An evaluation of per-scalar cochlear electrode implantation techniques
An histopathological study in cats

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Introduction
This study has been carried out primarily to evaluate the histopathological changes that occur in the cochlea and spiral ganglion of the cat following per-scalar cochlear electrode implantation techniques, prior to any surgical procedures on patients. A per-scalar implantation refers to one in which the electrode is threaded along the length of the scalae of the cochlea. This may be in an apical direction, where it is usually introduced through the round window, or in a basal direction where it is inserted through an opening drilled in the bone overlying the apical turn.

It was also considered of special importance to assess the risk of infection, and the effects of any trauma associated with the two procedures, as these two complications could lead to the loss of the auditory nerve fibres it was hoped to stimulate electrically.

With regard to infection, Simmons (1967) has shown that an electrode inserted through the round window into the scala tympani, can lead to a labyrinthitis with destruction of cochlear and neural tissue. Clark et al. (1975) have also found that following the trans-scalar implantation of electrodes into the apical and middle turns, without adequate sterility, destruction of the organ of Corti, and loss of neural tissues can occur throughout the cochlea.

Surgical trauma could also be hazardous. For example, Schlindler and Merzenich (1974) found that, in two cats following per-scalar electrode insertions through the round window, the basal turn was replaced by...
fibrous tissue and bone, and they attributed this to damage of the endosteum. Furthermore, Spoendlin (1975) has drawn attention to the fact that damage to certain structures in the cochlea can lead to degeneration of spiral ganglion cells, and auditory nerve fibres. He has also emphasized that this loss of spiral ganglion cells can occur up to 20 weeks after the initial damage of structures in the cochlea, but thereafter the loss is minimal.

Methods

This study was carried out on six adult cats. They were examined preoperatively to make sure that their tympanic membranes were otoscopically normal. Anaesthesia was induced with pentobarbitone sodium (40 mg./kg., ip.) and maintained with methoxyfluorane and halothane administered by a closed circuit technique.

On one side a teflon-coated multi-stranded wire (outside diameter, 0.125 mm.) was inserted through the round window, and on the other side it was introduced through an opening drilled in the bone overlying the middle and apical turns. The surgery was performed by the author or one of three registrars undertaking experimental surgery as part of their rotating training programme in otolaryngology. Following surgery the animals were given procaine penicillin (one million units, imi) daily for 3 to 5 days.

Four animals (Nos. 3, 4, 5 and 6) survived long enough for histological studies to be carried out. In the case of the other two, one died under the anaesthetic, and the other a few days post-operatively from a chest infection. After a period of time which varied from 42 to 59 weeks the animals were sacrificed, and perfused intra-arterially with normal saline followed by 10% formalin. Their temporal bones were decalcified, embedded in celloidin, and sectioned at a thickness of 30 μm. The sections were stained by the rapid Cason method of the Mallory-Heidenhain stain (Humason, 1966) which was found to be superior to haematoxylin and eosin, particularly for showing spiral ganglion cells, and differences between fibrous and endochondral bone.

Cat 3–75

This animal was sacrificed and perfused 59 weeks after the implant operations. On the left side the teflon-coated platinum wire passed easily through the round window into the scala tympani of the basal turn for a distance of 10 mm. The histological findings (Fig. 1) showed that the stria vascularis and organ of Corti were normal. The spiral ganglion cell densities in the apical, middle and basal turns were 4,188/mm², 5,345/mm² and 5,105/mm² respectively, and these findings were considered within normal limits. There was, however, amorphous pink-staining material in the scala vestibuli and media of the basal turn, and this finding suggests a serous labyrinthitis with resolution.
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On the right side an opening was drilled in to the apical turn of the cochlea, and the wire inserted a shorter distance than the one introduced through the round window. The histological findings can be seen in Fig. 2. This shows damage to the bony partition between the apical and middle turns, and a tear in the basilar membrane of the apical turn. Pink staining material was present throughout the scalae vestibuli, media and tympani, and was most predominant in the basal turn. The stria vascularis was normal in all sections. The organ of Corti was present with intact hair cells in all turns except the more apical part of the basal turn. The ganglion cell densities were as follows: 6,502/mm.²—basal part of basal, 1,341/mm.²—apical part of basal, 6,298/mm.²—basal part of middle, 5,530/mm.²—
FIG. 2.
Photomicrograph of the right cochlea in Cat 3–75. Per-scalar electrode implantation via the apical turn after 59 weeks. Magnification ×53.

apical part of middle, and 5,120/mm.²—apical cochlear turn. This indicates that the ganglion cell numbers were normal in all turns except the apical part of the basal turn where there was an 80% reduction in their numbers. This loss of spiral ganglion cells was also associated with loss of the organ of Corti, a relatively greater amount of exudate in the scala in this region, and a tear in the basilar membrane.

