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Transoral Laser Microsurgery (TLM) of the Upper Airways With a Novel Scanning CO_2 Ultrapulsed Laser System: SmartXide[2]

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Introduction

Carbon dioxide (CO_2) laser is nowadays considered the "gold standard" for treating laryngeal lesions. It is the elective method when high precision is required, especially in situations where an accurate control of the penetration depth is necessary.

CO_2 laser was first introduced in the laryngeal practice in the early 70's. The first laser machines were working only in continuous and "chopped" mode and were focused by micromanipulators with relatively big spots (> 1 mm). The development of pulsed emission modes and the availability of optical zooms producing submillimeter spots, made the laser able to ablate/incise tissues while protecting the surrounding delicate anatomical structures from thermal injury. The technical improvement of superpulsed and then ultrapulsed delivery of energy, refined even more the emission mode of this very versatile lasers (Fig.1). The combination of microspots and ultrapulsed emission guaranteed the transmission of higher energy densities on the target, reaching the state of "cold" photo ablation rather than the more thermal, traditional vaporization of tissue which tended to leave a zone of thermal injury and char (carbonization).

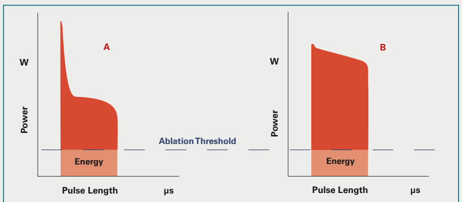

Fig:1 A: DC (Direct Current) excited CO_2 laser single pulse (Superpulsed emission) B: RF (Radiofrequency) excited CO_2 laser single pulse (Ultrapulsed emission) In RF excited CO_2 laser source the same pulse length produces more energy over the ablation threshold, compared to the DC excited one.

The most recent advance in Transoral Laser Microsurgery is the introduction of scanning CO_2 laser systems (commonly named "robotic"). Thanks to this technologic improvement, the surgeon has at his disposal a focused spot of ultrapulsed laser energy that is moved by computer control and can be shaped either as a cutting line or curve, or more complex ablation figures, with an extremely high degree of operating precision.

The fast (few microseconds of tissue laser exposure: dwell time) and constant movement of the spot guarantees the best soft-tissue results; simply put, a clean cut and NO char. The laser continuously tracing patterns, under the control of the computer-guided mirrors of the scanner, will prevent inadvertent deep cuts or hot spots which can and do happen when moving the laser beam freehand using the micromanipulator's joystick.

These significant technologic advances together with an increased knowledge of the microanatomy of the larynx, the physiology of speech and the pathophysiology of vocal cord disorders have made it possible to perform very refined trans-oral operations in the laryngopharynx.

The use of scanning CO_2 laser in endoscopic laryngeal microsurgery offers considerable advantages, namely:

- Surgery as performed through natural routes (transorally in direct micro laryngoscopy)
- Reduced tissue trauma
- Reduced local and general morbidity
- Rapid post-op recovery (shorter hospital stay)

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- Functional results comparable with those obtained with phonosurgical techniques using cold instruments
- Oncologic results comparable with those obtained with external surgery, when correct indications are adopted

SmartXide²: The Evolution of Ultrapulsed Scanning CO_2 Laser

The SmartXide² CO_2 Laser system (Fig. 2) was exclusively used. It is powered by a radiofrequency-excited CO_2 laser source, emitting in ultrapulsed mode and so producing high energy per pulse and minimizing heat damage to the surrounding tissues. Coupled with the HiScan Surgical scanner and the Easyspot Hybrid micromanipulator, this system ensures a flexible control of the ablation depth and the thermal collateral effects (coagulation and char).

