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수술 전 측두골 전산화 단층촬영을 이용한 와우 길이 측정 및 인공와우 전극 삽입 깊이각의 예측

Cochlear duct length determination and prediction of insertion depth angles for cochlear implant electrodes using preoperative temporal bone CT

2020 년 2 월

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지도 교수 천 정 은

이 논문을 의학석사 학위 논문으로 제출함

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Abstract

Cochlear duct length determination and prediction of insertion depth angles for cochlear implant electrodes using preoperative temporal bone CT

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Purpose

The purpose of this study was to determine the cochlear duct length (CDL) using preoperative temporal bone computed tomography (TBCT) in patients with hearing loss and to evaluate whether the final insertion depth angle of cochlear implantation (CI) electrode is related to the cochlear size (CDL or diameter of the cochlear basal turn).

Materials and Methods

Thirty-five patients (age <18) with hearing loss who underwent CI surgery from January 2014 to December 2018 were included in this study.

Measurement of CDL, distance A (diameter of the cochlear basal turn), and distance B (the diameter perpendicular to the distance A) was performed on preoperative TBCT using a commercially-available software. Postoperative cochlear view images were also retrospectively analyzed and final insertion depth angle of CI electrode was measured. Pearson correlation analysis was performed to determine whether the final insertion depth angle of CI electrode is related to the cochlear size. Interobserver agreement between the two observers was calculated using intraclass correlation coefficient (ICC).

Results

The mean CDL, distance A, and distance B in both temporal bones of 35 patients were 36.20mm, 8.67mm, and 5.73mm, respectively. The mean insertion depth angle was 431.45 ± 38.42°. There is no significant correlation between CDL and final insertion depth angle ($r = -0.2333$, $P > 0.05$). There is significant negative correlations between distance A and insertion depth angle ($r = - 0.7643$, $P < 0.0001$); distance B and insertion depth angle ($r = - 0.7118$, $P < 0.0001$), respectively. In terms of the interobserver agreements, CDL (0.864), distance A (0.862), distance B (0.529) and insertion depth angle (0.958) showed fair to excellent interobserver agreements as measured by the ICCs of the readers.

Conclusions

The cochlear size, especially the diameter and length of cochlear basal turn, was significantly correlated with the final insertion depth angles of CI electrodes. The preoperative estimation of the cochlear size and final insertion depth angle would be helpful to choose the correct electrode size for the individual patients and to precisely adjust the insertion depth during CI surgery to preserve residual hearing.

Keywords

Cochlear implantation, Cochlear duct length, Temporal bone computed tomography, Insertion depth angle

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Figure 2. Diagram showing the measurement of distance A and B.

Distance A is defined as the largest distance from the round window, through the modiolar axis, to the contralateral wall and distance B as the diameter perpendicular to the distance A.

Figure 3. Diagram showing the clinical method for estimating the insertion angles of electrode from an implanted array using the postoperative cochlear view.

(a) Unmarked cochlear view of a right cochlea. (b) The right image contains markers, added as follows: the apex of the superior semicircular canal (S) and the center of the vestibule (V) are determined by visual inspection of the plain film (dotted outline of vestibule, horizontal and superior semicircular canals) and a vertical line is drawn through them (dashed vertical line); the point where this line intersects the electrode lead (dashed curved line) approximates the round window (RW). The modiolus (m) is determined at the center of the electrode spiral (outlined by the individual electrode leads) and defines the 0° reference line (full line) from the RW. The insertion depth angle is the angle of rotation the most distal electrode assumes with respect to the 0° reference line (in this example, 360°+ θ') (Figure 3b adapted from Figure 2 in reference 23).

Figure 4. Scatter diagram of the correlations between cochlear duct length, distance A, and distance B.

(a)–(c) There is significant positive correlation between CDL and distance A ($r = 5107$, $P < 0.0001$); CDL and distance B ($r = 0.4594$, $P = 0.0001$); distance A and distance B ($r = 0.8947$, $P < 0.0001$), respectively.

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(a) There is no significant correlation between cochlear duct length and final insertion depth angle ($r = -0.2333$, $P > 0.05$). (b), (c) There is significant negative correlations between distance A and insertion depth angle ($r = -0.7643$, $P < 0.0001$); distance B and insertion depth angle ($r = -0.7118$, $P < 0.0001$), respectively.

