The Journal of Laryngology & Otology (2007), ***121***, *5–8.*

doi:10.1017/S0022215106002672
Printed in the United Kingdom
First published online 1 November 2006

Main Article

Experimental study on heat transmission to the vestibule during CO_2 laser use in revision stapes surgery

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Abstract

We studied the transmission of heat to the vestibule during revision stapes surgery with a piston in situ, using a CO_2 laser, in an *in vitro* model. A type K thermocouple was placed around the medial end of stainless steel and fluoroplastic wire pistons in a 'vestibule' filled with saline. The effect of laser hits on fluoroplastic wire and stainless steel stapes prostheses was investigated. The effect of introducing a vein graft to seal the stapedotomy was also examined. Greater temperature rises occurred with stainless steel than with fluoroplastic wire pistons. The addition of the vein graft reduced heat transmission.

Application of the CO_2 laser to fluoroplastic wire pistons, using the power settings suggested by the manufacturer, is not likely to damage the inner-ear structures. Application of 6 W laser energy to stainless steel pistons can potentially disturb the inner-ear function.

Key words: Stapes Surgery; Laser Surgery; Prostheses and Implants; Otologic Surgical Procedures

Introduction

The use of the CO_2 laser is advocated in primary and revision stapes surgery. The main advantage of using the laser in primary stapes surgery is its capability of forming a calibrated opening in the footplate without the risk of mobilizing it. Many experimental studies and clinical trials have demonstrated the safety and effectiveness of the CO_2 laser in stapes surgery.[1,2] Temperature experiments have focused on the temperature in the vestibule during application of the laser to the stapes footplate in primary stapedotomy or to the open vestibule in revision stapes surgery.

Wanamaker and Silverstein[3] and, more recently, Gerlinger *et al.*[4] have examined the effect of the potassium-titanyl-phosphate (KTP) laser on middle-ear implants. Both studies showed that the KTP laser may damage fluoroplastic pistons, especially when blood was added to the surface of the piston. Data from our previous work on the KTP laser[5] did not support these results. We showed that applying the KTP laser to fluoroplastic or stainless steel pistons, using the manufacturer's recommended power settings, was not likely to cause inner-ear irritation or piston damage.

Kodali *et al.*[6] compared the thermal effect of KTP and CO_2 laser stapedotomy in an animal model. They performed stapes surgery in chinchillas and measured the temperature changes, using a thermocouple placed in the vestibule. The maximum recorded temperature rise was 2.9°C for the KTP and 2.6°C for the CO_2 laser.

Lesinski and Stein[7] performed *in vitro* experiments for stapedectomy revision with the CO_2 laser. They showed that a single use of the CO_2 laser on the open vestibule caused a temperature rise of only 0.3°C. They advocate gradual, concentric vaporization of the granulation tissue in the oval window until the margins and depth of the oval niche were visible.

In some revision cases, it is necessary to clean the oval niche of granulation tissue or of the fat used in primary surgery, in order to visualize the margins of the footplate and to check if the piston is in the stapedotomy opening. Any manipulations with classical instruments carry the risk of sensorineural hearing loss. Lesinski and Stein[7] made extensive use of the CO_2 laser to clean the oval window and to vaporize adhesions surrounding the piston. This may cause inadvertent application of the laser to a prosthesis. In some situations, it would be desirable to apply the laser to a piston in order to separate it from a neomembrane in the oval window niche. It is crucial to be aware of the impact of the laser on a prosthesis that may still be within the stapedotomy.

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Accepted for publication: 29 March 2006.

The aim of our study was to assess the effect of a CO_2 laser on stapes prostheses and to try to measure the heat transmission to the vestibule, following application of the laser to the piston in an experiment model.

Materials and methods

The experiments were carried out using Pettigrew Temporal Bones® (AM Pettigrew, Stirling, Scotland, UK), which are plastic temporal bones prepared for training. The 'vestibule' had to be drilled out. The plastic stapes arch was removed and the footplate was fenestrated with a microdrill.

Fluoroplastic wire Schucknecht pistons (0.6 mm in diameter) and stainless steel McGee pistons (0.8 mm in diameter) were used. The pistons passed through the 'stapedotomy' so that their lower ends protruded into the 'vestibule'.

A type K (chromium and aluminium) thermocouple (1.2 mm in diameter) was attached to the module so that its end encircled the tip of the prosthesis. The 'vestibule' was filled with normal saline so that the tip of the piston and the thermocouple were surrounded by fluid.

