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Experimental selective posterior semicircular canal laser deafferentation

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Abstract
In this experimental study, we attempted to perform selective deafferentation of the posterior semicircular canal ampulla of guinea pigs using carbon dioxide laser beam. The results of this study document the efficacy of this procedure in achieving deafferentation of the posterior semicircular canal safely with regards to the other semicircular canals, the otolithic organ and the organ of hearing. Moreover, the procedure is performed with relative ease compared with other procedures previously described for selective deafferentation of the posterior semicircular canal. The clinical application of such a procedure for the treatment of intractable benign paroxysmal positional vertigo in humans is suggested.

Key words: Vertigo; Laser Surgery; Semicircular Canals; Guinea pigs

Introduction

Benign paroxysmal positional vertigo (BPPV) is a common peripheral vestibular disorder. Its incidence is often quoted to be 17 per cent of all causes of dizziness seen in neuro-otologic practice.[1] It is most likely that BPPV results from a peripheral end organ or primary afferent neuronal vestibular disturbance.[2] Numerous clinical, experimental and histopathological evidence strongly point to the posterior semicircular canal as the probable site of inner-ear pathology. Schuknecht[3] suggested that BPPV is the result of debris or deposits in the posterior semicircular canal attaching to its cupula and coined the term 'cupulithiasis' to refer to positional vertigo resulting from these deposits whose origin still remains unclear. Displaced or degenerated utricular otoconia have been postulated to be the origin of these deposits. The debris or deposits are thought to gravitate to the posterior semicircular canal ampulla where they may become attached to the cupula producing a density difference between the cupula and the endolymph. Thus in certain head positions gravity is thought to cause cupular deflection either by acting directly on the 'weighted' cupula or indirectly by setting up currents in the endolymph through its action on the free-floating debris.[4] Despite the frequent occurrence and wide distribution of the debris or deposits within the labyrinth, their presence in the posterior canal ampulla is thought to be responsible for BPPV at least in part. However, it is also postulated that the clinical findings of BPPV are not only the result of an isolated abnormality of the posterior semicircular canal but also represent a functional interplay between the utricle and the posterior semicircular canal.[5]

Benign paroxysmal positional vertigo is generally a self-limited disorder with spontaneous remission; however in 15-20 per cent of patients, the symptoms are persistent. Manoeuvres to reposition the particles in the inner ear such as those described by Semont *et al*.[6] and Epley[7] have proved efficient in achieving remission in 80 per cent of patients.[8,9] For the small proportion of patients who remain suffering with the condition, surgical treatment is considered.

Singular neurectomy deafferents the posterior canal ampulla and is very effective in relieving the symptoms and signs of BPPV. It is however one of the most technically demanding operations in otology. Singular neurectomy, in the best hands, has a 7.3 per cent incidence of sensorineural hearing loss and an 8.3 per cent failure rate.[10] Despite the technical difficulties, singular neurectomy has been the operation of choice for BPPV and has set the standard against which any new operation for the condition must be measured.[2]

Parnes and MacClure described an alternate selective surgery for BPPV by opening and obliterating the posterior semicircular canal, rendering it inactive.[11] This opened the way to several different technical procedures, all carrying the same principle, that is non-ampullary occlusion of the posterior semicircular canal.[2,8,9,12–14]

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It is the aim of this work to investigate a proposed alternative technique to manage intractable BPPV by utilizing a carbon dioxide (CO_2) laser beam to selectively deafferent the posterior semicircular canal ampulla.

Material and methods

Twenty-four healthy pigmented male guinea pigs (about 200 g) were used in this study. All animals had a preserved pinna reflex – an indication of normal hearing. Animals were divided into two equal groups: an experimental group and a control group of 12 animals each. Animals in the experimental group were anaesthetized using an intraperitoneal injection of ketamine 2.5 mg/100 g. The tympanic bulla was opened and subjected to a 4 W CO_2 laser beam targeting the posterior semicircular canal ampulla of both ears for 0.5 sec in a continuous mode and a 0.5 mm spot size. The surgical wound was closed and the guinea pigs were left to recover on a warm blanket. Animals were sacrificed 1 hour after the laser treatment and temporal bones were obtained for histological study. Animals in the control group were subjected to a sham surgery following the same surgical procedure as the experimental group without applying the laser beam on the semicircular canal. Temporal bones obtained were fixed in neutral buffered formalin and then decalcified using EDTA solution. Specimens were embedded in paraffin and cut to 5μ thick sections. Every 10th section was stained with haematoxylin and eosin (H&E) to study the general architecture of the inner tissues. The consecutive sections were stained with toluidine blue (TB) to demonstrate the Nissl's substance within the perikarya of the spiral ganglion of the cochlea; periodic acid schiff (PAS) to demonstrate the tissue neutral polysaccharides content (PAS positive materials) located in the cupula and basement membrane of the crista ampularis of the semicircular canals as well as in the otolithic membrane and basement membrane of the macula and the tectorial membrane and basement membrane of the organ of Corti of the cochlea. Finally, the Nauta and Gygax silver stain[15] was used for demonstration of the neural elements. Through this multiple-stain protocol we could study the inner-ear tissue reaction to the CO_2 laser at different structural levels.