Introduction

During recent decades, cochlear implantation (CI) has become the treatment of choice for hearing rehabilitation in patients with severe or profound hearing loss. A CI electrically stimulates spiral ganglion cells via an intracochlear electrode. Many studies have reported that the insertion depth of the electrode has a significant effect on the postoperative outcome, preservation of residual hearing and postoperative complications (1-8). Several studies have shown that deep electrode insertion is associated with better speech performance due to improved stimulation of the apical region (1-5). However, insertional trauma during CI surgery also strongly correlates with insertion depth of the electrode (6, 7) and deep electrode insertion significantly reduces the likelihood of residual hearing preservation (8). This has been even more important because the strategies used to insert the CI electrode array have changed with a greater focus on minimizing insertion trauma and preserving pre-existing hearing (9).

Meanwhile, multiple studies have shown that cochlear anatomy is variable in humans. Approximately 25% of patients with congenital hearing loss have inner ear malformations, and even with normal cochlear anatomy, the human cochlea demonstrates different lengths, widths and forms (10-15). In addition, advent of variable electrode length creates a need for preoperative techniques to determine the length of the patient's cochlea for appropriate electrode size selection.

Recent preoperative imaging studies have focused on preoperative estimation of cochlear duct length (CDL). Temporal bone computed tomography (TBCT) is usually performed prior to CI surgery to identify the presence of malformations or any structural abnormalities that may prevent appropriate introduction of the electrode array. Several methods including three-dimensional (3D) reconstruction of TBCT have been suggested to determine CDL (9, 13, 16-18). In addition, recent studies have suggested that several two-dimensional measurements, such as the diameter of the cochlear basal turn, have a significant association with CDL. However, few studies have explored the correlation between cochlear size (CDL or diameter of the cochlear basal turn) and final insertion depth angle of the electrodes.

Therefore, the purpose of our study was to determine CDL using pre-operative TBCT in patients with hearing loss and to evaluate whether the final insertion depth angle for the CI electrode is related to CDL and the diameter of the cochlear basal turn, respectively.

Materials and Methods

Patients

The institutional review board approved this retrospective study and waived the need for informed consent. The study population consisted of patients who underwent CI surgery at a single center from January 2014 to December 2018. The inclusion criteria were as follows: 1) patients (age <18) who underwent CI surgery with the Nucleus CI422 Slim Straight electrodes (CI422) from January 2014 to December 2018; 2) preoperative TBCT images that were obtained less than 4 weeks before surgery were available; 3) postoperative cochlear view images that were obtained less than 1 week after surgery were available. The exclusion criteria were as follows: 1) patients with imaging studies from outside institutions or inadequate CT images for the analysis because of motion artifacts or lack of thin-section images; 2) patients with acquired or congenital pathologies of the temporal bone and inner ear; 3) patients who already used a hearing implant, especially a CI, in one of their temporal bones.

Finally, 35 patients comprised the study group for this study (21 female and 14 male patients; mean age ± SD, 3.37 ± 3.32 years; age range 0-12 years). Among 35 patients, 16 patients underwent CI surgery on both temporal bones, 11 patients on the right temporal bones, and the remaining 8 patients on the left temporal bones.

CT Acquisition

All CT examinations were performed using multi-detector CT scanners (Brilliance iCT, Philips Healthcare, Cleveland OH, USA; Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany). Scanning parameters for MDCT scanners included a gantry rotation time of 0.5 seconds, a pitch of 1.0 to 1.5, 80 to 120 mAs, 100 to 120 kVp, a 512 x 512 matrix, and 0.7mm slice thickness.

Image analysis

We used commercially available software (MEDIP, MEDICAL IP, Korea) to measure cochlear size on preoperative TBCT images, which applied the Catmull-rom spline algorithm to determine length between the points (19, 20). Using this software, CDL was measured along the lateral wall of the bony cochlea from the distal bony rim of the round window to the helicotrema (Figure 1) (9, 16-18). First, we adjusted the axis of the 3D plane to find the section perpendicular to the modiolar axis, passing through the basal turn and the round window. Then, following the modiolar axis, we manually set the points from the round window to the helicotrema along the lateral wall of the bony cochlea and the software determined the length between the points using the Catmull-rom spline algorithm. In addition, we measured two perpendicular diameters of the cochlear basal turn (distance A and distance B) known to be correlated with CDL in previous studies - distance A or the diameter of the basal turn of the cochlea is defined as the largest distance from the round window, through the modiolar axis, to the contralateral wall. Distance B is defined as the distance perpendicular to the distance A (Figure 2) (9, 17, 18).

