


INTRACOCHLEAR FACTORS CONTRIBUTING TO PSYCHOPHYSICAL PERCEPTS FOLLOWING COCHLEAR IMPLANTATION: A CASE STUDY

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INTRODUCTION

It is conceivable that the variations of performance of cochlear implant patients can be related to several factors. Shiroma et al. investigated which factors contributed to the speech recognition ability of cochlear implant patients; multiple regression analysis showed that postoperative psychophysical percepts such as threshold level (T level), maximum comfortable loudness level (C level), and dynamic ranges (DR) may play an important role in speech recognition ability. In this paper, we focus on determining which intracochlear factors contribute to these postoperative psychophysical percepts of the 22-channel cochlear implant system. We made a three-dimensional (3-D) computer reconstruction from the temporal bone of a cochlear implant patient and measured the following factors: distance between the electrode ring's center and the Rosenthal's canal center (dis); the cross-sectional areas of loose and dense fibrous tissue (lft, dft), their sum, fibrous tissue (ft), and new bone (nb) as inner ear pathologic changes; and the density of residual spiral ganglion cells (sgc). The interrelationship between the postoperative psychophysical percepts and these factors is analyzed and discussed.

CASE REPORT

The 74-year-old patient had a history of sensorineural hearing loss of unknown cause from childhood, and became totally deaf at age 68 (average hearing threshold: right, 101.3 dB; left, 103.7 dB). He was implanted in the left ear at age 71, and received significant benefit from the use of the multichannel implant. The patient died of heart failure 33 months after implantation. A glutaraldehyde-formalin solution was injected into the middle ear and around the implanted receiver-stimulator package within 6 hours postmortem, and the left temporal bone was removed within 24 hours. At this time, the electrode array was removed from the temporal bone.

TEMPORAL BONE AND PREPARATION OF IMAGES

The temporal bone was prepared for light microscopy by the standard methods of decalcification, celloidin embedding, horizontal serial sectioning at 30 μm, hematoxylin and eosin stain, and mounting on glass slides. There was some fibrous tissue and new bone along the electrode array (Fig 1).
A 3-D computer model was created from the 107 sections including the cochlea; every third section including Rosenthal's canal was used to count the number of spiral ganglion cells.

Input for the reconstruction can be any series of histologic slices. Temporal bone sections were viewed through a microscope, and a video camera (the Panasonic WV-CD20) was connected to the personal computer via a Data Translation DT2851 frame-grabber card. We marked and stored coordinates of the loose and dense fibrous tissue, new bone, the centerpoint of spiral ganglion cells, and the midpoint of the basilar membrane and the organ of Corti (OC). Borders of each feature could be outlined manually via the screen cursor or detected automatically with an algorithm based on gray levels. Single-point features such as the position of spiral ganglion cells and OCs were entered manually with the cursor. After all relevant points and borders of a given section had been stored, they could be displayed as a red overlay on the real-time image of the next serial section. Thus, the next section could be maneuvered until the best visual fit with all the borders of the previous section had been obtained. The 3-D reconstruction was made after all features obtained from sequential sections were sorted; the area plus perimeter calculations were added in the file, and the positions were confirmed by the plain film postoperative radiograph (Fig 2). This temporal bone was cut at an angle of 62° between the plane of section and the plane of radiograph. Total volumes were calculated as the sum of areas times section intervals (30 μm).

The position of the OC was used as the abscissa for mapping all data. A distance map of the OC was made by summing the distances between successive pairs of points, starting at the osteotomy site (as zero) and continuing to the apical end. The position of each electrode’s ring was calculated by fitting the model to the radiograph. One program module can calculate the relative cross-sectional area (CSA) of features and the density of spiral ganglion cells. To find the CSA, each feature in each section is projected onto the display of the OC. The position of each endpoint, as found by the orthogonal projection, is noted. The contribution of each feature to the CSA is its volume (area times section interval) divided by the OC distance over which it is distributed. For the total CSA at a given OC point, the contributions of all features overlapping that point are summed. The sgc was calculated similarly, with ganglion cell counts (measured by the Königsmark formula) used instead of volumes, and densities per millimeter instead of CSA. In this study, we calculated the average CSA of loose fibrous tissue, dense fibrous tissue, and new bone at 0.3- to 0.4-mm intervals centered around the point corresponding to each electrode ring’s center. The dis was measured directly as a point-to-point distance.

Three psychophysical percepts were assessed for the bipolar + 1 mode, so all the anatomic factors were calculated for the electrode ring in the middle of bipolar + 1 stimulation. Furthermore, the psychophysical percepts’ values were converted from the relative numbers to milliamperes.

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**Fig 2.** Plain film postoperative radiograph showing electrode array in cochlea. + — center of electrode rings, number — electrode number on mapping.