Results

Haematoxylin and eosin staining of the posterior semicircular canal crista ampullaris (target organ) of the experimental group showed that 67 per cent of the animals showed complete degeneration of the cupula (a cone-shaped mass overlying the apex of the crista ampullaris) and congestion of the blood vessels with the preservation of the epithelial lining of the crista ampullaris (Figure 1). This was also documented by PAS-stained sections showing complete degeneration of the cupula but with intact basement membrane of the posterior crista ampullaris. In the rest of the animals, changes were less obvious, manifesting as mild cupula degeneration in addition to congested blood vessels with intact epithelial lining. No histological changes could be demonstrated in the crista ampullaris of both the lateral and superior semicircular canals that appeared similar to the control group. The epithelial lining of the macula of the utricle and the saccule remained intact and was similar to the control group, but in 33 per cent of the animals there were cytoplasmic vacuolation in some of the cells and partial loss of cilia (Figure 2). Congestion of the blood vessels of the cochlea stria vascularis was seen in 67 per cent of animals with extravasation of red blood cells especially in the basal turn. No changes were seen in the organ of Corti that showed intact hair and supporting cells similar to the control group. Spiral ganglion cells stained with TB showed chromatolysis affecting some of the cells of the ganglion occurring in 17 per cent of animals, giving the cytoplasm a pale appearance attributed to the

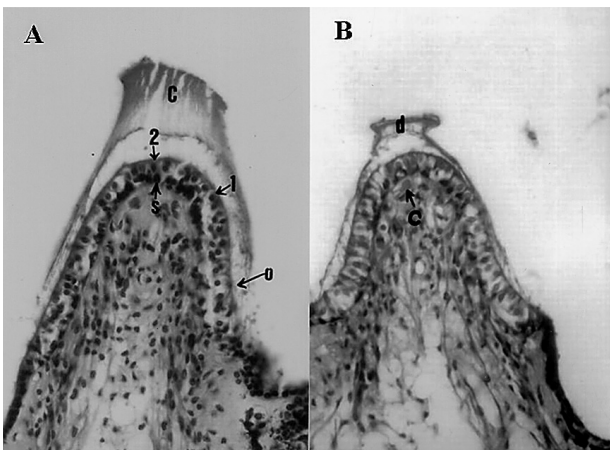

FIG. 1

A: Posterior semicircular crista ampullaris of a control guinea pig showing hair cells (1,2), stereocilia (O), supporting cells (S), cupula (C). B: Posterior semicircular canal crista ampullaris after laser treatment showing complete degeneration of the cupula (d) and congestion of blood vessels (C) with intact epithelial lining (H&E stain, 400x).

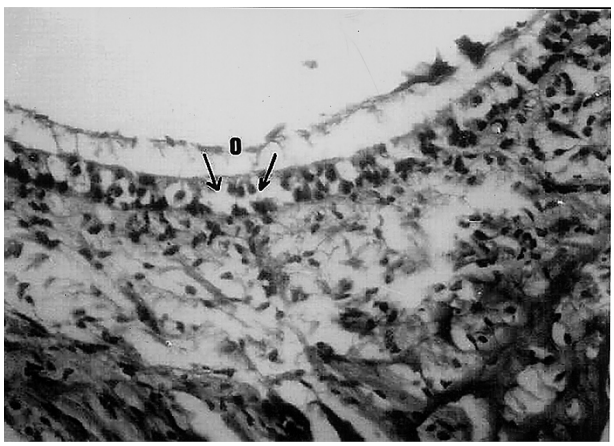

FIG. 2

Macula utriculi after laser treatment showing vacuolation of the cytoplasm of some of the epithelial cells (arrows) with partial loss of cilia and intact otolithic membrane (O) (H&E stain, 400x).