The length of cochlear basal turn (BTL) was calculated using a method proposed by Escude´ (17). He proposed an equation, $L = 2.62 \times A \times \log_e (1.0 + \theta /235)$, describing the length of the cochlear lateral wall (L) for a certain insertion angle (θ) and distance A (A). Through simple substitution, using an insertion angle of 360 degrees, BTL is defined as: $BTL = 2.62 \times A \times \log_e (1.0 + 360 /235) = 2.43 \times A$. In addition, the estimated CLD using distance A was calculated using a method proposed by Alexiades: $CDL_e=4.16A+0.18$ (21).

Postoperative cochlear view images were retrospectively analyzed by one rater (J.S.O., 4th year resident of the Department of Radiology) in 51 ears and electrodes insertion depth angles were measured according to the method of Xu et al (Figure 3) (22, 23).

For the analysis of the interobserver agreement, another rater (J.H.P., 4th year resident of the Department of Radiology) also measured CDL, distance A, and distance B on preoperative TBCT images using the software and electrode insertion depth angles on postoperative cochlear view images.

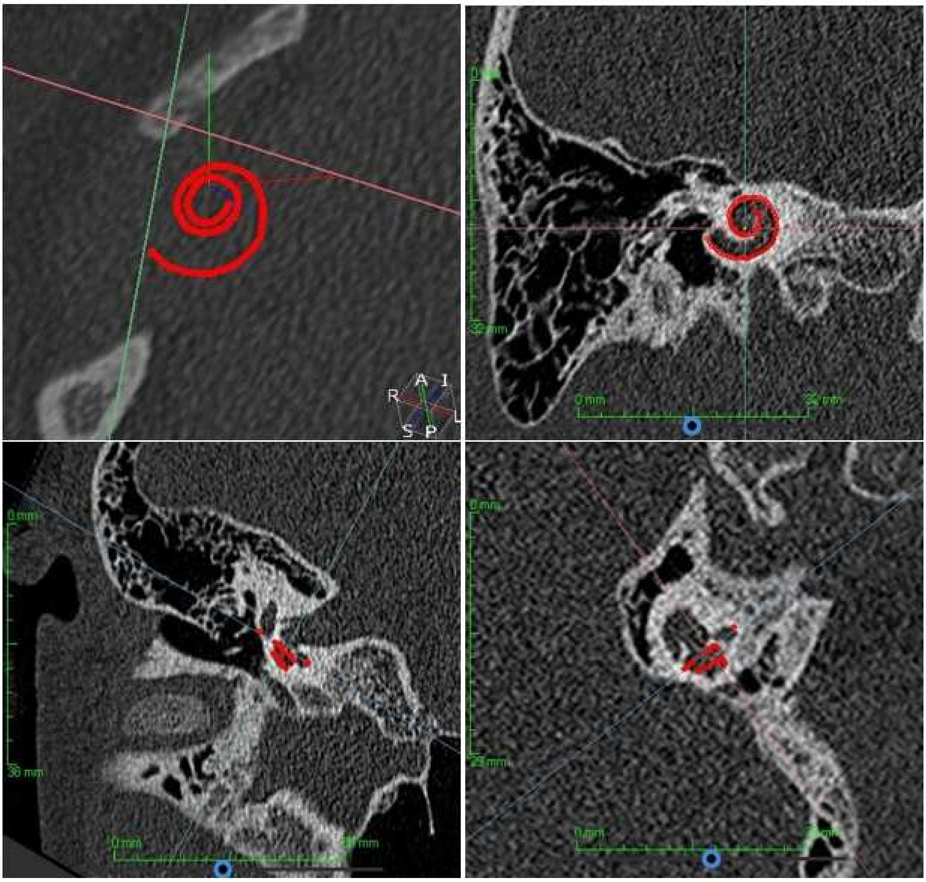

Figure 1. Measurement of cochlear duct length (CDL).

