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The width, height, and cross-sectional area of the scala tympani in both the human and cat were measured to provide dimensional information relevant to the design of scala tympani electrode arrays. Both the height and width of the human scala tympani decrease rapidly within the first 1.5 mm from the round window. Thereafter, they exhibit a gradual reduction in their dimension with increasing distance from the round window. The cross-sectional area of the human scala tympani reflects the changes observed in both the height and width. In contrast, the cat scala tympani exhibits a rapid decrease in its dimensions over the first 6 to 8 mm from the round window. However, beyond this point the cat scala tympani also exhibits a more gradual decrease in its dimensions. Finally, the width of the scala tympani, in both human and cat, is consistently greater than the height.

KEY WORDS — cochlear anatomy, cochlear implant, electrode array, scala tympani.

INTRODUCTION

Knowledge of the dimensions of the scala tympani in both humans and experimental animals is necessary for the continued development of cochlear implants. For example, such information would ensure that scala tympani electrode arrays are not inserted past a point in the cochlea dimensionally smaller than the electrode array. This knowledge would also provide the necessary anatomic information required for the development of improved scala tympani electrode arrays. In addition, comparative data from experimental animals would provide a means of examining the suitability and limitations of animal models that are used in physiologic experiments studying basic neural response properties associated with cochlear implants.

Dimensions of the cochlea in humans and laboratory animals have been reported by several authors.[1-7] However, these reports have some limitations: either the measurements were not made systematically along the scala tympani, or the cross-sectional area, the height, and the width of the scala tympani were not recorded in each cochlea. We required more systematic and detailed measurements of the scala tympani in order to develop improved electrode array designs. Evidence from electrode insertion studies in human temporal bones[8-11] has suggested that the Cochlear Corporation's (Nucleus) banded electrode array lies along the outer wall of the scala tympani. A subsequent histopathologic study of a cochlea from a patient implanted with the banded electrode array confirmed this finding.[12] Moreover, it highlighted the relatively large distance between the electrode array and the residual neural elements within Rosenthal's canal. Recent acute electrical stimulation studies in cats have shown that electrically evoked auditory brain stem response thresholds are reduced and the dynamic range is increased as the banded electrode array is moved from the outer wall of the scala tympani toward the modiolus.[13] These results suggest that an electrode array placed close to the modiolus would be capable of exciting a greater number of discrete groups of auditory nerve fibers, using electrodes with a narrower interelectrode spacing. The development of a more effective electrode array may be possible if the dimensions of the scala tympani are more precisely known.

The present study describes the comparative dimensions of the scala tympani in the human and cat. Silastic molds of the human and cat scala tympani were made, and the width, height, and cross-sectional area were measured every 0.5 mm from the round window.

MATERIALS AND METHODS

Eight human and 10 cat cochleas were used in this study. Cat cochleas were obtained from animals with weights that ranged from 0.35 to 4.0 kg. Human cochleas were obtained from adults. These cochleas were either freshly prepared or stored in a

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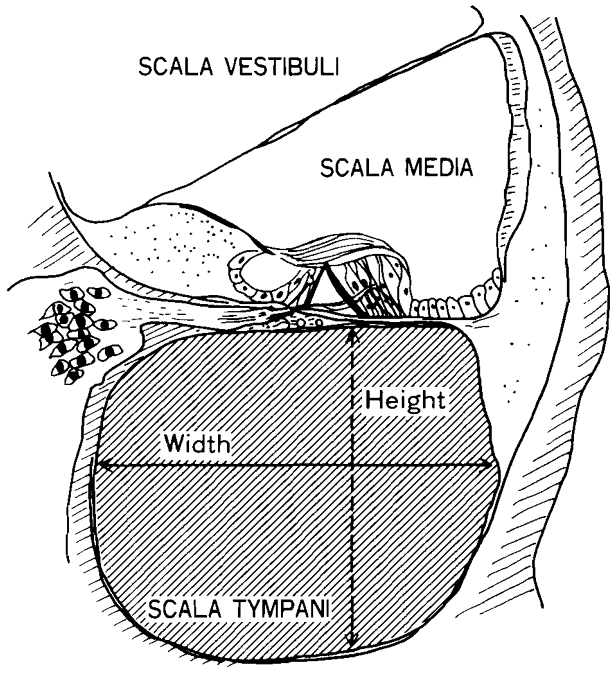