**Fig 3.** Three-dimensional reconstruction of organ of Corti, fibrous tissue, new bone, and spiral ganglion cells.
STATISTICAL METHOD

To correlate the psychoacoustic percepts with the anatomic factors, Pearson’s correlation coefficients were calculated. Multiple regression analysis was also performed to find the combination of factors that contribute to the performance. In the multiple regression analysis, T and C levels and DR were used as dependent variables, and the anatomic factors as independent variables. Furthermore, the correlation among independent variables was taken into consideration.

RESULTS

Values of Anatomical Factors. The length of the OC was 32.96 mm, the electrode array was inserted in the cochlea 18.04 mm, and Rosenthal’s canal center was 15.63 mm long. There was fibrous tissue and new bone along the electrode array; their total volumes were 12.12 and 2.00 mm$^3$ respectively, and the scala tympani was almost filled with them at the lower basal turn (Figs 1, 3, and 4). The electrode array tract was surrounded by dense fibrous tissue. Values for dis were between 1.23 to 2.47 mm and tended to be shorter toward the apex of the cochlea (higher number of electrodes). The total number of spiral ganglion cells was 5,591, and the average density at 1-mm intervals of OC was 172.6 cells per millimeter. The spiral ganglion cells tended to be clustered near electrodes 13 through 16 and 19 (Figs 3 and 4).

Simple Correlation. The correlation coefficients among T level, C level, and DR and all factors are shown in Table 1. There was a strong positive correlation between the T and C levels but no significant correlation between either level and DR. The T level showed higher correlations with dis, ft + nb, ft, lift, and nb. Similarly, there was a significant correlation between df and ft + nb and C level, and a moderately high negative correlation between sgc and DR. Among the anatomic factors, there were especially high positive correlation coefficients among ft + nb, ft, lift, df, and nb.

Multiple Regression. The ft + nb was selected as an independent variable because of the high correlation coefficients among ft + nb, ft, lift, df, and nb. Thus, dis, sgc, and ft + nb were used as independent variables. All standard regression coefficients ($r^2$) and multiple regression coefficients ($R^2$) are shown in Table 2. For the T level, a shorter dis and a smaller ft + nb contributed significantly to its reduction; its coefficient of determination ($R^2$) was quite high (.876). The same com-

<p>| Table 1. Results of Simple Correlation Analysis (Pearson's Correlation Coefficients) |
|---------------------------------|------|------|------|------|------|------|------|------|------|</p>
<table>
<thead>
<tr>
<th>$T$ level</th>
<th>$C$ level</th>
<th>$DR$</th>
<th>$dis$</th>
<th>$sgc$</th>
<th>$ft + nb$</th>
<th>$ft$</th>
<th>$lift$</th>
<th>$df$</th>
<th>$nb$</th>
</tr>
</thead>
<tbody>
<tr>
<td>T level</td>
<td>1</td>
<td>$0.823^*$</td>
<td>1</td>
<td>$-0.338$</td>
<td>$0.814^*$</td>
<td>$-0.523^*$</td>
<td>$-0.736^*$</td>
<td>$0.823^*$</td>
<td>$0.644^*$</td>
</tr>
<tr>
<td>C level</td>
<td>$0.823^*$</td>
<td>1</td>
<td>$0.256$</td>
<td>$-0.914^*$</td>
<td>$-0.154$</td>
<td>$-0.655^*$</td>
<td>$-0.741^*$</td>
<td>$-0.624^*$</td>
<td>$-0.235$</td>
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<tr>
<td>DR</td>
<td>$-0.338$</td>
<td>$0.256$</td>
<td>1</td>
<td>$-0.914^*$</td>
<td>$-0.154$</td>
<td>$-0.655^*$</td>
<td>$-0.741^*$</td>
<td>$-0.624^*$</td>
<td>$-0.235$</td>
</tr>
<tr>
<td>dis</td>
<td>$-0.338$</td>
<td>$0.256$</td>
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<td>$-0.154$</td>
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<td>sgc</td>
<td>$-0.814^*$</td>
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<td>$-0.914^*$</td>
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<td>$-0.823^*$</td>
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<td>$-0.543^*$</td>
</tr>
<tr>
<td>$ft$ + nb</td>
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<td>$-0.655^*$</td>
<td>$-0.741^*$</td>
<td>$-0.624^*$</td>
<td>$-0.914^*$</td>
<td>1</td>
<td>$-0.896^*$</td>
<td>$-0.772^*$</td>
<td>$-0.823^*$</td>
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<tr>
<td>df</td>
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<td>$-0.741^*$</td>
<td>$-0.624^*$</td>
<td>$-0.543^*$</td>
<td>$-0.914^*$</td>
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<td>1</td>
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<tr>
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<td>$-0.85$</td>
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<td>$-0.796^*$</td>
</tr>
</tbody>
</table>

See text for abbreviations. *p < .001, tpt .01, §p < .05.
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