This article reports our results with the AcuBlade™, a new scanner application that improves CO_2 laser-assisted microincision.

MATERIALS AND METHODS

The AcuBlade™ is a scanner software modification that allows the beam to travel across the target as a straight or curved incision line instead of "shaving" a given surface (Fig. 1 a, b). Various lengths (range: 0.3-5.0mm) and penetration depths (range: 0.2-2.0mm) are programmable. A left-curved incision line and a right-curved incision line are obtainable. Line curvature is achieved by rotating the scanner. The curvature follows that of the Bouchayer microscissors (Micro-France- Xomed).

The software-calculated penetration depth is based on the average absorption of the CO_2 laser by living soft tissues. Depending on the desired length and penetration, the software calculates the required power and pulse duration for the single pulse mode. Pulsed and continuous modes are available.

The AcuBlade™ can be used either with an operating microscope or a hand-held device. If the operating microscope is used, the reflection of the beam to the left or right can be adjusted by rotating the scanner, connected between the laser-arm and the operating microscope, with a joystick-controlled electrical motor.

The width of the incision line tallies with the diameter of the beam travelling along the line, i.e. 250µ for a focal length of 400mm.

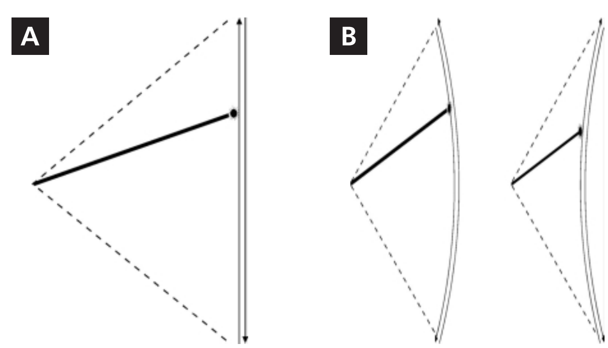

Figure 1. Schematic representation of the CO_2 laser beam sweep as a straight incision line, a left-curved incision line and a right-curved incision line.

Since March 1999, we have used the AcuBlade™ to operate on 155 patients who required laryngeal or pharyngeal microsurgery.

Phonomicrosurgery addressed 83 cases of benign vocal fold lesions: nodule (25 cases); angiectatic polyp (14 cases); Reinke's edema (18 cases); mucous retention cyst (3 cases); epidermoid cyst (4 cases); sulcus vocalis and sulcus vergeture (11 cases); scar (4 cases); granuloma (3 cases); and resection of the ventricular folds for dysphonia plicae ventricularis (1 case). The laser settings used were 1.5 to 2mm beam length; 1mm penetration; and the superpulsed wave in single pulse mode with a 400mm focal length. The recommended power, software-calculated, was 10W with a pulse duration of 0.05sec. The curved incision was used for the resection and dissection of lesions involving the free edge of the vocal fold (Fig. 2): concave towards the right for the left vocal fold, and concave towards the left for the right vocal fold. The use of the curved incision line avoided injuring the vocal ligament while the operator maintained the free edge of the vocal fold taut with microforceps in order to draw the lesion aside from the vocal ligament. The exerted traction stretched Reinke's space and the epithelium surrounding the lesion. A linear incision would have required exceedingly extensive resection of these adjacent tissues, and would have needlessly exposed Reinke's space and the vocal ligament. This was avoided with the curved incision. The curvature angle design was based on that of the Bouchayer microscissors (Micro-France, Xomed).

Nodules, polyps, granulomas, mucous retention cysts and epidermoid cysts underwent resection whereas Reinke's edema, scars and the sulcus vergeture underwent dissection. [7]

For Reinke's edema, the procedure came from that of Gould and Hirano. [14] The operation commenced by coagulating the microvessels on the upper surface of the vocal fold. The epithelium was then incised along the length of the upper surface, from the vocal process up to 2-3 mm from the anterior commissure. After the incision, the freed flap was pulled away towards the midline with Bouchayer forceps, and the glue accumulated within Reinke's space was aspirated. The microflap, held by the forceps, was then put back in its place. If Reinke's edema was more voluminous, then any excess epithelium was resected in order to achieve better edge-to-edge fit of the incision. Both vocal folds were operated on during the same surgical stage providing that 2 to 3 mm of mucosa near the anterior commissure remained untouched.

