The Journal of Laryngology & Otology
May 2003, Vol. **117,** pp. 349–352

Transmission of heat to the vestibule during revision stapes surgery using a KTP laser: an *in vitro* study

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Abstract
The transmission of heat to the vestibule during revision stapes surgery with a piston *in situ* has been studied using a KTP laser in an *in vitro* model. A type K thermocouple was placed around the medial of each piston tested in a 'vestibule' filled with saline. The effect of laser hits on fluoroplastic, fluoroplastic-wire and stainless steel stapes prostheses was investigated. The effect of adding blood to the operative field, of introducing a vein graft to seal the stapedotomy and of vaporizing soft tissue in the oval window were also examined. Greater temperature rises occurred with stainless steel than with the other piston types and smaller rises occurred when there was a vein graft *in situ*. The maximum temperature rise recorded was 2.6°C. We conclude that the use of the KTP laser to clear soft tissue from the oval window is safe when operated at the power levels recommended by the manufacturer.

Key words: Stapes Surgery; Reoperation; Laser Surgery; Thermal Conductivity

Introduction

Since the introduction of the argon surgical laser to stapes surgery by Perkins,[1] lasers of various types have been used. Their use has been particularly advocated in revision surgery.[2–4] In some revision cases, a piston will be found *in situ* and the laser may be used to clear soft tissue closely related to it. This may result in inadvertent laser hits on the prosthesis. Wannamaker and Silverstein[4] and Gerlinger *et al.*[5] have studied the effect of KTP lasers on various materials and prostheses used in middle-ear surgery and Wannamaker and Silverstein[4] also examined the effects of the argon laser. Both groups reported that little damage occurred to stapes pistons unless blood was present on their surfaces. In these circumstances superficial burns were produced on Teflon® pistons following a single laser pulse and melting and vaporization followed repeated laser hits at a power level of 2 W. Prostheses made from hydroxylapatite shattered when exposed to laser energy.

Gerlinger *et al.*[5] suggested that heat might be transmitted to the vestibule when a piston is hit by a laser pulse or pulses and that this might have undesirable effects. This would depend on the resultant temperature change. Temperature rises in the vestibule also occur during primary laser stapedotomy. Lesinski and Palmer[6] studied the temperature rise in saline beneath the stapes foot plate using a thermocouple. They reported maximum temperature changes of 6.3°C for a KTP laser used with a 0.4 mm optical fibre (2 W in 0.1 second bursts) during stapedotomy. However, when the laser was fired into an open 'vestibule' a maximum rise of 12.9°C was observed. The same authors also investigated the effects of the carbon dioxide laser in the same experimental preparation. The maximum temperature change with an open vestibule was 0.5°C. Gherini[7] repeated this study using an argon laser and reported no rise in temperature during stapedotomy. Kodali[8] studied temperature changes in the vestibule of the chinchilla animal model during laser stapedotomy. He reported a maximum temperature change of 2.9°C for the KTP laser and 2.6°C for carbon dioxide.

During revision surgery with a piston *in situ* there is a risk of laser hits to the piston while soft tissue is being vaporized within the oval window. In addition, heat generated by the vaporization process may be transmitted to the vestibule via the piston. We postulated that this would be more likely when the piston is made of a good conductor of heat, such as metal, than for a material such as fluoroplastic. The aim of the present study was to test this hypothesis and to try and determine the likely maximum temperature change which would result.

Materials and methods

The study was carried out using stapedotomy modules from the Mills Middle Ear Surgery Trai-

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Accepted for publication: 8 January 2003.

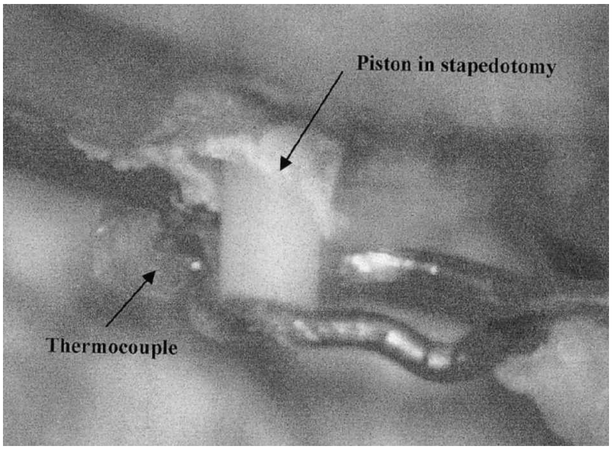

Fig. 1

Photograph showing a type K thermocouple positioned around the tip of a fluoroplastic piston in the 'vestibule'. The piston tip and thermocouple are immersed in a bath of saline.

