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An *in vitro* comparison of the Erbium: YAG laser and the carbon dioxide laser in laryngeal surgery

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Abstract
This study compares the relative thermal damage caused by a surgical CO_2 laser and the Erbium : YAG laser when used to incise the human vocal fold *in vitro*. Results show that charring is completely eliminated when using the Erbium: YAG laser. The depth of coagulative necrosis adjacent to an incision is reduced from 510 μm (± 75) using the CO_2 laser to 23 μm (± 12) using the Ebrium: YAG laser and at the base is reduced from 125 μm (± 45) using the CO_2 laser to 12 μm (± 8) using the Erbium: YAG laser. The potential advantages regarding post-operative healing after laryngeal surgery are discussed.

Key words: Laser surgery, larynx; Erbium: YAG laser; Carbon dioxide laser

Introduction

The Erbium: YAG (Er: YAG) laser, operating at 2.94 μm has recently aroused great interest because of its potential uses in surgery (Walsh *et al.*, 1989). The main advantage of the Er: YAG laser over the CO_2 laser is its high cut seal ratio due to an operational wavelength of 2.94 μm. This wavelength is at the peak of the water absorption curve and its absorption by water is about ten times greater than that of the CO_2 laser operating at 10.6 μm. This means that for any given energy the extent of tissue ablation is greater and the surrounding tissue damage less using the Er: YAG laser. The Er: YAG laser can produce fine incisions in a wide range of tissues with secondary damage to surrounding tissues limited to only 25 μm (Dickinson *et al.*, in press). Provided, therefore, that the laser radiation produces acceptable haemostasis, it could potentially have a place in operations where charring and thermal damage decrease the speed of healing or lead to post-operative scarring. One such area of particular interest is in endolaryngeal surgery where there have been a number of reports on the complications of thermal injury within the larynx (Garcia-Tapia *et al.*, 1984; Durkin *et al.*, 1986; Leonard *et al.*, 1988).

The purpose of this work is to compare the thermal damage caused by the continuous wave CO_2 laser in an *in vitro* experiment with that produced by the Er: YAG laser in similar circumstances.

Materials and methods

Human larynges were removed shortly after death, wrapped in plastic to prevent dessication and stored in a deep freeze until ready for use.

The lasers used were a continuous wave CO_2 Sharplan laser with a micromanipulator which is currently used for laryngeal surgery in this department. The laser was focused with a 400 mm focal length lens to a spot size of 700 μm, set at 10 W or 15 W and used in the continuous mode. The movement of the CO_2 laser beam was controlled using a micromanipulator and was approximately 5 mm/s. The Er: YAG laser was purpose built and capable of output powers of up to 10 W at repetition rates up to 15 Hz (Charlton *et al.*, 1989). In practice the actual settings were varied between 1.5 and 2.5 W at repetition rates between 5 and 10 Hz in order to determine the optimum operating condition (see Table I for settings). The laser radiation was focused using a 75 mm focal length lens to a spot size of approximately 700 μm. The pulse length was 200 μs and at settings of 5 Hz and 2.5 W the average power density was 6.5 W/mm^{-2} and the total energy deposited 4.5 J mm^{-2}. The specimen was placed on a motorized sledge and then moved at 1 mm/s below the static laser beam in order to make the incisions.

The larynges were thawed and opened from behind to give wide exposure of the true vocal folds. The folds were held taut by a suture placed through the arytenoid cartilage which exerted traction in a posterior direction.

Four larynges were used and on each one the vocal fold of one side was treated with the CO_2 laser and the other was treated with the Er: YAG laser. The surgery consisted of a simple incision perpendicular to the free edge of the fold and extending through the full thickness of the fold. The fold that was treated by the CO_2 laser had two incisions made in it, one on a power setting of 10 W and the other at 15 W. A single incision was made in the other fold using the Er: YAG laser, although the first specimen had two incisions made at identical settings. The folds were separated from the larynx and placed in 10 per cent formol

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TABLE I
COAGULATIVE NECROSIS AND VACUOLATION IS MUCH MORE PRONOUNCED USING THE CO_2 LASER THAN WITH THE ERBIUM: YAG LASER

Laser details		Vacuolation (µm)	Coagulative necrosis (µm)	
			Base	Edge
CO_2 laser				
Specimen 1	10 W power	25	185	430
	15 W power	25	100	565
Specimen 2	10 W	50	55	640
	15 W	70	105	505
Specimen 3	10 W	25	160	430
	15 W	30	145	505
Erbium: YAG laser				
Specimen 1	5 Hz; 2.5 W			
	First incision	0	10	20
	Second incision	20	0	5
Specimen 2	5 Hz; 2.5 W	0	10	30
Specimen 3	5 Hz; 1.5 W	0	5	5
Specimen 4	10 Hz; 2.5 W	0	30	40

saline. They were then routinely processed into paraffin wax, sectioned at 6 µm on a base sledge microtome and stained with haematoxylin and eosin for examination by light microscopy.