The above findings suggest that there was initial trauma to the basilar membrane of the apical turn, and the partition between the apical and middle turns. The electrode tip may have also caused a laceration in the basilar membrane of the apical portion of the basal turn, and this could have led to a localized serious labyrinthitis and damage to the spiral ganglion cells in the area.
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Cat 4-75

This animal was sacrificed and perfused 58 weeks after the implant operations. On the right side the round window membrane was pierced with a 25 gauge needle, and the teflon-coated platinum electrode inserted into the scala tympani of the basal turn for a distance of 8.2 mm. The histological findings (Fig. 3) show that the whole of the basal part of the basal turn was replaced with fibrous tissue, and fibrous bone formation took place on the upper surface of the spiral lamina, and around the wall of the scala vestibuli. In the basal part of the basal turn there was a marked loss of ganglion cells with a density of only 758/mm., indicating an 85–90% loss. The apical part of the basal turn was also affected, although to a lesser extent. In this segment there was fibrous tissue in the scala

Fig. 3.
Photomicrograph of the right cochlea in Cat 4-75. Per-scalar electrode implantation via the round window after 58 weeks. Magnification ×53.
vestibuli and tympani, loss of the organ of Corti, and a ganglion cell density of 963/mm.² which is equivalent to an 80–85% reduction. There was also some pink staining material in the scala vestibuli and tympani of the middle and apical turns without, however, loss of the organ of Corti or spiral ganglion cells.
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Serial sections of the basal turn were also stained and examined to help determine whether the pathology was primarily due to trauma or infection. In the sections examined there was no obvious evidence of trauma to the spiral lamina or endosteum, but there was a small collection of pus cells in the centre of the fibrous tissue in some of the sections (Fig. 4).

On the left side a small opening was made in the bone overlying the middle turn of the cochlea, the stria vascularis was stripped up, and an opening made in what was considered to be the scala tympani. Bone dust was aspirated, there was a slight ooze of perilymph from the opening, and the teflon-coated platinum wire inserted towards the basal turn for a distance of 5–10 mm. A piece of compressed muscle was then placed around the electrode, and over the opening into the cochlea. The histological findings (Fig. 5) show that the entry point of the electrode overlay the scala tympani of the apical turn. The bony partition between the scala tympani of the apical turn, and the scala vestibuli of the middle turn, was damaged. At the site of the electrode implantation there was also loss of the organ of Corti and Reissner’s membrane. Some atrophy of the stria vascularis was present, and there was a ganglion cell density of 492/mm.² indicating a 90% of marked cell loss. In the middle turn there was atrophy of the organ of Corti, and a spiral ganglion density of 2,048/mm.² indicating a 50–60% loss. It is also interesting to note that the opening drilled in the bone was filled in with material which had staining properties consistent with fibrous tissue, and that fibrous bone formation occurred around the margins of the opening (Fig. 5).

Cat 5–75

This animal was sacrificed and perfused 42 weeks after the implantation operations. On the right side the oval window membrane was punctured with a 25 gauge needle and the teflon-coated platinum wire inserted into the scala tympani of the basal turn. The length of electrode introduced was not recorded. The histological findings (Fig. 6) show a small amount of pink staining material in the scala tympani and media of the basal turn. Otherwise the stria vascularis, organ of Corti, and Reissner’s membrane were normal in all turns. The ganglion cell densities in the middle and basal turns were 5,427/mm.² and 5,837/mm.², and this is consistent with normality. These findings suggest that the teflon-coated platinum wire caused little reaction in the surrounding tissue.