ner.[9] These are plastic replicas of the medial wall of the middle ear. A plastic incus and malleus are supported in the attic by silicone. In the complete module a stapes arch is attached to the foot plate, which is integral to the medial wall of the middle ear, using epoxy resin. For these experiments the stapes arches were removed and the footplates were fenestrated with a microdrill. Three different types of stapes prosthesis were inserted, an all fluoroplastic Cawthorne piston (0.6 mm diameter), a stainless steel McGee piston (0.8 mm diameter) and fluoroplastic-wire Schucknecht piston (0.6 mm diameter). The pistons passed through the 'stapedotomy' so that their lower ends protruded from the medial side of the module. 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 (Figure 1). The module was placed in a bath of 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).

An 'Aura' KTP laser (Laserscope) was used to deliver laser light via a 0.2 mm fibre. For the initial experiments the manufacturer's recommended setting for stapes surgery were used (1 W power in 0.1 second pulses). Initially a single pulse of laser energy was applied and any temperature rise was noted. Then a series of laser pulses were applied until a total of two J of laser energy had been used. The laser pulses were delivered at a rate of approximately one pulse per second. The procedure was repeated three times for each type of prosthesis. In the case of the fluoroplastic-wire prosthesis, two procedures were carried out, one in which the laser was fired at the wire portion and one in which the fluoroplastic was targeted. Human blood was then applied to each piston and the experiment was repeated. The pistons were then removed and a vein graft harvested during a stapedectomy operation was placed over the foot plate. The pistons were replaced and a further series of laser pulses were applied as before.

Finally the area of vein graft around the piston was partially vaporized using the laser to simulate a revision procedure in which soft tissue is cleared from the oval window to expose the stapedotomy. Initially the laser settings were as described above. Subsequently the duration of the laser pulse was increased to 0.2 seconds and then the power setting was changed to 2 W. The end point of the procedure was a free flow of saline from the oval window.

Results

No temperature rise was recorded for a single laser impact for any of the pistons tested. The mean temperature rises recorded during the initial series of multiple impact experiments varied between 0.2 and 2.47°C (see Table I). The maximum temperature change recorded during these procedures was 2.6°C (stainless steel piston). When the fluoroplastic-wire piston was tested, the temperature rises were the same for the fluoroplastic and wire portions of the piston. The addition of a vein graft appears to provide a degree of insulation which limits the maximum temperature change. The temperature change for the wire and fluoroplastic elements of the fluoroplastic-wire piston were comparable. Examination of the underside of the stapes foot plate following insertion of the pistons with the vein graft *in situ* revealed that the vein was pushed through the stapedotomy without being perforated so that it formed a sheath for the piston within the vestibule. A specimen temperature graph is shown in Figure 2. The addition of blood resulted in a smoke plume, but no additional rise in temperature. Assuming a normal body temperature of 37°C, this would mean a peak temperature of 39.5°C in the vestibule close to the piston. We did not observe any damage to any of the pistons following laser impacts even when blood was applied prior to exposure.

During the simulated surgery in which the vein graft was vaporized around the piston larger temperature changes were recorded for the McGee

TABLE I

MAXIMUM TEMPERATURE CHANGES FOLLOWING LASER APPLICATION TO STAPES PISTONS, MEAN VALUES (KTP 'AURA' LASER; 1 W POWER IN 0.1 SECOND PULSES, TOTAL ENERGY INPUT 2J

	Stainless steel [°C]	Fluoroplastic [°C]	Fluoroplastic-wire [°C]
piston	2.47	1.12	1.43
piston + blood	2.17	1.62	1.48
piston + vein	1.3	0.2	–

https://doi.org/10.1258/002221503321626375 Published online by Cambridge University Press

TABLE II

MAXIMUM TEMPERATURES RESULTING FROM VAPORIZATION OF VEIN GRAFT IN THE 'OVAL WINDOW' (KTP 'AURA' LASER, TOTAL ENERGY INPUT 2–10 J).

Power level/ pulse duration	Fluoroplastic [°C]	Stainless steel [°C]
1W;0.1s	1.0	1.6
1W;0.2s	1.3	5.3
2W;0.2s	1.5	8.0

piston, but not for the fluoroplastic piston (Table II). The temperature change was greater when a longer pulse duration was used and also when the power level was increased.