Results

Naked eye examination showed evidence of carbon formation in all the incisions made by the CO_2 laser but none made by the Er: YAG laser. However the washing of the specimens during the fixing process removed most of the carbon and it was therefore not often seen on the microscope sections.

Under light microscopy it was evident that the width of tissue damage at the epithelial edge of the wound was more extensive than that in the depth of the wound. Therefore separate measurements were made of tissue damage at the wound base and at the wound edge one third of the distance from the epithelial surface to the base. Damage was evidenced by a change in the colour of the matrix and/or vacuolation of the cell cytoplasm in the tissue bordering the wound and the measurements were taken from the inner surface of the crater to the nearest normal tissue. Table I shows the results. The sectioning on Specimen 4 of the CO_2 treated folds unfortunately missed the incisions and the specimen was therefore discarded. Average widths of tissue damage for the CO_2 laser are 125 µm at the base of the incision and 510 µm at the edge. For the Er: YAG laser the values are 10 µm at the base and 25µm at the edge. It can be seen that the Er: YAG laser causes only about 5–10 per cent of the tissue damage that the CO_2 laser does both superficially and in the wound depth. The average width of cells affected by vacuolation, which occurs alongside the damaged cells, was 35 µm for the CO_2 laser and the Er: YAG laser caused 20 µm of vacuolation in one incision and none in the other three. Figures 1 and 2 show the typical microscopic appearances of a vocal fold treated by the CO_2 and Er: YAG lasers respect-