For the sulcus and the scar, the procedure was based on Bouchayer's technique. [15] The incision began at the external upper edge of the lesion. The epithelium was seized with the Bouchayer forceps on the internal side of the incision; the dissection then carefully continued by following the epithelium as closely as possible. During dissection, up to the lower surface of the vocal fold, care was taken to grasp all the dissected epithelium in order to draw it away from the vocal ligament as much as possible. In the event of a sulcus vergeture with substantial vocal fold atrophy or a scar with significant defect, we completed the procedure with an injection of Gax-collagen

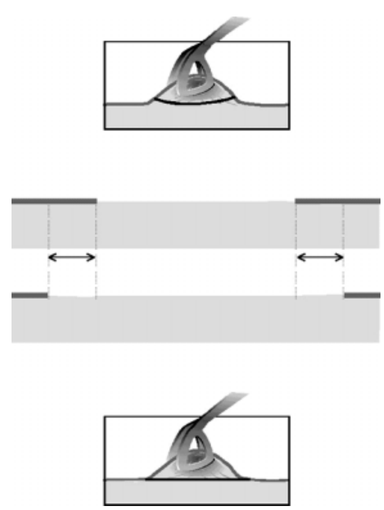

Figure 2. Schematic representation of the Acublade™-assisted resection of a nodule. The difference between the linear resection and the curved resection is shown: the linearly resected epithelium is longer. The excessive exposure of Reinke's space is a potential threat for the vocal ligament.

(Zyplast™ Collagen Corporation, Palo Alto, California, USA) [8] in order to obtain a vocal fold volume as near to normal as possible.

Twenty-three cases of epithelial hypertrophy required diagnostic- and curative-aimed epithelial resection with frozen section analysis. For the epithelial incision, the parameters used were 2mm length with a 2mm penetration. The penetration depth was reduced to 1mm for the dissection of Reinke's space performed using the superpulsed wave in single pulse mode with a 400mm focal length. The computer-recommended setting for a 2mm penetration was a power of 10W with a pulse duration of 0.1sec; for a 1mm penetration, the recommended power was 10W with a 0.05-sec duration.

Of the 26 early laryngeal carcinomas, 5 cases required subligamentous cordectomy, 8 cases transmuscular cordectomy, 5 cases complete cordectomy, 4 cases extended cordectomy and 4 cases required partial supraglottic laryngectomy. [16] The laser parameters used were a length of 2 to 3mm with a 2mm penetration; and the superpulsed wave in continuous mode with a focal length of 400mm.

Apart from papillomatous lesions of the vocal fold free edges that underwent dissection, the SurgiTouch™ was used to vaporize 7 cases of laryngeal papillomatosis. The parameters used were the same as for phonosurgery.

The same parameters as those used for the endoscopic treatment of laryngeal cancer were used for 5 cases of subtotal arytenoidectomy [17], 2 cases of anterior glottic stenosis and 9 cases of Zenker's diverticulum.

In accordance with Monnier's technique, both glottic stenoses were managed with a Silastic sheet stent placed for 3 weeks. [18] The patients presenting with Zenker's diverticulum were treated by incising the wall separating the diverticulum from the esophagus. [19]

The safety rules and remainder of the technique were unaltered: face protection using a soaked towel; high-frequency jet ventilation during phonosurgery and laser-adapted endotracheal tubes for cases at risk of bleeding; fibrin glue to cover the resection zone or redrape the epithelium on completion of surgery; steroid aerosol therapy; antibiotic therapy; complementary speech therapy, …

The operating time of the various operations was compared with the operating time of similar operations previously performed with the AcuSpot™.

Using a ruler adapted to the pathologist's microscope, one of the authors (FH) measured on 41 operative specimens the laser-produced coagulation thickness at the incision (16 phonomicrosurgical procedures, 10 subepithelial cordectomies, 6 subligamentous cordectomies, 4 transmuscular cordectomies and 5 subtotal arytenoidectomies) (Table 1). Thermal damage was defined as a layer of cells exhibiting thermal cellular necrosis, i.e. loss of nucleus, denatured cytoplasmic protein and membrane disruption.

Procedures	Number of procedures	Maximum tissue thickness (mm)	Minimum tissue thickness (mm)	Mean thickness of thermally damaged tissue (mm)
Phonomicrosurgery	16	13.07	0.35	0.0069 – 0.014
Subepithelial cordectomy	14	1.64	0.47	0.016 – 0.009
Subligamentous cordectomy	6	3.62	0.25	0.017 – 0.004
Transmuscular cordectomy	4	4.86	0.29	0.018 – 0.007
Subtotal arytenoidectomy	5	16.00	0.23	0.016 – 0.006

Table 1. Comparison in terms of mean thickness between laser-induced thermal injury following various types of procedures and the yielded operative specimens.