Temperature data were sampled to a computer at the rate of 100 recordings per second, using a data logger (model TC-08, Pico Ltd, Cambridgeshire, UK).

A CO_2 laser (Sharplan 30C, Sharplan, Cambridgeshire, UK) with SurgiTouch scanner system (Yokneam, Israel) was used to deliver energy, directed via a mirror micromanipulator, to a stapes piston. The power settings suggested by the manufacturer were used (i.e. 2 W and 6 W power, 0.05 second pulse duration, and continuous wave mode). We delivered six laser impulses for each experiment, with approximately one pulse per second. The laser was aimed at the cylinder of the piston close to the stapedotomy opening. The procedure was repeated three times for both types of prosthesis. A further series of impulses were applied to prostheses after placing a vein graft on the footplate. The effect of the laser on prostheses was assessed using a light microscope.

Results

Application of the laser energy to the stainless steel piston did not have any effect on the structure of the prosthesis. The use of the laser on the fluoroplastic wire piston caused local melting and produced superficial burns in the piston. These changes were more evident in the 6 W than in the 2 W power setting (Figures 1 and 2).

Delivery of six bursts of laser with power set at 6 W caused a mean 'vestibule' temperature rise of 12.3°C for the stainless steel prosthesis and 5.4°C for the fluoroplastic wire prosthesis. The maximum temperatures recorded during the experiments were 13.0°C for the stainless steel prosthesis and 7.6°C for the fluoroplastic wire prosthesis. The addition of a vein graft reduced the heat transmission to 2.4 and 0.6°C, respectively (Table I). A specimen temperature graph for the fluoroplastic wire piston experiment is shown in Figure 3. The same set of experiments performed with power set at 2 W showed mean temperature rises of 4.7°C at the lower end of the stainless steel piston and only 1.2°C for the fluoroplastic wire piston. Further reduction of heat transmission was recorded after addition of a vein graft (Table II).

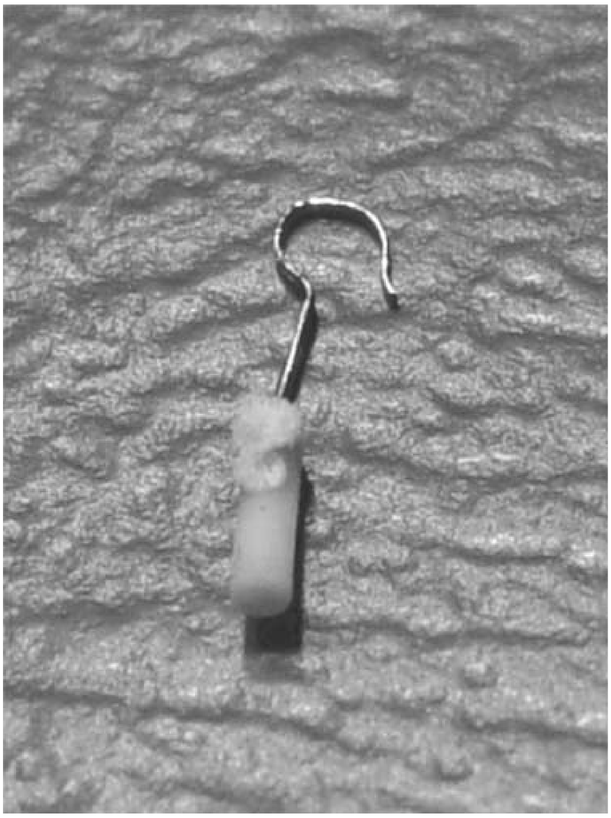

FIG. 1
Fluoroplastic wire piston exposed to CO_2 laser (6 W, 0.05 seconds, continuous wave).