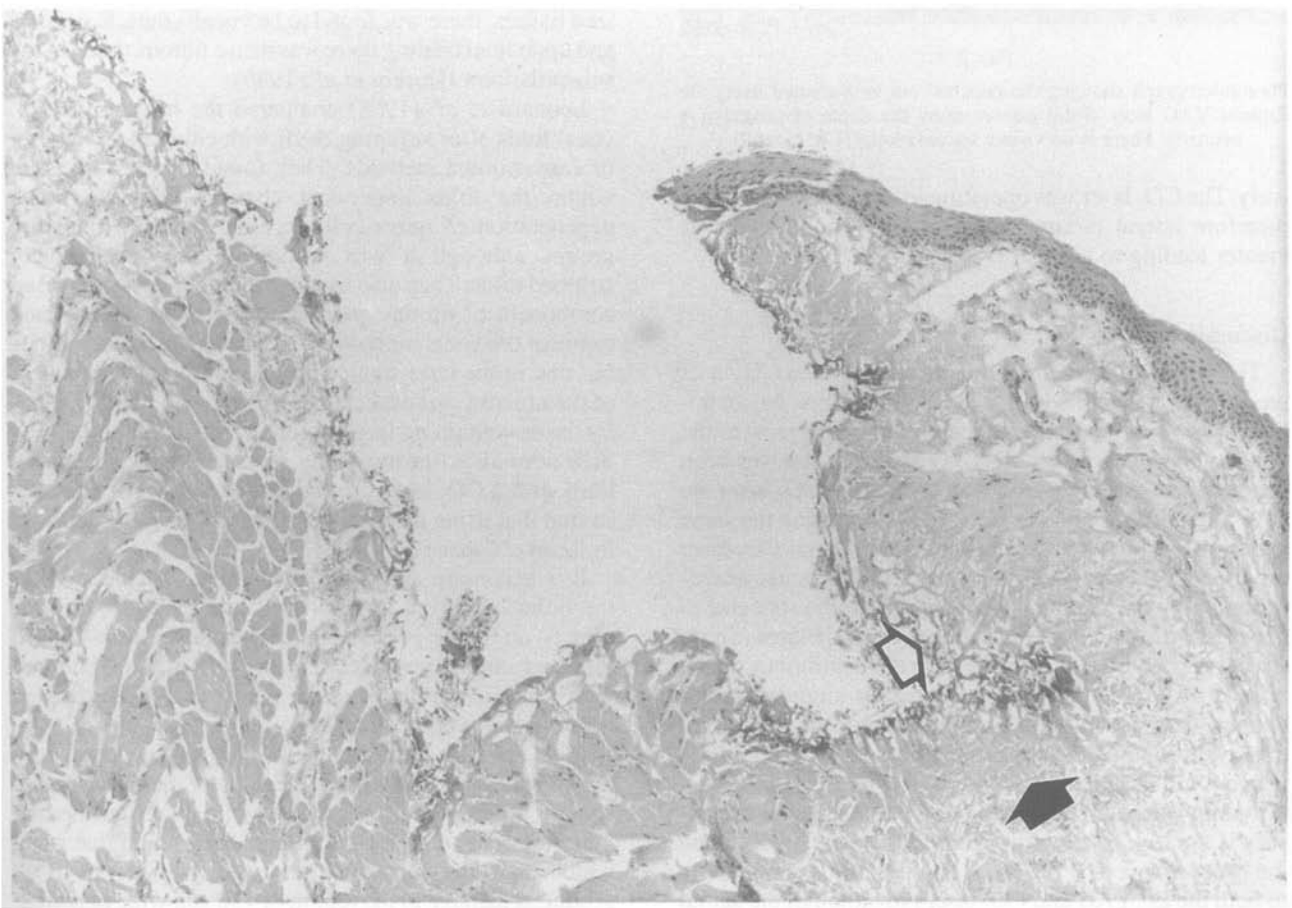

FIG. 1

Photomicrograph showing crater produced using the CO_2 laser. The outline arrow shows an area of vacuolation and the solid arrow shows the depth of coagulative necrosis. (H & E × 60).

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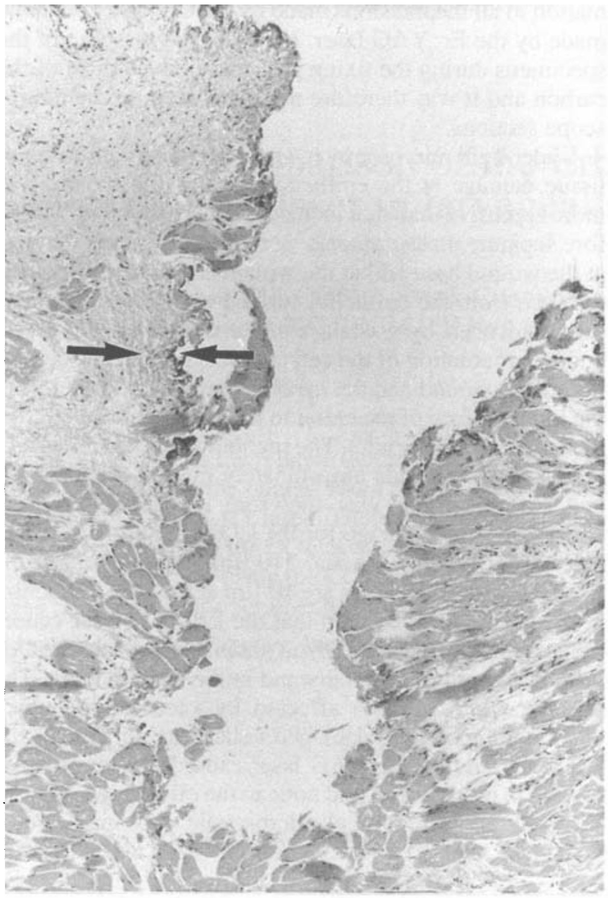

FIG. 2

Photomicrograph showing the punched out area created using the Erbium: YAG laser. Solid arrows show the depth of coagulative necrosis. There is no visible vacuolation. (H & E × 60).

ively. The CO_2 laser was operating in the continuous mode therefore lateral thermal damage and vaporization was greater leading to a larger crater size.

Discussion

The purpose of this study was to compare the CO_2 laser used in our hospital with the Er: YAG laser as we anticipate using it in clinical practice. Although at present the delivery system for the Er: YAG laser has not yet been developed to the same extent as that of the CO_2 laser we have attempted to remove the variables by using the same spot size for the two laser beams. Although our CO_2 laser produces a 700 μm spot size, newer CO_2 lasers use microspot micromanipulators which can reduce the spot size to about 300 μm so will produce less thermal damage (Shapshay *et al.*, 1990). Use of the laser in the continuous mode, as used in this experiment, also causes slightly greater damage than use in the repeat pulse mode. In the pulsed mode surrounding tissues can cool down between pulses hence limiting lateral damage.