The top right window shows the section perpendicular to the modiolar axis, passing through the basal turn and round window. Starting from this section, the CDL is measured as the distance between the points taken from the round window to the helicotrema along the lateral wall of the bony cochlea.

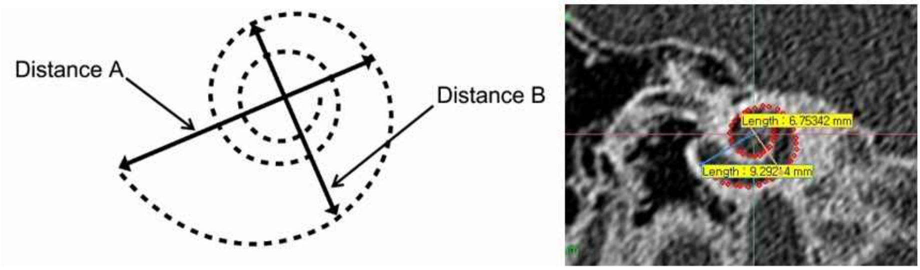

Figure 2. Diagram showing the measurement of distance A and B.

Distance A or diameter of the basal turn of the cochlea is defined as the largest distance from the round window, through the modiolar axis, to the contralateral wall. Distance B is defined as the distance perpendicular to the distance A.

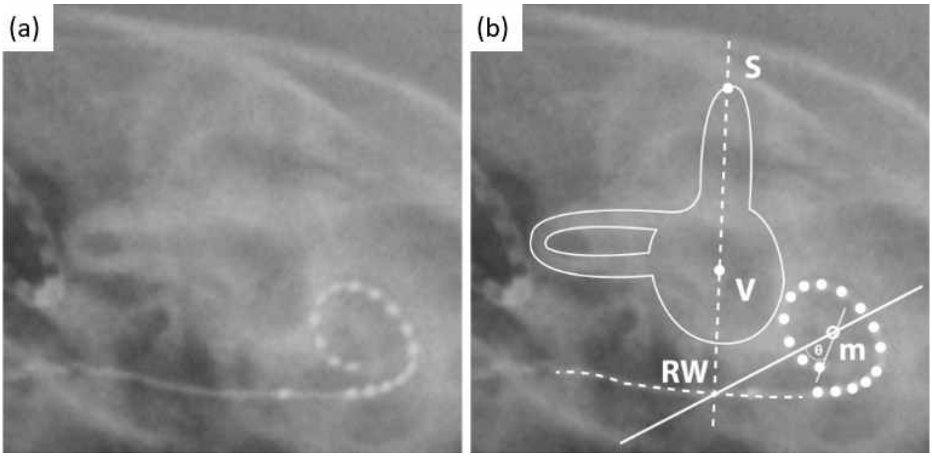

Figure 3. Diagram showing the clinical method for estimating the insertion angles of electrode from an implanted array using the postoperative cochlear view.

(a) Unmarked cochlear view of a right cochlea. (b) The right image contains markers, added as follows: the apex of the superior semicircular canal (S) and the center of the vestibule (V) are determined by visual inspection of the plain film (dotted outline of vestibule, horizontal and superior semicircular canals) and a vertical line is drawn through them (dashed vertical line); the point where this line intersects the electrode lead (dashed curved line) approximates the round window (RW). The modiolus (m) is determined at the center of the electrode spiral (outlined by the individual electrode leads) and defines the 0° reference line (full line) from the RW. The insertion depth angle is the angle of rotation the most distal electrode assumes with respect to the 0° reference line (in this example, 360°+ θ′) (Figure 3b adapted from Figure 2 in reference 23).

Statistical analysis

Data were checked with the Kolmogorov-Smirnov test for normality. Data were analyzed using the independent samples t-test for differences in CDL between sex, age, and temporal bone side (left or right). Pearson correlation analysis was performed to determine the relationship between CDL, distance A, and distance B. The independent samples t-test was used to compare measured CDL and estimated CDL using distance A. In addition, Pearson correlation analysis was also performed to determine whether the final insertion depth angle for CI electrode is related to the cochlear size (CDL, distance A, and distance B). Interobserver agreement between the two raters was measured using intraclass correlation coefficients (ICCs). A P value less than .05 was considered to indicate a significant difference. All statistical analysis was performed using commercially dedicated software (MedCalc for Windows, version 19.1; MedCalc, Mariakerke, Belgium and SPSS 23 software for Windows; IBM, Armonk, NY, USA).