HiScan Surgical scanner can produce the widest array of scanning figures available in the market (cutting figures: lines of various length and arcs of circle, up to a full circle; ablation figures: spiral, clover, and hexagon). The rotation and dimension of the figures (max available 6.3mm) as well as the passage, from scan on to scan off mode (freehand) and back, can all be controlled by the surgeon thanks to the innovative micro-switch controller sited on top of the micromanipulator's joystick. This technical solution enables the surgeon to perform the whole procedure without moving the eyes away from the microscope, thus saving time and maintaining the right concentration. SmartXide² has also a great flexibility of use, giving the possibility to set the depth of ablation and the amount of coagulation needed. The laser spot is crisp and precise and the delivery of energy to the tissue is highly variable and efficiently delivered.

The precise delivery of energy in each single scan ("depth mode") allows to ablate a predetermined depth of tissue (from 0,1 to 2mm per passage) and then stop, thus preserving the healthy tissue underneath as well as on the perimeter of the lased area. The expert surgeon can work safely and comfortably, thanks to the user-friendly control system. Less experienced surgeons and even beginners can feel confortable with advanced skills as well. The SmartXide² ultrapulsed scanning CO_2 laser is able to fulfill all the needs of every level of laser surgeon, for the most refined laser surgery, enhancing the abilities of even the most experienced and creative surgeons. The SmartXide² ultrapulsed scanning CO_2 laser is also a perfect device for the group practice where a range of skills and experience levels exist. One laser for all the CO_2 laser needs you can imagine.

Fig. 2: SmartXide² C80H CO_2 laser, Easyspot Hybrid Micromanipulator with Hiscan Surgical scanner system, selectable ablation figures.

Material and Methods

In order to demostrate the features and benefits of the SmartXide² CO_2 laser scanning system, 6 patients were treated by P. F. Castellanos as guest surgeon at the Otorhinolaryngologic Department of Humanitas Clinical and Research Hospital of Rozzano, Milan - Italy

In the pre-op work-up all patients underwent :

- complete ENT examination
- video laryngostroboscopy
- phoniatric assessment.

Surgery was performed under direct micro-laryngoscopy with general anesthesia via oral-tracheal intubation using laser armored endotracheal tubes in full compliance with all the standards of protection.

At their post-op evaluation, all patients underwent the same pre-op check-up list.

All patients were treated with scanning CO_2 laser surgery, according to the kind of intervention warranted by their disease.

The following scanning figures and laser parameters were used:

A. Line: 1.3/5mm, power: 5/10 W, mode of emmision: UP, dwell time: 1.5 to 3ms, exposure: continuous, single or repeated scanning.
B. Hexagon: 0.6/1.3mm, power: 5W, mode of emission: UP, dwell time: 1.5ms, exposure: continuous scanning.
C. Hexagon: 1.3mm, power: 7W, mode of emission: CW, dwell time: 0.1ms, exposure: continuous scanning.
D. Spiral: 0.6/0.8/1.1mm, power: 5W, mode of emission: UP, dwell time: 1.5/3ms, exposure: continuous scanning.
E. Full Circle: 3,8mm, power: 5W, mode of emission: UP, dwell time: 1,5ms, exposure: continuous scanning.
F. "Cue ball" (Clover): 1,3mm, power: 5W, mode of emission: UP, dwell time: 0,1ms, exposure: continuous scanning.

The patients had the following conditions and treatments:

1. Subglottic laryngeal stenosis (scanning CO_2 laser assisted laryngeal widening and "core drilling" of the stenotic tract plus balloon dilation).
2. Massive and obstructive polypoid degeneration of the vocal cords (scanning CO_2 laser excision).
3. Left vocal fold paralysis in previously chemo-radiated patient for laryngeal cancer (CO_2 scanning laser assisted arytenoid lateralization).
4. Recurrence of Laryngeal Papillomatosis (scanning CO_2 laser excision/ablation).
5. Laryngeal glottic squamous-cell carcinoma T1b (scanning CO_2 laser resection).
6. Glottic laryngeal leukoplakia (scanning CO_2 laser cordectomy ELS Type I).