Discussion

The effect of laser energy on the piston is important and may influence the choice of surgical technique. Gerlinger *et al.*[4] assessed the effect of the KTP

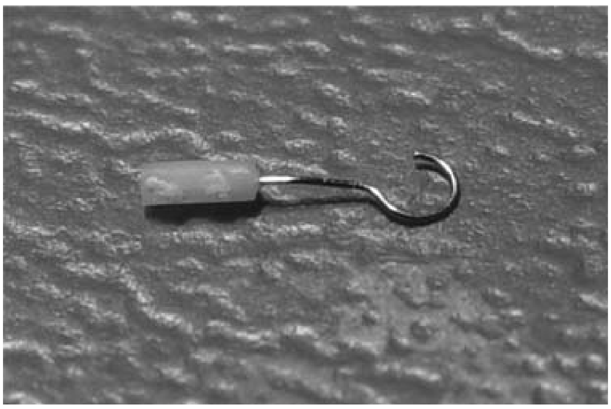

FIG. 2
Fluoroplastic wire piston exposed to CO_2 laser (2 W; 0.05 seconds, continuous wave).

https://doi.org/10.1017/S0022215106002672 Published online by Cambridge University Press

TABLE I

MAXIMUM TEMPERATURE RISE FOLLOWING 6 W CO_2 LASER TO STAPES PISTONS

Prosthesis	Max temperature rise (°C) (mean ± SD)	
	Without vein graft	With vein graft
Stainless steel	12.3 ± 0.84	2.4 ± 0.24
Fluoroplastic wire	5.4 ± 1.95	0.6 ± 0.30

Max = maximum; SD = standard deviation

TABLE II

MAXIMUM TEMPERATURE RISE FOLLOWING 2 W CO_2 LASER TO STAPES PISTONS

Prosthesis	Max temperature rise (°C) (mean ± SD)	
	Without vein graft	With vein graft
Stainless steel	4.72 ± 0.72	1.36 ± 0.07
Fluoroplastic wire	1.24 ± 0.25	0.2 ± 0.08

Max = maximum; SD = standard deviation

laser on different types of prostheses. Hydroxylapatite prostheses shattered when exposed to KTP laser energy. A CO_2 laser caused similar changes in hydroxylapatite prostheses.[8] Plastipore prostheses showed diffuse melting after application of CO_2 laser impulses. These types of material are used in middle-ear surgery for chronic otitis rather than for otosclerosis.

In the present study, the CO_2 laser had no effect on the stainless steel pistons but caused melting of the fluoroplastic pistons. Those changes are not important when removing the old piston and replacing it with a new one. When a fluoroplastic piston cannot be removed because of suspected adhesions to the inner-ear structures, exposure to laser energy should be avoided.

It is recommended to use a power setting of 1–2 W for soft tissue adhesions and 6 W for the bony footplate. In revision stapes surgery, the laser is mainly used to divide scar tissue or to clean the oval window of granulation tissue. However, in rare cases, it can be used to create the opening in the footplate, with the previous piston left in situ.[9] In these cases, 6 W power would be used. It is not likely that a laser would be deliberately used on the piston several times; however, the CO_2 laser beam is invisible, requiring a helium–neon aiming beam. The accuracy of the alignment of both beams may change with time and it is advisable to check it regularly. When the aiming beam and the treatment beam are not correctly aligned, the CO_2 laser beam may contact not only the adhesions but also the piston. No change in the piston surface would be visible

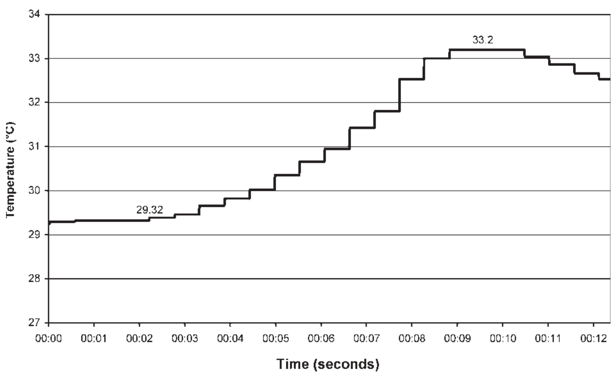

FIG. 3

Temperature at inferior end of a fluoroplastic wire piston during 6 W laser application.

during laser application to warn the surgeon, especially in the case of stainless steel or titanium pistons.

The inner-ear thermal damage depends not only on the temperature level reached but also on the duration of exposure. Drettner *et al.*[10] demonstrated that, in patients with Ménière's disease subjected to ultrasonic irradiation of the labyrinth, a vestibule temperature increase of up to 4°C for about 7–8 minutes did not cause any deterioration of hearing. Noyes *et al.*[11] measured distortion product otoacoustic emissions in rabbits subjected to temperature changes and found that a cochlear temperature elevation of 4°C did not impair the outer hair cells.