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reduction of the Nissl's granules. The silver stain to demonstrate the vestibular nerve fibres showed that nerve fibres of the posterior crista ampullaris appeared moderately thickened in 83 per cent of the animals in this group. The vestibular nerve fibres of the other cristae (lateral and superior) showed no changes and were similar to the control group. Vestibular nerve fibres of the maculae showed thickening and beading in 17 per cent of the animals. The auditory nerve fibres showed segmentation in 17 per cent of the animals in this group.

Discussion

In recent years, the use of laser technology in otology was directed to surgery of the inner ear for the management of intractable vertigo secondary to inner-ear conditions such as endolymphatic hydrops and benign paroxysmal vertigo. The rationale being laser energy precisely directed to ablate the neuroepithelium of the targeted vestibular end organ without the need for direct contact or extensive surgery on the bony labyrinth. The background for such rationale was the accumulation of surgical experience in the management of intractable vertigo giving evidence that vertigo secondary to the semicircular canal or otolithic organ dysfunction can be abolished by the deafferentation of this organ because of the interruption of the neural input to the brainstem from the disturbed end organ. Furthermore, selective deafferentation of one of the vestibular end organs may minimize the post-treatment morbidity by selectively preserving the other semicircular canals and the otolithic organs (utricle and saccule) in the treated ear.

The present work was designed to investigate the acute inner-ear tissue reaction ensuing from the application of a CO_2 laser beam to ablate the neuroepithelium of the posterior semicircular canal. We focused on two main points. First the efficiency and second the safety of using this modality in achieving selective deafferentation of the posterior semicircular canal ampulla and at the same time preserving the neuroepithelium of the other semicircular canals and the otolithic organs as well as the preservation of the organ of Corti and the auditory nerve itself.

The results of this study showed that all animals demonstrated congestion of the blood vessels in the posterior semicircular canal crista ampullaris (target organ) with complete degeneration of their cupula in 67 per cent and thickening of the vestibular nerve fibres in 83 per cent. Reviewing the basic laser physics, laser light is absorbed by clear fluids and structures. The relative absorption of CO_2 laser light is much greater than the absorption of visible light lasers. The absorbed laser light energy causes elevation of tissue temperature. The resultant hyperthermia leads to congestion of blood vessels and protein denaturation as temperature rises. This explains the cupular degeneration seen in this study. Laser exposure below ablation thresholds produces heat injury with a zone of thermal injury explaining the thickening of the vestibular nerve fibres of the crista ampullaris. The other semicircular canals (superior and lateral) were preserved in all animals while the otolithic organs (utricle and saccule) were preserved in more than 75 per cent of animals. Preserving the other semicircular canals as well as the otolithic organs could decrease the post-treatment morbidity with less chronic disequilibrium compared with that seen after total deafferentation of the vestibular end organ. The cochlear structure was also preserved with only congestion of the stria vascularis of the organ of Corti detected in the basal turn in 67 per cent of the animals in this group, a finding also reported by other investigators.[16] The cochlear nerve fibres were preserved in 83 per cent of the animals. In 17 per cent, evidence of chromatolysis was seen in some of the spiral ganglion cells showing chromatolysis associated with segmentation of some auditory nerve fibres probably because of propagated thermal injury.

- **In this study the guineapig is used as an animal model in exposure and deafferentation of the posterior semicircular canal ampulla**
- **Deafferentation was achieved with the use of a carbon dioxide laser**
- **Histological analysis of treated posterior canals showed complete cupula degeneration compared with controls**
- **The possible application of this technique in human BPPV is discussed**

Selective laser ampullary deafferentation of the posterior semicircular canal was achieved without fenestration of the semicircular canal using the 4 W laser power setting. This could decrease violation of the inner ear which remains a feared complication in otologic surgery as it commonly leads to profound sensorineural hearing loss.[17] The 4 W laser power setting caused only charring of the ampullary bone in contrast to the 8 W laser power setting that we have tried in a pilot study (unpublished data). This higher power setting caused fenestration of the ampulla bony covering with more degenerative effect on the posterior semicircular canal affecting also the other semicircular canals, the otolithic organs as well as the organ of hearing and the cochlear nerve.

In this work, we have only studied the acute reaction of the inner-ear tissues after subjection to a CO_2 laser beam. A number of authors have concluded that laser treatment of the inner ear causes healing by fibrosis in animals.[8,9,11–13] It is thus our assumption that in addition to the degenerated cupula seen in 67 per cent of cases, the 4 W CO_2 laser power setting could achieve more deafferentation effect by fibrosis by the time necessary for healing. This could avoid the unwanted side effects using higher powers pertaining to the other vestibular end organs as well as the organ of hearing. Additionally, the use of a pulsed laser instead of the continuous

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mode type, which we have used in this work, reduces the chances of thermal injury to adjacent tissue by virtue of the higher peak powers that enables it to reach ablation thresholds over short durations.