Results

Cochlear size

CDL was measured in both temporal bones of 35 patients, resulting in 70 measurements (Table 1). CDL ranged from 32.33 to 39.41 mm (mean ± SD, 36.20 ± 1.57 mm). Mean distance A was 8.67 ± 0.42 mm (range; 7.74 - 9.41 mm) and mean distance B was 5.73 ± 0.32 mm (range, 5.73 – 6.88 mm).

Table 1. Summary of the measurements

	Cochlear duct length [mm]	Distance A [mm]	Distance B [mm]
Gender			
Male (n=28)	36.72±1.63(32.33–39.18)	8.84±0.35(8.09–9.37)	6.46±0.26(5.93–6.82)
Female (n=42)	35.86±1.45(33.05–39.41)	8.56±0.42(7.74–9.41)	6.23±0.33(5.73–6.88)
P-value	0.495	0.331	0.226
Side			
Right (n=35)	36.24±1.73(32.33–39.41)	8.74±0.44(7.74–9.41)	6.36±0.34(5.73–6.88)
Left (n=35)	36.16±1.42(33.45–39.18)	8.61±0.38(7.92–9.37)	6.28±0.30(5.77–6.84)
P-value	0.834	0.205	0.302

* Data expressed as mean ± SD (range)

There was no significant correlation between subject age and CDL (r = 0.0879, P = 0.4693); age and distance A (r = 0.1680, P = 0.165); or age and distance B (r = 0.228, P = 0.058), respectively. In addition, no significant difference was found between mean CDL in male (36.72 mm) and female

(35.86 mm) patients (P = 0.495). Also, no significant difference was found between mean CDL in the left (36.16 mm) and right (36.24 mm) ears (P = 0.834).

There was a significant positive correlation between CDL and distance A (r = 5107, P < 0.0001); CDL and distance B (r = 0.4594, P = 0.0001); distance A and distance B (r = 0.8947, P < 0.0001), respectively (Figure 4).

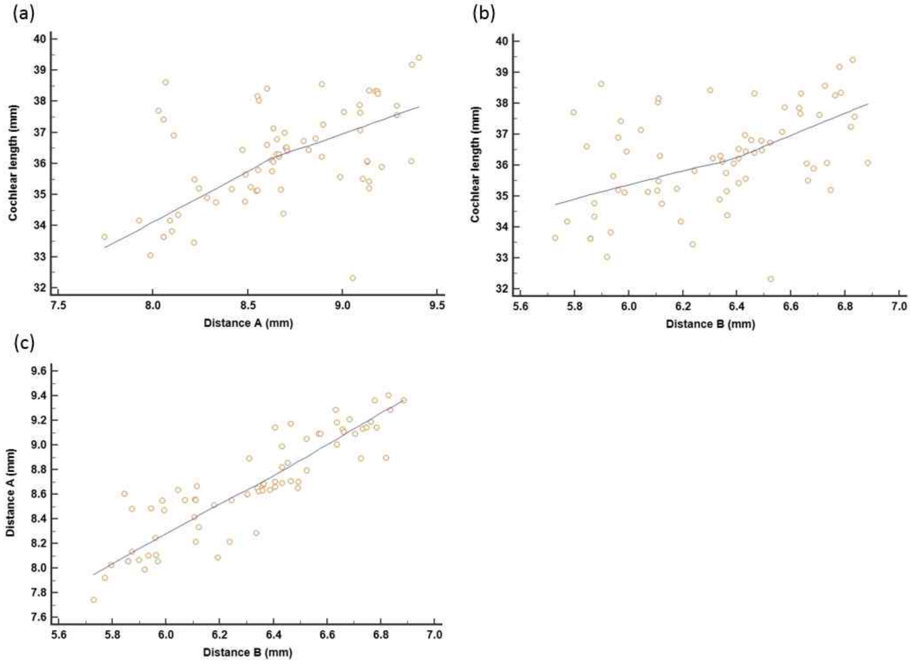

Figure 4. Scatter diagram of the correlations between cochlear duct length (CDL), distance A, and distance B.