RESULTS

The AcuBlade™ enabled us to create an accurate incision line comparable to that achieved with microscissors (Fig. 3). Irregular incision lines did not occur, unlike those yielded with the micropoint (Fig. 4).

Microscopic examination of the incision edges revealed that the AcuBlade™ causes less charring than a manually guided beam. The coagulation thickness was less than 10µ for phonomicrosurgical procedures and less than 20µ for the different cordectomies and subtotal arytenoidectomies (Table 1) (Fig. 5). Similar to that which had already been observed with the micropoint [7,8,11], Reinke's space was spared of any thermal damage during scanner-assisted phonomicrosurgery.

The pathologist (MD) did not encounter any difficulty with the histological frozen section analysis of the 23 cases of chronic hypertrophic laryngitis. The results revealed 5 cases of hyperplasia, 14 cases of dysplasia, 2 cases of carcinoma in situ and 2 cases of microinvasive carcinoma.

Because the sweeping speed was constant, the energy distribution was uniform along the entire length of the line. This ensured a more even incision and an improved hemostasis in comparison with the results achieved using the manually guided beam.

Hemostasis of blood vessels larger than 0.5mm required, however, the use of monopolar electrocoagulation.

The swift beam sweep along the line reduced the operating time of procedures performed with continuous mode settings, such as cordectomies and arytenoidectomies. In comparison with similar procedures performed with the AcuSpot™ alone, we estimate the operating time gain as approximately 30%. The operating time, from incision onwards, remained under 20 minutes for non-extended cordectomies and for subtotal arytenoidectomies. This gain was not demonstrated for single pulse phonomicrosurgery, nor for procedures that required more pauses and more time for hemostasis such as extended cordectomies.

The manually guided beam rotation of the AcuBlade™ required the assistance of a staff member fully versed in microsurgery. This rendered the manual rotation less practical than the electrical motor-controlled rotation.

We did not observe any AcuBlade™-induced intraoperative or postoperative complication.

The first postoperative follow-up, usually conducted at 8 days, revealed, on stroboscopic examination, complete healing and normal cordal vibration following phonomicrosurgery for simple lesions such as nodules, polyps or epidermoid cysts. Surgery addressing Reinke's edema required 2 to 3 weeks before normal and symmetrical vibration was present.

The postoperative follow-up at 2 months showed that the patients operated for sulcus vergeture, or scar, progressed favorably with speech therapy: improved glottic closure, symmetrical vibratory amplitude and presence of a

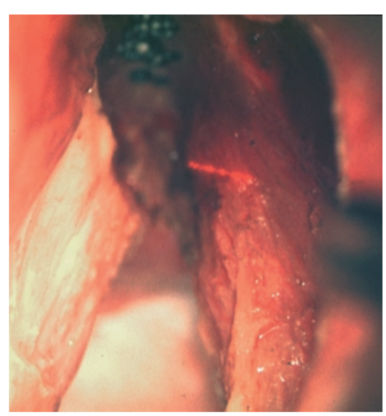

Figure 3. Laser–assisted subligamental cordectomy. The straight incision line of the laser beam is visible.

mucosal wave. Asymmetry during the vibratory phase still remained.

One of the authors (DC) undertook daily stroboscopic examination of 4 patients who had undergone surgery for vocal fold nodules. In all 4 patients he observed symmetrical cordal vibration from the second postoperative day.

The postoperative period was overall uneventful.

Follow-up was, of course, mandatory for laryngeal papillomatosis. Breathing was sufficiently improved in the cases that had required subtotal arytenoidectomy and both cases of anterior glottic stenosis.

The postoperative management of Zenker's diverticula included a videoradiography on the third day. This examination proved normal for all patients, and resumption of food intake was authorized.

DISCUSSION

For more than 10 years the decisive progress in the surgical use of CO_2 laser has focused on its application modes and laser light delivery systems from the laser-arm to the target [9,10,11,12]. No decisive progress has focused on CO_2 production and wave types.

In the field of oncology and cosmetology, the scanner ensures extremely accurate vaporization. [10,11,12]

In phonomicrosurgery, the AcuSpot™ micromanipulator has rendered incision with limited thermal damage possible. [6,7,8] Single pulse dissection, however, required for accurate procedures, does not attain an incision as regular as that achieved with microscissors: the edges of the incision appear slightly indented. This is no longer the case with the AcuBlade™. While achieving hemostasis unattainable with cold instruments, the AcuBlade™ also provides an incision as regular as the incision obtained with microscissors.