Fig 1. Diagram of scala tympani illustrating three measurements recorded in present study: height, width, and cross-sectional area (shaded) of scala tympani.

deep freezer until required.

Following the resection of the temporal bone, the round window membrane was incised under magnification with use of a hook. Care was taken to avoid damage to the osseous spiral lamina superomedial to the round window. A small hole was made in the apex of the cochlea with a diamond paste drill, the stapes footplate was removed, and the oval window was opened. Each cochlea was then dehydrated in absolute alcohol. To accelerate the dehydration process, each human cochlea was placed under vacuum (−100 kPa) for 15 minutes and then placed in an oven at 70°C overnight.

The Silastic (J RTV silicone rubber) was injected into the scala tympani through the round window. The cochlea was placed under vacuum to assist the infiltration of the Silastic. Finally, the Silastic was allowed to harden at room temperature for 24 hours. The rubber mold of the scala tympani was removed from the cochlea by drilling the overlying bone with use of diamond paste drills under magnification. The rubber mold was then cut at right angles to the basilar membrane. Each section was 0.5 mm thick.

In a preliminary experiment, we had shown that this Silastic was not subject to shrinkage during curing. A resin cast was made, and a mixture of Silastic J RTV was cured in it. The Silastic mold was then removed, and both the cast and the mold were sectioned. Their cross-sectional dimensions were determined by use of a light microscope equipped with a calibrated eyepiece graticule. The outside diameter of the Silastic mold was the same size as the inside diameter of the resin cast, indicating that no shrinkage had occurred.

The cross-sectional area, the width (the widest distance parallel to the basilar membrane), and the height (the longest distance perpendicular to the basilar membrane) of the scala tympani were measured for each 0.5-mm section with use of the graticule and light microscope. The scala tympani measurements we recorded are illustrated in Fig 1. The area, width, and height of the round window were measured from the first 0.5-mm section. This first measurement was made in the plane of the round window. Subsequent measurements from all remaining 0.5-mm-thick sections were made at right angles to the basilar membrane. For each 0.5-mm section, results from the eight human cochleas were combined, and standard deviations were calculated. This procedure was repeated for the data obtained from the 10 cat cochleas.

RESULTS

Shrinkage of the Silastic rubber did not occur. These measurements therefore reflect the absolute dimensions of the scala tympani in both humans and cats.

Although there were difficulties in obtaining accurate molds of the scala tympani in the most apical region of the cochlea, due to the failure of the Silastic to flow into this region, accurate molds of the basal and middle turns were routinely obtained. For this reason, our results are restricted to the basalmost 25 mm of the human cochlea and the basalmost 15 mm of the cat cochlea. These regions, however, cover the maximum insertion distance of a scala tympani electrode array in both human and cat, and are therefore adequate for this study.

The cross-sectional area of the human scala tympani as a function of distance from the round window is illustrated in Fig 2A. For comparison, the cross-sectional area of the Cochlear Corporation's banded scala tympani electrode array is also illustrated in the diagram. As evident from Fig 2A, the cross-sectional area of the human scala tympani exhibits an initial rapid decrease resulting in the halving of the cross-sectional area within the first 1.5 mm from the round window. From this point, the cross-sectional area, which is approximately 2.25 mm^2, gradually reduces with distance from the round window. Twenty-five millimeters from the round window the cross-sectional area of the human scala tympani is approximately 0.75 mm^2.