Case 1: Progressive subglottic laryngeal stenosis after surgery (2003) for parathyroidectomy and operative rigid bronchoscopy with laser treatment in 2013. The orotracheal intubation was expected to be very difficult due to this patient's severe subglottic stenosis and therefore was performed directly by the surgeon. Upon induction of intravenous general anesthesia and systemic neuromuscular blockade (the latter of which was administered once mask ventilation was found to be physically possible) his airway was secured starting with rigid suspension laryngoscopy. Then a 30-degree optical telescope was used to inspect the airway and to quickly place a 4 mm pediatric endotracheal tube into the narrow larynx. The airway lesion was identified as subglottic stenosis at the cricoid level based posteriorly. Using intermittent apnea, (extubation for lasing, followed by reintubation and reoxygenation using FiO_2 of 1.0), the operation was carried out. The airway was widened beginning with two radial incisions, in this case at 5 and 7 o'clock because the scar was posteriorly oriented. This was followed by use of the laser in a spiral figure to "drill" holes into the scar tissue with the scanning mechanism in order to preserve as much mucosa as possible. After this step, a 18 mm semi-compliant balloon dilator was introduced and inflated to 6 atmospheres of pressure for approximately 30 seconds, until no additional fluid needed to be added to maintain the target pressure. Sub-mucosal injections of corticosteroids were then made in order to reduce the rate and degree of scar tissue production. The radial incisions predetermine where the balloon will sheer the scar. Without this step the balloon will sheer at the weakest point which is commonly the healthiest tissue; not the desired effect. The laser "drill holes" into the scar were intended to decrease the volume of this abnormal tissue in the submucosa such that the balloon dilation didn't just compress the tissue but rather collapsed it into the new desired wider airway.

Before *After*

Case 2: This patient's anatomy produced a very difficult exposure. It was finally achieved with a small sized laryngoscope. The abnormalities of the larynx included huge polypoid degeneration of the vocal folds with mucosal redundancy of the lateral right edge of the epiglottis. Highly congested and hyperemic mucosa was also present. For a better visualization of the lesions during the resection of the two vocal fold polyps, extubation and intermittent apnea was used as in Case 1. The inferior edges of the mucosa were bilaterally preserved and folded laterally onto the vocal cords in order to avoid synechia and web formation. The scanning CO_2 laser was used either with a line or with a small hexagon figures for cutting and ablation, respectively.

Before *After*

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Case 3: This patient had airway stenosis with an established tracheotomy. The Lindholm laryngoscope was passed from the left side of the tongue to expose the left arytenoid region. The arytenoid cartilage was exposed from above through a supraglottic laryngotomy (Castellanos' R-TLM technique; see below for additional details). Once separated from the surrounding soft tissues, its central portion was progressively removed (ablated) by means of the scanning CO_2 laser. Both the medial portions of the arytenoid (the vocal process and the medial surface of the arytenoid) and the posterolateral cartilage (the muscular process) were preserved. These anterior and posterior remnants were then sutured together, collapsing the residual arytenoid to a much smaller transverse thickness. They were simultaneously lateralized. Both processes were performed with a pair of 4-0 Prolene sutures on a P-3 reverse cutting needle. The arytenoid mucosa was sutured with Monocryl 4-0 also on a P-3 needle in a figure of eight configuration. All the stiches were secured with titanium clips rather than traditional knot tying. At the end of the procedure a good lateralization of the posterior portion of the vocal fold and of the residual arytenoid were achieved. The cuffed tracheostomy cannula (# 6) was replaced. The scanning CO_2 laser was used either with line or hexagon figure for cutting or ablating respectively.