(a)–(c) There is significant positive correlation between CDL and distance A (r = 5107, P < 0.0001); CDL and distance B (r = 0.4594, P = 0.0001); distance A and distance B (r = 0.8947, P < 0.0001), respectively.

Mean BTL was 21.07 ± 1.01 mm (range, 18.81 – 22.85 mm) and mean estimated CDL using distance A was 36.25 ± 1.73 mm (range, 32.39 – 39.31 mm). When we compared estimated CDLe and measured CDL, no significant difference was found between the two groups ($P = 0.8449$).

Correlation between cochlear size and insertion depth angle

Mean insertion depth angle was 431.45 ± 38.42° (range, 354.16° – 551.87°). There was no significant correlation between CDL and final insertion depth angle ($r = -0.2333$, $P > 0.05$). There were significant negative correlations between distance A and insertion depth angle ($r = - 0.7643$, $P < 0.0001$) and between distance B and insertion depth angle ($r = -0.7118$, $P < 0.0001$) (Figure 5). In addition, there were also significant negative correlations between BTL and insertion depth angle ($r = -0.7643$, $P < 0.0001$) as well as between estimated CDLe and insertion depth angle ($r = -0.7643$, $P < 0.0001$).

Interobserver agreement

In terms of interobserver agreement, CDL (0.864, 95% confidence interval [0.775-0.925]), distance A (0.862, 95% confidence interval [0.769-0.919]), distance B (0.529, 95% confidence interval [0.175-0.731]) and insertion depth angle (0.958, 95% confidence interval [0.948-0.963]) showed fair to excellent interobserver agreement as measured by ICC.

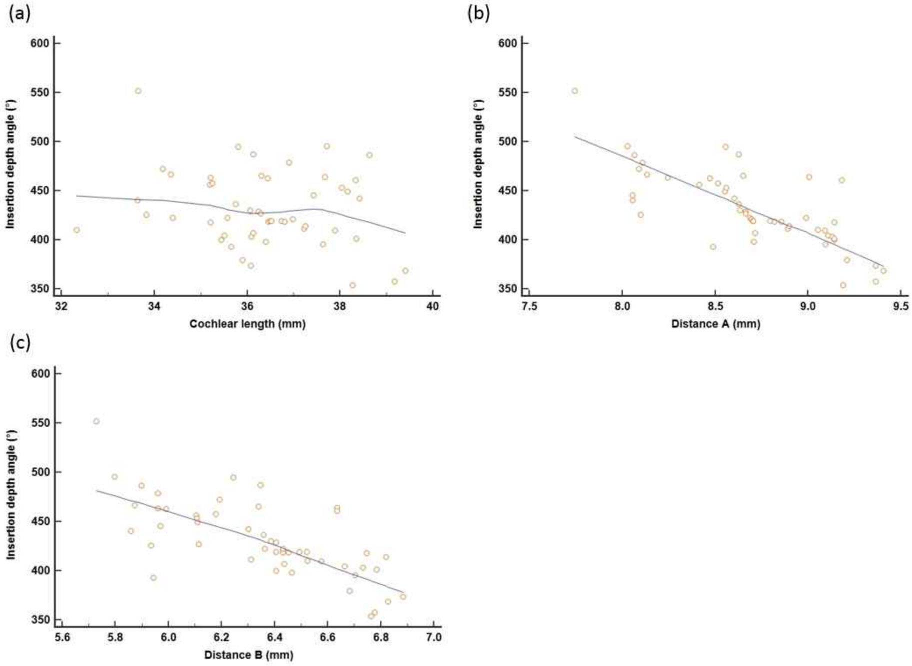

Figure 5. Scatter diagram of the correlations between cochlear size and final insertion depth angle of electrodes.

(a) There is no significant correlation between cochlear duct length and final insertion depth angle ($r = -0.2333$, $P > 0.05$). (b), (c) There is significant negative correlations between distance A and insertion depth angle ($r = - 0.7643$, $P < 0.0001$); distance B and insertion depth angle ($r = -0.7118$, $P < 0.0001$), respectively.