A drawback of *in vitro* studies on thermal damage to tissues is the lack of a microcirculation which can dissipate the heat produced by the laser. However this would apply to both the Er: YAG and CO_2 lasers so although the actual values may vary, the ratios of damage would be expected to remain constant. The width of tissue damage that we produced using the Er: YAG laser *in vitro* is similar to that produced by Walsh *et al.* (1988) using the Er: YAG laser on animals *in vivo*.

Of course the trade-off for less tissue damage and coagulation is increased bleeding. The ideal is to have a laser which will cause as little tissue damage as possible but at the same time be sufficiently haemostatic to give a clear operative field. We have tested the haemostatic properties of the laser in a separate study (unpublished data) by incising anaesthetized rats' tails with the laser. In each case the only vessel not sealed by the laser was the main tail artery, which had a collapsed diameter of 100 μm, although the laser energy appeared to seal veins of up to 200 μm (the CO_2 laser can usually seal arteries of up to 500 μm). The ability to seal small vessels has been postulated as being important when excising small tumours because lymphatic vessels are also sealed hence theoretically decreasing tumour spread (Mihashi *et al.*, 1976).

Fisher *et al.* (1983) compared the healing of wounds created on canine buccal mucosa using a scalpel and the CO_2 laser. They found that there was less inflammatory reaction with a laser wound and fewer myofibroblasts were present. There was also less collagen formation and epithelial regeneration was delayed and more irregular. Durkin *et al.* (1986) used dogs' larynges to compare the healing after vocal fold stripping using microcup forceps with healing after CO_2 laser ablation of the vocal fold epithelium. They also found that there was delayed formation of granulation tissue and re-epithelialization in the larynges treated by the CO_2 laser. As well as giant cell reaction in the submucosa, probably a reaction to carbonized tissues, there was found to be vocalis muscle oedema and upon final healing there was dense fibrous tissue in the subepithelium (Durkin *et al.*, 1986).

Leonard *et al.* (1988) compared the healing of cats' vocal folds after stripping them with either the CO_2 laser or conventional methods. They found that neural tissue within the folds underwent changes associated with degeneration of nerve cells in both treatment modality groups although it was worse in the conventionally stripped folds. They also found that there was an increased component of fibrous granular tissue in the regenerated tissue of the vocal mucosa after both treatment modalities but that in the laser-treated group the fibrous component of the mucosa was especially aberrant with highly irregular tissue containing larger, more irregular epithelial cells than normal. After removing surface vocal fold epithelium with a CO_2 laser Garcia-Tapia *et al.* (1984) demonstrated that using the CO_2 laser thermal damage occurred in Reinke's space.

It is becoming apparent that thermal damage, even in the order of only a few hundred μm, can have adverse effects on voice production. For patients who require repeated endolaryngeal laser surgery, such as children with juvenile papillomata, the prospect of such damage occurring is even greater.

In an effort to decrease the thermal damage caused by the CO_2 laser Walsh *et al.* (1988) used the CO_2 laser in shorter pulse widths in order to minimize the thermal build up in the non-ablated tissue. They found that pulse widths of 50 ms with a maximum average power of 40 W, produced damage in the region of 750 μm wide in normal guinea pig skin but by reducing pulse width to 2 μs the damage zone was reduced to as little as 50 μm. Most CO_2 lasers at present in clinical use are unable to attain this pulse rate. Even as little damage as 50 μm is still twice as much as that produced by the Er: YAG laser *in vitro*.

Erbium: YAG laser radiation can also be transmitted through zirconium fluoride fibres and research is underway to make these fibres flexible and strong enough to be used endoscopically. The laser could also be used as a hand-held 'laser scalpel' with a suitable contact tip. This would have the advantage of allowing the surgeon the all important tactile feedback and with the extremely small area of thermal damage created by this laser the skin healing is likely to be much more like that of a scalpel rather than that of a CO_2 laser. One possible disadvantage of the Er: YAG laser is the limited haemostasis that can be expected which may well be a significant problem in clinical practice.

Conclusion

Initial studies show that the Er: YAG laser causes very little thermal damage to cadaveric tissue. If it is also shown to have acceptable haemostatic properties it may, with development, have a role in endolaryngeal surgery. However, *in vivo* studies are required to further evaluate its potential.

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