Before *After*

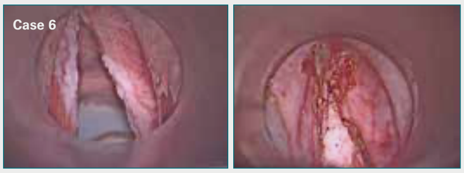
Case 4: Under direct microlaryngoscopy a major lesion on the superior side of the right vocal fold was visualized, extending posteriorly toward the vocal process of the arytenoid and laterally toward the floor of the ventricle. Foci of suspicious tissue where also present on the inferior third of the ipsilateral false vocal fold. After taking biopsies for frozen sections, the lesions were found to be benign and were ablated with the scanning CO_2 laser. Histologic analysis diagnosed Squamous Papilloma in the right vocal fold and ventricle. The anterior commissure was protected as much as possible to reduce the risk of web formation. The scanning CO_2 laser was used either with a "Cue ball" (Clover) or with a small hexagon figures for ablation.

Case 5: In this patient a good line-of-sight laryngoscopic exposure was obtained with the Lindholm laryngoscope. Using a 4 mm 30 degree endoscope, a granulomatous lesion was found on the posterior medial third of the true left vocal cord. A similar reddish lesion was found on the inferior side of the right vocal cord and finally an irregular granuloma-like thickened area in the anterior third of the left true vocal cord that reached the commissure. All the lesions were excised or ablated using the scanning CO_2 laser (in a line or a hexagonal configuration). An anterior left para-commissure biopsy was performed. A steroid suspension (Depomedrol® 40 mg per cc) was then injected in the left anterior infra-commissure region. The final inspection with filtered light (SPIES system, STORZ) didn't show any suspicious areas on the right side. Histologic analysis showed granulation and inflammatory tissue in the infracordal right side. On immunohistochemical analysis the CK pool, p53 and ki67 test were positive in the posterior medial third of the left vocal fold, suggesting an in situ squamous cell carcinoma with possible stromal infiltration. CK pool, p53 and ki67 test were consistent with simple dysplasia in the left side of the commissure.

Before *After*

Case 6: A good laryngoscopic exposure was obtained. Leukoplakia was found on both vocal cords. An infiltration of the vocal fold epithelium with saline solution and epinephrine was performed, achieving a good elevation of the superficial layers. On the left the whitish lesion reached the edge of the anterior commissure. Three excised pieces were sent for the histological analysis. The whitish lesions were then ablated bilaterally. The scanning CO_2 laser was used either with line and/or hexagonal figures. The subcordal and subglottic regions were normal. A steroid suspension (Depomedrol® 40 mg per cc) was injected in the anterior commissure region in order to prevent exuberant granulation, web or synechia formation. Histologic analysis showed orthokeratosis, hyperkeratosis and focal activation of the basal layer with chronic inflammation and fibrosis, all aspects consistent with a low-grade reactive-dysplastic lesion.

CK pool, p53 and ki67 immunohistochemical analysis confirmed the diagnosis.



Before *After*

Results

All the patients were examined and found stable on the first post-operative day, when discharged (cases 2,4,5,6) and during the hospital stay and before discharge (cases 1 and 3).

Further follow up evaluations were performed on a monthly basis for the first, second and third month.

Three months post-operatively all the patients underwent a complete examination according to the pre-operative protocol. The follow up is at least six months in duration at the time of this report.

The results were as follows:

Case 1: Good post-operative airway patency. At three-months control a re-stenosis (70% of the initial dilation) was noticed and the patient underwent a new CO_2 laser procedure (according to Castellanos' technique). At a further evaluation, three months after the second surgery, the patient had a good airway (subglottic) patency.

Follow up at 6 months

Case 2: Good result at three months. The patient didn't discontinue smoking and was lost to follow up.

Case 3: Good immediate post-operative result. The patient was put on intensive PPI treatment and the tracheostomy was removed safely two months after the operation. At the three-month post-operative evaluation, an optimal lateralization of the left arytenoid was found with good airway patency. The result was stable at a six month evaluation.

Follow up at 6 Months

Case 4: At the three-month post-operative evaluation small recurrences were found on the right false vocal cord, right true cord and right ventriculum. A new ablation/vaporization procedure with the CO_2 laser was then carried out and at a six-month endoscopy the larynx was clear of new lesions.