Figure 2A also illustrates the free-fitting nature of the banded scala tympani electrode array. At the 25-mm point, for example, the electrode array occupies less than 25% of the cross-sectional area of the scala tympani.

The height and width of the human scala tym-

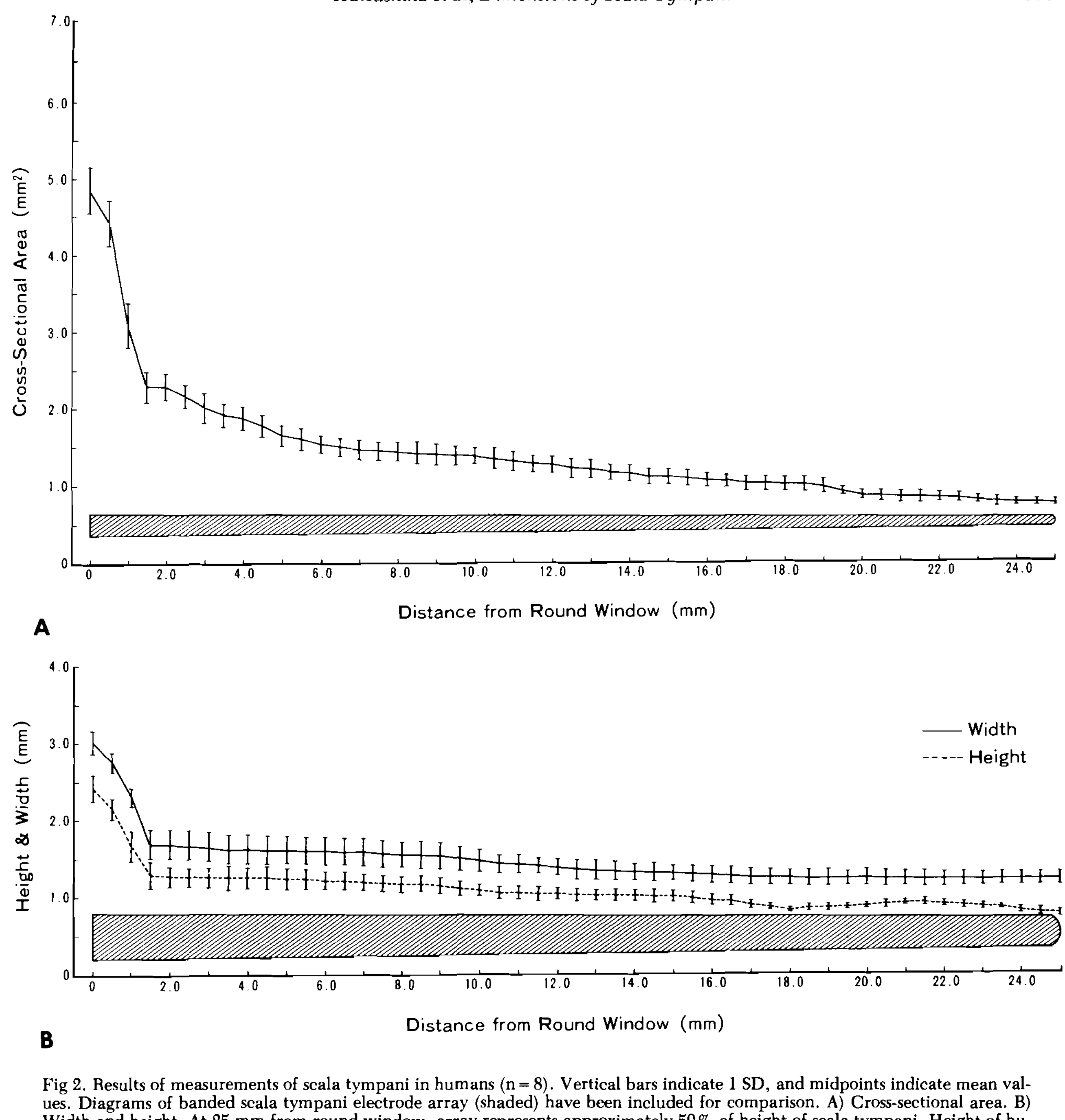

Fig 2. Results of measurements of scala tympani in humans (n = 8). Vertical bars indicate 1 SD, and midpoints indicate mean values. Diagrams of banded scala tympani electrode array (shaded) have been included for comparison. A) Cross-sectional area. B) Width and height. At 25 mm from round window, array represents approximately 50% of height of scala tympani. Height of human scala tympani does not decrease continuously, but shows slight increase in region 18 to 21 mm from round window.

pani, as a function of distance from the round window, are illustrated in Fig 2B and reflect the changes observed in the cross-sectional area. The width of the scala tympani was consistently greater than the height. Although, in general, both the width and height showed a gradual reduction with increasing distance from the round window, the height of the scala tympani did exhibit a sharper reduction, followed by a slight increase in its dimension over a 4-mm region centered around a point 21 mm from the round window.

For comparison, the dimensions of the banded scala tympani electrode array are included in Fig 2B. While the dimensions of the electrode array are somewhat less than the height and width of the scala tympani in the region 25 mm from the round window, the tip of the array is approximately 60% of the height of the scala tympani at this location. This observation should be a consideration if improvements in the design of the electrode array include changes in its dimensions.

The cross-sectional area of the cat scala tympani as a function of distance from the round window is illustrated in Fig 3A. The cross-sectional area of a