In conclusion, it appears that selective CO_2 laser deafferentation of the posterior semicircular canal ampulla lends itself to be an efficient method for the treatment of intractable BPPV for the small proportion of patients who fail to respond to conservative measures and remain suffering with the condition. The procedure is performed with relative ease compared with the other procedures previously described for selective deafferentation of the posterior semicircular canal. However, one should not apply indiscriminately to humans the findings in experimental animals. Firstly, while the posterior semicircular canal ampulla is not covered by bone and is therefore easily accessible in the guinea pig, the contrary is encountered in humans. Drilling is required to expose the posterior semicircular canal ampulla in humans which requires knowledge of the detailed anatomical landmarks of the immediate relations, namely the facial nerve and the jugular bulb.[18] Secondly, the difference in bone thickness of the posterior semicircular canal ampulla in guinea pigs compared with humans should be taken into consideration while adjusting the laser power. Thirdly, although histological evidence in this study documents the safety of this technique as regards the inner-ear structure, yet safety as regards to hearing would not have been decided except after additional work is done to determine the impact of this technique using electrophysiological measures.

References

1 Nedzelski JM, Barber HO, McIlmoyl L. Diagnoses in a dizziness unit. *J Otolaryngol* 1986;**15**:101–4
2 Pace-Balzan A, Rutka JA. Non-ampullary plugging of the posterior semicircular canal for benign paroxysmal positional vertigo. *J Laryngol Otol* 1991;**105**:901–6
3 Schuknecht HF. Positional vertigo: clinical and experimental observations. *Trans Acad Opthalmol Otolaryngol* 1962;**66**:319–32
4 Hall SF, Ruby RRF, McClure JA. The mechanics of benign paroxysmal vertigo. *J Otol* 1979;**8**:151–8
5 Fluur E, Siegborn J. Interaction between the utricles and the vertical semicircular canals. *Acta Otolaryngol* 1974;**77**:80–5
6 Semont A, Freys G, Vitte E. Curing the BPPV with a liberatory maneuver. *Adv Otorhinolaryngol* 1988;**42**:290–3
7 Epley JM. The canalith repositioning procedure: for treatment of benign paroxysmal positional vertigo. *Otolaryngol Head Neck Surg* 1992;**107**:399–404
8 Zappia JJ. Posterior semicircular canal occlusion for benign paroxysmal positional vertigo. *Am J Otol* 1996;**17**:749–54
9 Kartush JM, Sargent EW. Posterior semicircular canal occlusion for benign paroxysmal positional vertigo – CO_2 laser-assisted technique: preliminary report. *Laryngoscope* 1995;**105**:268–74
10 Gacek R. Singular neurectomy update. *Ann Otol Rhinol Laryngol* 1982;**91**:469–73
11 Parnes LS, McClure JA. Posterior semicircular canal occlusion for intractable benign paroxysmal positional vertigo. *Ann Otol Rhinol Laryngol* 1990;**99**:330–4
12 Hawthorne M, El-Naggar M. Fenestration and occlusion of posterior semicircular canal for patients with intractable benign paroxysmal positional vertigo. *J Laryngol Otol* 1994;**108**:935–9
13 Anthony PF. Partitioning the labyrinth for benign paroxysmal positional vertigo: clinical and histologic findings. *Am J Otol* 1993;**14**:334–41
14 Antonelli PJ, Kartush JM, Lundy LB, Burgio DL, Graham MD. Mechanical versus CO2 laser occlusion of the posterior semicircular canal in humans. *Am J Otol* 1996;**17**:416–20
15 Nauta WIH, Gygax, PA. Silver impregnation of the degenerating axons terminals in the central nervous system. *Stain Tech* 1951;**26**:5–11
16 Escudero LH, Castro AO, Drumond M, Porto SP, Bozinis DC, Penna AF, Callego-Lluesma E. Argon laser in human tympanoplasty. *Arch Otolaryngol* 1979;**105**:252–3
17 Isaacson DJ, Antonelli PJ. Labyrinthine fenestration in the guinea pig. *Otolaryngol Head Neck Surg* 1999;**120**:394–9
18 Saleh E, Naguib, M, Aristegui M, Cokkeser Y, Sanna M. Lower skull base: anatomic study with surgical implications. *Ann Otol Rhinol Laryngol* 1995;**104**:57–61

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