The AcuBlade™-produced curved incision line is clearly effective for lesions of the vocal fold edge. For the curvature angle of the line, we followed the curvature of the Bouchayer microscissors (Micro-France–Xomed) which, we find, are the best microscissors for cold-instrument phonomicrosurgery.

The coagulation thickness at the resection margin is clearly smaller than that obtained with the AcuSpot™ alone. This finding was observed with the phonomicrosurgical procedures, where coagulation thickness averaged 50µ [7], as well as with the procedures where higher powers were used, such as cordectomies, where the coagulation thickness averaged 100µ [20]. This explains the stroboscopically observed reduction in postoperative healing time, comparable with that obtained with cold instruments. The decrease in thermal effect is achieved by the accuracy and speed of the laser beam sweep along the software-programmed line. The manual control cannot achieve such thermal reduction. This thermal advantage, however, is lost if monopolar electrocoagulation is required to ensure hemostasis, as is frequently the case during total or extended cordectomies or even during arytenoidectomies.

The AcuBlade™ reduces the operating time, at least for relatively long procedures in continu-

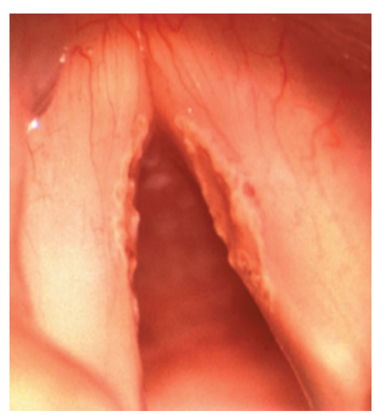

Figure 4. Irregular appearance of the free edge following resection of nodules with the micromanipulator alone.

ous mode and where laser is practically the sole instrument employed. It is more difficult to demonstrate the time gain for phonomicrosurgery where operative maneuvers (such as exploration and palpation) and intraoperative inspection of the surgical steps represent most of the time spent vs. the time required for the actual incision or resection. Time gain is also harder to demonstrate for procedures, such as extended cordectomies or supraglottic laryngectomies, where pauses, to approach the lesion or to achieve hemostasis with monopolar electrocoagulation, increase the operating time. Demonstration of operating time gain was possible for relatively simple procedures with steady duration, such as partial cordectomies or subtotal arytenoidectomies.

For the surgeon with little CO_2 laser experience in vocal fold microsurgery, the "dot per dot" method remains, however, preferable in order to avoid a misoriented beam, fraught with more consequences when delivered along a line than when delivered on a sole point.

In order to ensure uniform incision, caution must be taken to constantly maintain in the same dissection plane the tissue that requires incising. Nonobservance of this principle results in defocused line over a more or less large portion of its length with consequent reduced incision uniformity.

The AcuBlade™ control panel is sufficiently user-friendly to allow quick intraoperative parameter modifications, if required.

The incision length is, of course, exact, but depth remains an estimate. The actual depth varies according to the water content of tissues: the beam penetrates deeper in a highly hydrated tissue such as Reinke's space, and less in a denser tissue such as the keratotic epithelium of chronic hypertrophic laryngitis. It is therefore appropriate to modulate the theoretical depth of the incision according to the incised tissue, for example, a 2mm deep incision for the epithelium and then a 1mm incision for Reinke's space.

The operator can, at all times, modify the parameters proposed by the laser-controlling software.

In the initial prototypes, the beam reflection was manually controlled by rotating the scanner at the connection between the scanner and the laser-arm. The joystick-controlled electrical motor is, of course, much more practical.

The present study has covered the use of the AcuBlade™ for laryngeal microsurgery using the operating microscope. It is, of course, perfectly possible to use the AcuBlade™ with the handheld device, e.g. for resection of oral cavity lesions.

CONCLUSION

We find that the AcuBlade™ is currently the most effective tool for CO_2 laser-assisted microsurgical incision. With the use of this computer-guided scanner, the scanner applications now range from vaporization to incision. The scanner-assisted incision reinforces the accuracy of the CO_2 laser-assisted microdissection, previously demonstrated as safe and effective providing that the appropriate laser parameters are met.