Case 5: A good result. Free of disease at three and six months post-operative endoscopy.

Case 6: A good result. Free of disease at three and six months post-operative endoscopy.

Special Notes on Reconstructive Trans-oral Laser Microsurgery (R-TLM)

The basics instrumentation for reconstructive trans-oral laser microsurgery (R-TLM) is founded on the use of a scanning CO_2 laser such as the SmartXide[2] and rigid instrumentation such as the Storz Lindholm laryngoscope, suction graspers, left and right alligator forceps, left and right clip appliers, and small and large suction cautery catheters. A high-resolution bright microscope with a zoom function are also critical tools. Good plume evacuation with the side port of the laryngoscope and on the suction graspers is also important. This decreases the thermal effect of the laser plume and guarantees a better view of the operating field.

The basics of the techniques of R-TLM involve the use of the scanning CO_2 system at high microscopic magnification and at a wattage that will incise or ablate the tissue, with good plume evacuation. Soft tissue handling needs to be gentle. Laser cutting of the tissue is made best by putting it under tension and cutting it at as vertical an angle as possible. Soft tissue ablation (as opposed to cutting of tissue) warrants particular attention to plume evacuation because a lot more heat is generated in the vaporization of a wide area compared to a thin incision line. Char is unusual when scanning CO_2 laser energy is used with a sharp focus (around 250μm of spot diameter) and at a wattage that is at or above photoablation threshold. High energy density and fast scanning prevents the formation of charring. Ultrapulsed mode with 5W of medium power and dwell time of 1.5ms is an optimal setting of the laser. When blood (or muscle, which contains a lot of myoglobin/protein) is lased more char is generated. Char is itself hard to laser because it is devoid of water (the chromophore of CO_2) and therefore it becomes very hot. This extends the thermal damage to the surrounding tissues and has some potential to ignite. This last factor is particularly important if there are other flammable media in the airway such as an endotracheal tube (non armored), cottonoids or fat. The other circumstance in which this is hazardous is when jet ventilation is employed and high FiO_2 tensions are being used.

As stated earlier, the "R" in R-TLM stands for reconstruction. This involves some degree of soft tissue rearrangement. The technique of flap generation and its suturing into its new position are the essential elements. Gentle grasping of the reconstructive materials are important here just as they are for any type of reconstruction. This is particularly true when the flap is generated by the lasing of the tissues beneath it. Using photo-ablating wattage and good plume evacuation are very important for obvious reasons. Once raised and repositioned, it is sutured into place with a variety of techniques depending on the location of the tissue, the tension it is likely to be holding, and the length of time it is expected to be held in place. For example, closing a tension free wound in the supraglottis can be done with Monocryl 4-0 and a P-3 needle. This a moderately slow absorbing suture of a size big enough to be held securely by the titanium clip with a needle that passes through most soft tissues with little force. If a lateralization is going to be performed such as in an airway obstruction from a flail arytenoid, a permanent suture such as a Prolene 4-0 on a P-3 needle needs to be used. It is permanent and also of adequate thickness. The other benefit is that it is sufficiently inert biologically that it can be brought out into the airway lumen and buries itself without soft tissue reaction in a short period of time. PDS, as a long lasting monofilament, is useful when there is a lot of tension on a wound and/or the healing potential is so low as to warrant a long lasting suture as in the case of radiated surgical fields or in extended anti sleep apnea surgery. In all cases the same suturing technique is employed and it is performed with two "alligator" (AKA "crocodile") curved laser forceps with the tips pointing inwardly, that is the right hand instrument points toward the left and vice-versa. Needle drivers have been tried for R-TLM but they are generally lacking the grasping and easy releasing feature of a simple curved forceps devoid of any locking mechanism as is common with an instrument claiming to be an endoscopic needle driver.