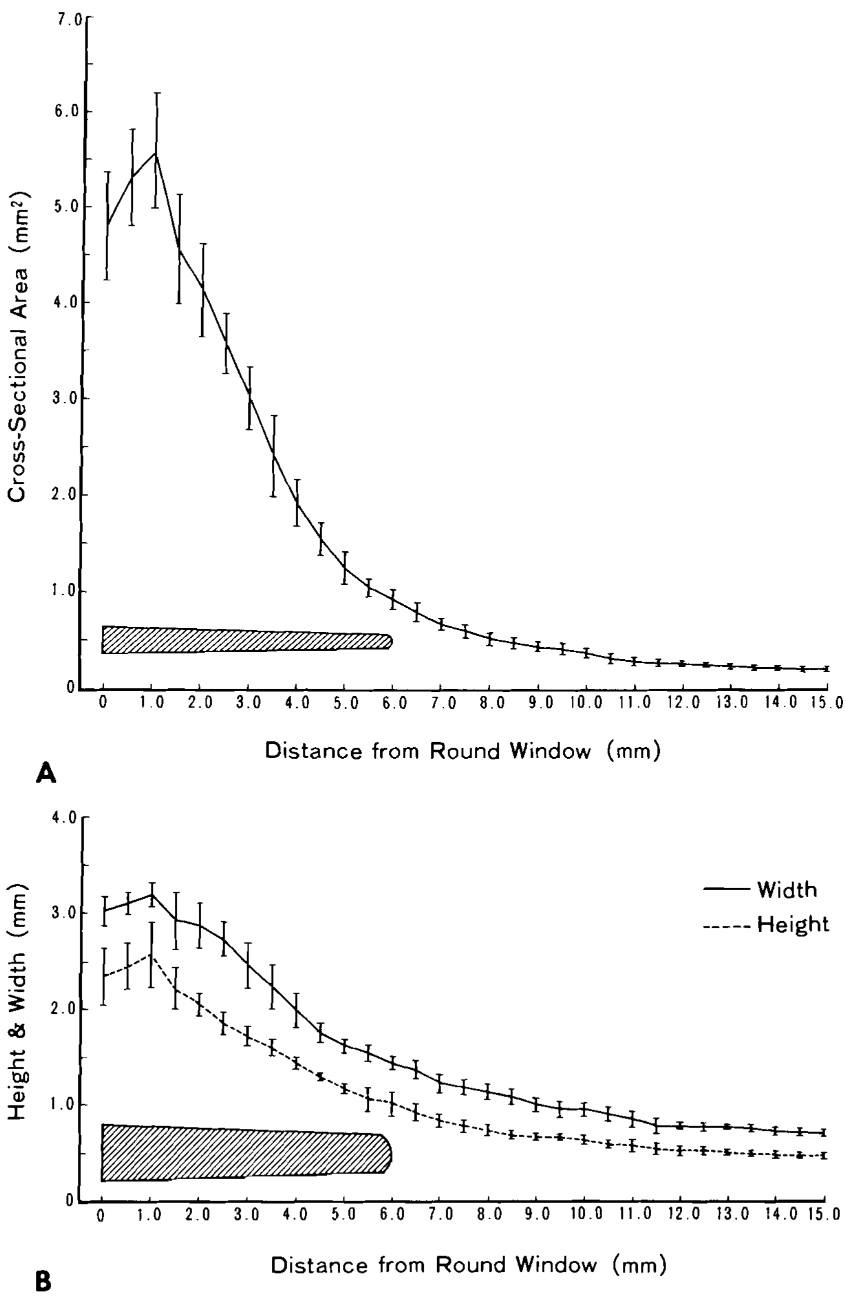

Fig 3. Results of measurements of scala tympani in cats (n = 10). Diagrams of banded scala tympani electrode array (shaded) have been included for comparison. A) Cross-sectional area. B) Width and height. Difference between width and height decreases gradually with increasing distance from round window.

banded scala tympani electrode array — inserted to a distance of 6 mm — is included for comparison. At the round window, the cat scala tympani is almost identical in cross-sectional area to that of the human. This area actually increases over the first millimeter from the round window, but then rapidly decreases over the following 6 to 8 mm, after which it continues to decrease gradually. While in the middle and apical turns the cross-sectional area of the cat scala tympani is 25% to 30% of the human, the cat has a larger scala tympani cross-sectional area than the human within the first 4 mm from the round window.

The height and width of the cat scala tympani as a function of distance from the round window are illustrated in Fig 3B. The changes in these dimensions with distance along the scala tympani reflect the changes observed in the cross-sectional area of the cat scala tympani. As observed in the human, the width of the cat scala tympani is greater than its height. The scala tympani electrode array is usually inserted to a distance of approximately 6 mm from the round window in the cat. At this point the tip of the electrode would occupy approximately 40% to 50% of the height of the scala tympani.

DISCUSSION

The dimensions of the round window in both human and cat are very similar. The cross-sectional area of the human scala tympani then undergoes a