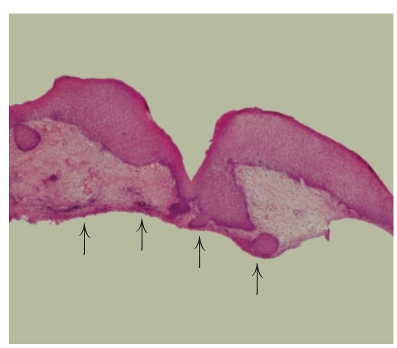

Figure 5. Histological specimen of epithelium (chronic hypertrophic laryngitis). Magnification 4X (Hematoxylin-Eosine). Coagulation thickness less than 20μ (black arrows).

REFERENCES

1. Polanyi TG, Bredmeier Hc, Davis TW Jr. A CO_2 laser for surgical research. Med Biol Eng 1970;8:541-8.
2. Reinisch L. Laser physics and tissue interaction. Otolaryngol Clin North Am 1996;29:893-914.
3. Lesinski SG, Palmer A. Lasers for otosclerosis : CO_2 vs. Argon and KTP-532. Laryngoscope 1989; 99:1-8.
4. Reinisch L, Ossoff RH. Laser applications in otolaryngology. Otolaryngol Clin North Am 1996;29:891-2.
5. Wilder- Smith P, Dang J, Kurosaki T. Investigating the range of surgical effects on soft tissue produced by a carbon dioxide laser. J Am Dent Assoc 1997;128:583-8.
6. Benninger MS. Microdissection or microspot CO_2 laser for limited vocal fold benign lesions : a prospective randomized trial. Laryngoscope 2000;110:1-17.
7. Remacle M, Lawson G, Watelet JB. CO_2-laser microsurgery of benign vocal fold lesions. Indications, techniques and results of 251 patients. Ann Otol Rhinol Laryngol 1999:108:156-64.
8. Remacle M, Lawson G, Degols JC, Evrard I, Jamart J. Microsurgery of sulcus vergeture with carbon dioxide laser and injectable collagen. Ann Otol Rhinol Laryngol 2000;109:141-8.
9. Gannot I, Dror J, Calderon S, Kaplan I, Croitoru N. Flexible waveguides for IR laser radiation and surgery applications. Lasers Surg Med 1994,14:184-9.
10. Brodsky L, Brookhauser P, Chait D, *et al.* Office-based insertion of pressure equalization tubes: the role of laser-assisted tympanic membrane fenestration. Laryngoscope 1999;109:2009-14.
11. Ossoff RH, Werkhaven JA, Raif J, Abraham M. Advanced microspot microslad for the CO_2 laser. Otolaryngol Head Neck Surg 1991;105:411-4.
12. Papadakis CE, Skoulakis CE, Nikolidakis AA, Velegrakis GA, Bizakis JG, Helidonis ES. Swiftlase inferior turbinoplasty. Am J Rhinol 1999;13:479-82.
13. Ross EV, Grossman MC, Duke D, Grevelink JM Long-term results after CO_2 laser skin resurfacing: a comparison of scanned and pulsed systems. J Am Acad Dermatol 1997;37:709-18.
14. Hirano M. Endolaryngeal microsurgery. In Otolaryngology.Philadelphia, Lippincott Vol 3, p21,1988.
15. Bouchayer M, Cornut G, Witzig E, Loire R, Roch JB, Bastian RW. Epidermoid cysts, sulci, and mucosal bridges of the true vocal cord: a report of 157 cases. Laryngoscope 1985; 95:1087-94.
16. Remacle M, Eckel HE, Antonelli A *et al.* Endoscopic cordectomy. A proposal for a classification by the working committee, European laryngological society [In Process Citation]. Eur Arch Otorhinolaryngol 2000;257:227-31.
17. Remacle M, Lawson G, Mayne A, Jamart J. Subtotal carbon dioxide laser arytenoidectomy by endoscopic approach for treatment of bilateral cord immobility in adduction. Ann Otol Rhinol Laryngol 1996;105:438-45.
18. Brossard E, Monnier P, Lang F, Ravussin P. Current possibilities in endoscopic microsurgery of the pharyngo-larynx. Rev Med Suisse Romande 1992;112(1):27-34.
19. Remacle M, Chouvel P, Lawson G, Mayne A. CO_2 laser endoscopic microsurgery of Zenker's pharyngoesophageal diverticulum. Techniques and long term results on 25 cases (Belgium experience). Operative Techniques in Otolaryngology- Head and Neck Surgery 1997;8:213-8.
20. Lawson G, Delos M, Betsch C, Marza L, Keghian J, Remacle M. Co2 laser type I cordectomy: reliability for histopathological assessment. In: Kleinsasser O, Glanz H, OlofssonJ, editors. Amsterdam: Elsevier, 1997: 267-269.

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