On the left side an opening was made in the bone overlying the middle turn of the cochlea. The teflon-coated wire was inserted towards the basal turn until it commenced to buckle. As the length of insertion had not been recorded it was removed and reinserted for a distance of 10 mm. A piece of compressed muscle was placed over the opening in the cochlea. The histopathological findings (Fig. 7) show the site of the electrode
implantation overlying the scala vestibuli of the middle cochlear turn. The space occupied by the electrode was surrounded by a thin layer of pink staining material as far as the basal turn. There was loss of the organ of Corti in the middle turns, but it appeared normal in the apical and basal turns. In the middle turn there was an absence of Reissner's membrane, a dehiscence in the basilar membrane, and material which had the appearance of loose fibrous tissue in the scala tympani. The presence of fibrous tissue in the scala tympani of this turn could have been induced by trauma to the basilar membrane. Furthermore, there was amorphous pink staining material overlying Reissner's membrane in the scala
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vestibuli of the basal portion of the basal turn. The ganglion cell densities in the middle and basal turns were 2,458/mm.² and 5,530/mm.² indicating normality in the basal turn, and 50% reduction in the middle turn.

Cat 6–75
This animal was sacrificed and perfused 46 weeks after the implantation operations. A teflon-coated electrode was inserted through the round window into the cochlea on the right side. The temporal bone was inadvertently damaged during removal following the perfusion of the cat, and consequently no histology is available on this side.
On the left side an opening was drilled in the bone overlying the cochlea, and the wire inserted an estimated 8 mm. These histological findings (Fig. 8) show that the electrode entered the scala vestibuli of the apical turn, and passed around to the apical portion of the basal turn. There was a loss of the organ of Corti in the apical turn at the site of the electrode implantation. In the apical part of the middle turn there was a large dehiscence in the basilar membrane, the organ of Corti was absent, there was atrophy of the stria vascularis, and fine membrane lined both the scala vestibuli and tympani. In the basal portion of the middle turn
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There was loss of Reissner’s membrane, and the hair cells and tectorial membrane were missing from the organ of Corti. In the scala vestibuli of this turn, near the modiolus, there was an accumulation of fibrous tissue which surrounded material with the appearance or haemosiderin. This could have arisen from bleeding at the time of operation. In the basal turn there was loss of the tectorial membrane and hair cells in the organ of Corti. This section did not show the ganglion cell region for the apical turns, but in the middle turn the densities were 881/mm² and 2,621/mm² indicating an 85% and 50% loss of cells, while in the basal turn the ganglion cell density was 4,198/mm² indicating only a 10% cell loss.
From this study it can be seen that a per-scalar cochlear electrode implantation through an opening drilled in the cochlea over the apical or middle turns can be performed without significant infection, provided the operation is carried out aseptically with an antibiotic cover. The evidence of infection was in fact much less than in a previous study (Clark et al., 1975) which was carried out with less attention to asepsis, and where a larger opening was drilled in the overlying bone and two stainless steel electrodes simply placed directly into the cochlea. In the present study, the opening was also made as small as possible, all bone dust was sucked away, and a compressed muscle graft manoeuvred into position over the opening. These procedures could have contributed to the greatly reduced evidence of infection. Furthermore, it can be seen from Fig. 8 that the opening was filled with bone and fibrous tissue which firmly embraced the electrodes, and could therefore act as a barrier to infection. It is also interesting to note that the fibrous tissue and bone did not extend into the cochlea and replace the enclosed structures, as this would have led to destruction of spiral ganglion cells. In any similar operation on patients it is also helpful to know that if the electrode array failed and had to be replaced, this need not be prevented by the obliteration of the apical turn with bone or fibrous tissue.

The per-scalar cochlear implantations through the round window membrane were free of any significant infection in two out of three cats examined. In one, however, the basal part of the basal turn (Fig. 3) was completely replaced with fibrous tissue. There was also evidence of new bone formation around the periphery of the scala vestibuli, and along the spiral lamina. Similar findings also occurred in a study by Schindler and Merzenich (1974) where two cats had the scala tympani near the round window replaced by bone. In this study the authors considered that the ossification resulted from damage to the endosteal lining induced by the insertion of the electrode. There is still the possibility however, that these changes were the result of infection. For this reason, in our present study where ossification and fibrosis developed after the round window insertion, we stained all sections in the region and examined them for evidence of either trauma or infection. Consequently, it was of interest to find that in two sections there was a collection of pus cells in the centre of the fibrous tissue, and this suggests infection as the cause of the pathology.