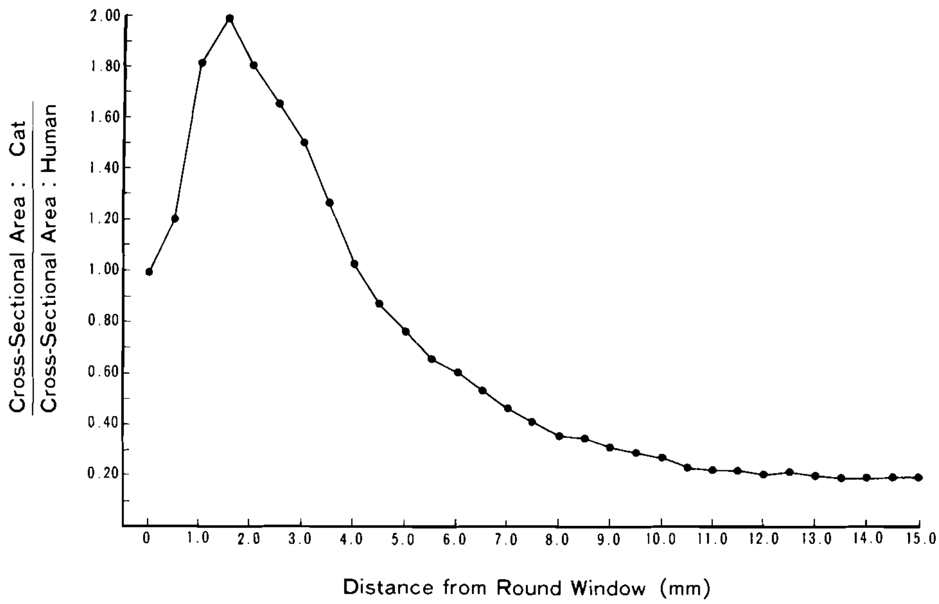

Fig 4. Ratio of cross-sectional area of cat scala tympani to human scala tympani as function of distance from round window.

significant reduction over the next 1.5 mm. This new anatomic finding has not been reported in previous studies, as this region of the scala tympani was not examined in any detail.[6,7] In contrast, the cross-sectional area of the cat scala tympani actually increases over the first 1.0 mm from the round window, and is in fact larger than the human scala tympani in this region. However, the cat scala tympani then funnels dramatically, while the human scala tympani undergoes a very gradual reduction in cross-sectional area with increasing distance from the round window. The ratio of cross-sectional area of the cat scala tympani to that of the human is illustrated in Fig 4.

Our measurements of the width and height of the human scala tympani are in general agreement with the results of Zrunek et al,[7] who recorded the width and height of the human scala tympani at eight specific locations above the round window using resin molds. In addition, our measurements of the cross-sectional area of the scala tympani are similar to the results recorded in the basal and middle turns of the human and cat by Igarashi et al.[6]

In the present study, the height of the scala tympani in the human did not decrease continuously, but showed a slight increase in the region 18 to 21 mm from the round window. A similar observation was made by Zrunek et al.[7] However, they also reported a corresponding increase in the width of the scala tympani in this region. The reason for the discrepancy between the study of Zrunek et al[7] and the present study is not clear. Except for an initial increase in the height and width in the lower basal turn, the cat scala tympani decreased continuously with increasing distance from the round window.

The Cochlear Corporation's banded scala tympani electrode array has a maximum diameter of 0.6 mm and tapers to a tip diameter of 0.4 mm. This electrode array has been designed for insertion to a depth of 25 mm from the round window. At this point, the electrode array is considerably smaller than the scala tympani, occupying less than 25% of its cross-sectional area. However, since the scala tympani is somewhat smaller in height than in width, the electrode array at this point represents at least 50% of the height of the scala tympani, and in some cases significantly more, depending on individual anatomic variations. Therefore, in order to ensure that the dimensions of the electrode array are significantly less than the dimensions of the scala tympani, any future changes in the design of this array should ensure that the tip diameter is not increased.

Our understanding of the physiologic mechanisms associated with electrical stimulation of the auditory nerve via cochlear implants has chiefly come from studies using cats, in which the electrode array is inserted to a depth of 5 to 6 mm from the round window and either evoked potentials or single unit activity is recorded in response to an electrical stimulus. The comparative data in the present study show a significant difference in the relationship of the scala tympani to the electrode array in the human compared with the cat. The rapid decrease in the size of the cat scala tympani adjacent to the 6-mm-long electrode array contrasts with the gradually varying relationship between the electrode array and the dimensions of the human scala tympani beyond the first 1.5 mm. Such a rapid change in the dimensions of the cat scala tympani could result in significant differences in the distance between an electrode and its closest neural elements for several electrodes positioned along the array. This limitation must be taken into account when interpreting physiologic data from this animal model. It may also be worth examining the possibility of using alternative animal models that would allow greater electrode insertion depth while providing less radical changes in the dimensions of the scala tympani.

Future improvements in the performance of patients using cochlear implants may depend on improving both the depth of the electrode insertion and the location of the electrode array within the scala tympani. To do this we need to improve the scala tympani electrode array design while ensuring minimal insertion trauma. The present data provide an anatomic basis for the development of improved scala tympani electrode arrays.

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