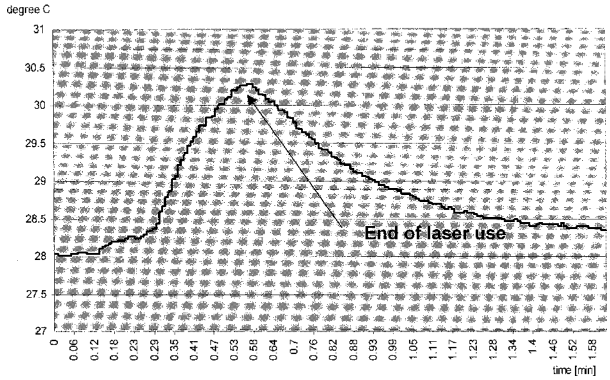

FIG. 2

Specimen graph showing temperature changes at the inferior end of a fluoroplastic stapes piston, coated in blood, during laser application (KTP 'Aura' laser; 1 W power in 0.1 second pulses, total energy input 2 J).

Discussion

Comparison of the results of revision stapes surgery with, and without, a laser suggest that the hearing results are better and the risk of sensorineural hearing loss is less when a laser is used.[3] Data from the experiments in which prostheses were exposed to laser energy suggested that the use of a laser could be associated with damage to the piston.[4,5] Our results do not support this view. It is true that these workers used higher power levels than we have, but even at the level we have employed they reported superficial burns on a fluoroplastic piston.

Our data suggest that inadvertent laser hits on a piston during revision surgery are unlikely to result in a significant change in the temperature in the vestibule. At power levels normally used during stapes surgery vaporization of soft tissue in the oval window is also unlikely to produce a significant temperature rise if there is a fluoroplastic piston *in situ*. With a metal piston a greater rise in temperature occurs in all the situations covered by our experiments. However, this difference is only likely to be significant if higher power levels are used.

The use of vein grafts in stapes surgery provide an excellent soft tissue seal around the piston and this reduces post-operative dizziness. The presence of the graft also helps to prevent the piston from descending too far into the vestibule. Our data suggest that in addition such grafts reduce the transmission of heat to the vestibule when a laser is used in the oval window. However, the fate of vein grafts used in this way is not known. They may become thinner or thicker with time and this would affect their ability to provide insulation. In addition it should be pointed out that soft tissue membranes often form around the tip of a piston when a vein graft has not been used and these would provide similar insulation.

The potential adverse effects of lasers in the ear during stapes surgery extend beyond the vestibule. Delayed facial palsy appears to be more prevalent in laser cases as compared to those in which other techniques are used and this is probably due to heating of the facial nerve during surgery, possibly resulting in reactivation of viruses within the nerve.[10–12]

Examination of data from thermocouple experiments involving *in vitro* simulations of the vestibule indicates some differences in the results for visible light lasers.[6,7] These differences may be related to the type of thermocouple used. The diameters of the thermocouples used varied (Gherini: 0.025 mm;[7] Kodali: 0.127 mm;[8] Lesinski: 0.5 mm;[6] Szymanski, the present study: 1.2 mm). Gherini[7] has suggested that the thermal mass of a larger thermocouple in relation to the thermal mass of the vestibule together with its colour (black) may lead to an erroneously high reading. A comparison between these studies is difficult because of the use of different experimental models, power levels and laser types. None of the models used reflects exactly the conditions in the vestibule of a living patient. Thus it is impossible to say from the data what the temperature in the vestibule would be during surgery. It is, however, possible to make valid comparisons between variables within each model. From the studies carried out by Lesinski[6] we can say that carbon dioxide lasers appear to generate less heat than KTP lasers, but not that KTP lasers cause a clinically significant rise in temperature during surgery. The fact that Kodali,[8] who used an animal model rather than an artificial model, found no significant difference between the temperature rises with the two lasers suggests that this is the case.

Conclusion

From the data from our model we can conclude that stainless steel pistons conduct heat to the vestibule better than fluoroplastic pistons and that vein grafts used to seal the stapedotomy reduce the transmission of heat. The use of a KTP laser to vaporize soft tissue in the oval window during revision surgery with a piston appears to be safe with respect to heat transmission to the vestibule when the power levels recommended by the manufacturers are used.

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