Barnett[12] carried out an *in vivo* study to analyse the effect of heat on the inner ear in cats and guinea pigs. He recorded changes in cochlear microphonic potentials (CM) during ultrasound irradiation of the cochlea through the round window. Raising the temperature in the vestibule by 5°C had no effect on the CM. A series of experiments showed that the CM impairment threshold was around 7°C above normal body temperature. However, even applying temperatures just above this threshold for up to 30 seconds caused a completely reversible, slight reduction of CM. Following fluoroplastic wire piston exposure to laser, a maximum 7.6°C increase in the vestibule temperature was detected; it seems unlikely that this would cause any inner-era damage. Stainless steel pistons transmitted heat better than fluoroplastic pistons. Laser application to the stainless steel piston, using 6 W power settings, increased the temperature to 13.0°C, which is above the threshold of 7°C set by Barnet.[11] Therefore, even when exposure time is much less than 30 seconds, thermal trauma to the inner ear cannot be excluded.

In our previous study,[5] we concluded that there was little risk of inner-ear trauma following use of the KTP laser on stapes pistons. Despite the different properties of the KTP laser (wave length 532 nm) and CO_2 laser (wave length 10 600 nm), the results of both series of experiments are comparable. The KTP laser is a visible light laser which requires some pigment for absorption. However, even when blood was applied to the surface of the stapes piston, the maximum temperature rise following KTP laser application was only 2.5°C. The disadvantage of the KTP laser lies in its capacity to pass through clear fluids, so it may injure the inner-ear

https://doi.org/10.1017/S0022215106002672 Published online by Cambridge University Press

structures when applied to an open vestibule. The CO_2 laser is absorbed by fluids, and so application to the open vestibule does not carry the risk of inner-ear irritation.

The potential adverse effects of laser use during stapes surgery extend beyond the inner ear. Delayed facial nerve palsy appears to be more prevalent in patients following laser stapedotomy, compared with those in whom other techniques are used. In an experimental model using the KTP laser, we showed that it is possible to heat the facial nerve during stapedectomy. The temperature rise may injure the nerve or may cause reactivation of viruses within the nerve.[13]

Although we attempted to reproduce the setting of middle-ear surgery, our experimental setting had some limitations. In the patient, a temperature rise in the vestibule could be reduced by blood flow in the middle-ear mucosa. We used the laser on clean pistons whereas, in revision surgery, the pistons would be surrounded by fibrous tissue. The size and thickness of the vein graft and the amount of granulation tissue may also change the heat transmission. These factors would be expected to further reduce the maximum temperature rise in the inner ear.

The addition of a vein graft in our experiments significantly reduced heat transmission to the vestibule. *In vivo*, even in cases in which a vein graft was not used, the healing process produces a neomembrane which may also decrease heat transmission.

Inner-ear irritation due to the temperatures we recorded for the 6 W laser on the stainless steel piston cannot be excluded. The use of the CO_2 laser on fluoroplastic wire pistons is not likely to cause any inner-ear injury, especially when a vein graft is used.

- **This study investigates transmission of heat to the vestibule during revision stapes surgery with a piston in situ, using a CO_2 laser in an *in vitro* model**
- **Greater temperature rises occurred with stainless steel than with fluoroplastic wire pistons. The addition of a vein graft reduced heat transmission**
- **Application of the CO_2 laser to a fluoroplastic wire piston, using the power settings suggested by the manufacturer, is not likely to damage inner-ear structures**
- **Application of CO_2 laser energy to a stainless steel piston, using 6 W power, can potentially disturb inner-ear function**

The maximum temperature change following application of the 2 W laser to a fluoroplastic wire piston did not exceed 1.5°C. Thus, the use of laser at this setting on fluoroplastic pistons seems to be safe. It should be noted that applying a series of laser pulses may result in an accumulation of thermal energy; the maximum temperatures reached could have been higher if we had delivered laser pulses more frequently or for longer.

Therefore, it is advised to avoid exposing pistons to laser energy unless necessary. The laser should be used with pauses between impulses in order to reduce accumulation of energy.

Conclusions

Stainless steel pistons transmit heat to the vestibule better than fluoroplastic wire pistons. The use of a vein graft reduces heat transmission to the inner ear. Application of the CO_2 laser to fluoroplastic wire pistons, using the power settings suggested by the manufacturer, is not likely to damage the inner-ear structures. Application of 6 W laser energy to stainless steel pistons can potentially disturb the inner-ear function.

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Dr M Szymański takes responsibility for the integrity of the content of the paper.
Competing interests: None declared