The other main point of this study was to assess the trauma produced, particularly by a per-scalar cochlear electrode inserted through an opening drilled into the apical and middle turns. Studies by Spoendlin (1975) indicate that any diseases which damage the cochlea are likely to lead to loss of spiral ganglion cells. For this reason it seemed important to assess the trauma produced by an electrode inserted along the length of the
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cochlea, and the effects of the trauma on spiral ganglion cell viability. The results of the study could also be applied to the insertion of an electrode in patients, and the development of a surgical technique that would lead to minimal damage of the organ of Corti and spiral ganglion cells.

The results of the study showed that an electrode inserted into the scala tympani was less likely to cause trauma and loss of spiral ganglion cells than one in the scala vestibuli, and this supports a prediction made by Lawrence (1964). Furthermore, with care it was possible to place an electrode in the scala tympani of the cat provided the stria vascularis was dissected upwards to allow better access.

In the cats where the electrode passed along the scala vestibuli it was surprising how frequently Reissner's membrane remained intact, particularly in the turns close to the point of insertion. This could be attributed to the fact that as the electrode was advanced it came to lie against the upper outer wall of the scala. When penetration of Reissner's membrane occurred, however, it was usually associated with an 80–90% loss of spiral ganglion cells in a localized area. Furthermore, in one cat, penetration of Reissner's membrane was associated with disruption of the basilar membrane at the same site, and there was a more complete loss of spiral ganglion cells locally. These findings indicate that the electrode should have a blunt tip (not present in this experimental series), and be inserted with care. It appears that any attempts to force the electrode, particularly during the later stages of its insertion, should be avoided as this is likely to cause disruption of the Reissner's and basilar membranes. At the site of implantation it was also apparent that there was local damage of the organ of Corti and spiral ganglion cells. This could have been due to trauma produced during the creation of an opening into the cochlea, or reflex vascular spasm associated with the procedure (Axelsson and Hallen, 1973).

It was noted during the surgery that the bony partition between the apical and middle turns needed to be drilled to allow adequate access to the scala tympani of the apical turn, and the histology showed that care must be taken to insert the electrode in the scala tympani of the apical turn, and not the scala vestibuli of the middle one. As the scala tympani of the apical turn is also narrow in its outer position, the diameter of the electrode should be smaller than the width of this turn, otherwise it is likely that the electrode will distend and rupture the basilar membrane. Furthermore, it was noted that trauma was more marked in the case where the electrode was inserted a second time, and this emphasizes the importance of doing everything possible to ensure that the first insertion is satisfactory. One important surgical point in this connection is to be sure that an opening is made through the endosteal lining into the scala tympani, and that the endosteal lining is not inadvertently stripped from the bone, thus making a false path for the electrode.
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Finally, in two of the cats where histology was available following a round window insertion, there was little evidence of damage to the cochlea, and the hair cells of the organ of Corti in the basal turn appeared to be normal. On the other hand, Schindler and Merzenich (1974) reported that in their study nearly all hair cells were lost in the basal turn, and this difference in the results between the two studies could be due to the fact that they used a larger electrode which was more likely to cause trauma, and secondly the material used was Silastic which could have tissue toxicity effects. The fact that in the present study there was little reaction around the electrode supports the evidence that teflon is biologically inert, and causes little tissue reaction in the form used in these experiments.

Summary

This study was carried out to evaluate the effects of infection and trauma on the organ of Corti and spiral ganglion cells following per-scalar cochlear electrode implantations in cats. The results showed that the incidence of infection with a per-scalar electrode inserted through an opening made directly into the apical and middle turns is low, provided the procedure is carried out aseptically with an antibiotic cover. Trauma could also be kept to a minimum by inserting the electrode into the scala tympani, taking care to insert the electrode without applying force, and ensuring that the first insertion is the only one. Furthermore, the tip of the electrode should be blunt, and its diameter smaller than the width of the scala tympani. It was noted that damage to the organ of Corti, and loss of spiral ganglion cells only occurred as a local phenomenon, and its extent was related to the severity of the damage to the Reissner’s and basilar membranes.

The insertion of an electrode through the round window and along the scala tympani was not free of risk, as infection which led to a marked loss of spiral ganglion cells occurred, particularly in the basal turn. On the other hand, when the size of the electrode was small in relation to the cross sectional area of the scala tympani, and it was not inserted far along the length of the basal turn, the evidence of trauma was minimal. Tissue reaction to the teflon-coated platinum electrode was also not observed.

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