The laser parameters are important to describe. First and foremost, a scanning CO_2 laser beam is better than a non-scanning because it is always moving. Consequently it cannot be left in any spot long enough to pierce a vessel deep to the surface as is possible with non-scanning systems. Because of this first feature, the laser can be used at high energy densities above the ablation threshold. Ablation itself is an extremely quick phenomenon and amounts to micro-explosions making the so-called photoacoustic "pop". More importantly laser ablation is definitively associated with significantly lower thermal soft tissue injury. If the tissue is not photoablated but vaporized, it is burned and charred. This produces a much greater depth of injury to the surrounding tissues and increases how much "debris" will need to be sloughed before healing will take place. In the case of R-TLM this is a big issue, since the surgeon is expecting to have the edges of the tissue incised by the laser to heal readily and to hold a suture. Conversely, the ablated area of soft tissue generates a much hotter plume than the one generated by charring and it must be evacuated by suction devices. This is easy to do but must be attended to by the surgeon by the use of a good suction grasper and even a suction device attached to the laryngoscope itself. Laser plume that is not removed can cause rise of the temperature end edema in the surrounding soft tissue. If the airway is already narrow, swelling from the surrounding tissues may compromise the airway further. This may also impede healing and may cause sutures to cut through their tissues.

If the tissue to be removed is a small volume containing a lot of water (the chromophore for CO_2 wavelength), then ablation is generally fine. If it is cartilage and needs to be removed, cutting into it with the laser and then using cup forceps to take it out in pieces may be a better option compared to simply laser ablating it. If the cartilage is ossified, the energy needed to ablate it is much greater. The plume produced is additionally more damaging to the surrounding soft tissues.

This brings the next issue to light: once you have a scanning laser, do you cut with a line, a curve or a small circle or do you ablate an area of tissue to be removed by simply ablating it away with a larger circle or hexagon, or even a random figure (see Figure 2)?

Different scanning figures produce different kind of ablation separate from the shape of the laser pattern. For example, the hexagon is the least prone to generate thermal injury, while the "clover" is more apt to generate a deeper thermal burn; the latter is better used when more coagulation is needed. The thermal effect of the cutting lines and curves is affected only by the laser and scanning settings and not by their length. All of these parameters are being focused on a single flat plane, but the tissues being lased are intrinsically not flat. The surgeon needs to finely adjust the laser to keep it sharply focused to guarantee the best ablation or cutting effect.

Once the surface has been cut and the soft tissues underneath have been either removed or freed up for suturing, the advancement flaps of mucosa need to be extended to their target locations. In the case of posterior glottic stenosis, the scar bed is cleared of disease and the advancement flap is used to reline the area (such as the posterior commissure) and sutured into position. In the case of a supraglottic stenosis, the scar is cut across and the unhealthy mucosa and submucosa is removed (if present). The wound is then closed orthogonally (at right angles to the incision line through the scar) so as to lengthen the circumference of the laryngeal inlet, relieving the stenosis. The critical component of being able to accomplish these surgical maneuvers is the healthy soft tissue within the operative site that is the direct result of the laser-tissue interaction of a scanning CO_2 laser source such as the SmartXide[2].

One area of soft tissue laser work warranting special mention, relative to the Smartxide[2] system specifically, is in the cutting of very vascular muscle such as the tongue. Very important is the ability to adjust the laser to promote hemostasis by changing the scanning figure, dwell time, or laser mode of emission: eg., from ultrapulsed to a continuous wave (CW, produced with extremely high frequencies). This gives the surgeon, in essence, the best of both types of lasers; the continuous wave based cautery and the ultra pulse based cutting and ablation.

Conclusions

The potential for minimally invasive trans oral (natural orifice) surgery of the laryngopharynx is enhanced if not primarily enabled by scanning CO_2 laser technology.

The SmartXide[2] is an excellent scanning CO_2 laser machine with unique characteristics that make it the "new standard" in the market of ENT high precision CO_2 lasers. The surgical techniques described in this work are relatively simple and can be adopted by laser surgeons already expert in the basics of this sphere of care.

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