Discussion

Our study demonstrated that cochlear size measured on preoperative TBCT was significantly correlated with the final insertion depth angle of CI electrodes. In addition, there was significant positive correlation between CDL and distance A; CDL and distance B; and distance A and distance B. Therefore, preoperative estimation of cochlear size and final insertion depth angle would be helpful for choosing the correct electrode size for individual patients and to precisely adjust insertion depth during CI surgery to preserve residual hearing.

To date, several previous studies have suggested how to measure CDL using preoperative TBCT (9, 15-17). One study that assessed CDL in 218 patients with hearing loss suggested a reproducible methodology to determine CDL using 3D multi-planar reconstruction of TBCT data (16). Recent studies suggested that several two-dimensional measurements, such as distance A and distance B, have significant association with CDL (9, 15, 17). In addition, another study published by Alexiades et al. in 2015 proposed a method for estimating two-turn and complete CDL in normal human temporal bone using the diameter of the basal turn, i.e. distance A (21). Our study results are in good agreement with the results of previously published studies, and furthermore, we demonstrated that these measurements correlate with final insertion depth angle of the CI electrodes and showed acceptable interobserver agreement.

To improve postoperative outcomes, an important aim of CI surgery is to preserve residual hearing of patients and prevent insertional trauma. In addition, these outcomes can be achieved by selecting an electrode of the appropriate size for each patient and inserting it to the optimal insertion depth. In particular, in order to preserve a patient's pre-existing hearing, it is necessary to carefully adjust the insertion depth to insert the electrode only up to the corresponding insertion depth angle. Therefore, determination of cochlear size using preoperative TBCT will be helpful to individualize electrode insertion depth for each patient.

There were, however, several limitations in this study. First, this was a retrospective, single center-based study with potential bias. In addition, the sample size was somewhat small because we included only patients who underwent CI surgery using the same electrodes. Therefore, further studies with a larger number of cases should be performed. Second, we excluded patients with acquired or congenital pathologies of the temporal bone and inner ear. Given that quite a few patients who undergo CI surgery have acquired or congenital pathologies of the temporal bone or inner ear, further studies including patients with congenital anomalies or acquired disease are warranted. Third, the final insertion depth angle of the electrodes can be influenced by several different factors. We included 35 patients who underwent CI surgery using the same electrodes (CI422). However, even when the same electrode is used, insertion depth varies slightly from patient to patient during CI surgery and this may affect final insertion depth angle. Therefore, further study is needed to evaluate how insertion depth angle changes according to actual insertion depth in the same electrode and to evaluate other factors that may affect insertion depth angle, including electrode type.

In conclusion, cochlear size, especially the diameter of the cochlear basal turn, distance A, was significantly correlated with final insertion depth angle of CI electrodes. Preoperative estimation of cochlear size and final insertion depth angle would be helpful for selecting the correct electrode size for individual patients and for adjusting insertion depth during CI surgery to preserve residual hearing.

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요약 (국문초록)

연구 목적

본 연구에서는 난청 환아들에서 인공와우 이식술 전 시행한 측두골 전산화 단층촬영(TBCT)을 이용하여 와우 길이를 측정하고, 이것이 실제 수술 시 사용된 전극의 삽입 깊이각을 예측할 수 있는지를 알아보고자 한다.

연구 방법

2014년 1월부터 2018년 12월까지 인공와우 이식술을 시행받은 35명의 난청 환아들을 대상으로 하였다. 이 환아들은 모두 수술 전 TBCT를 시행받았으며, 상용화된 소프트웨어를 이용하여 해당 CT 영상으로부터 와우의 길이, 기저부(basal turn)의 직경에 해당하는 길이 A, 그와 수직거리인 길이 B를 측정하였다. 수술 후 촬영한 단순와우촬영검사 역시 후향적으로 분석되었고, 이 영상에서 전극의 삽입 깊이각을 측정하였다. 이후 측정한 전극의 삽입 깊이 각이 수술 전 CT에서 측정한 와우의 길이, 길이 A, 길이 B와 연관되어 있는지를 알아보기 위해 Pearson 상관 분석을 시행하였다. 또한,

두 명의 관찰자 사이의 신뢰도는 급내 상관계수 (intraclass correlation coefficient)를 이용하여 분석하였다.

연구 결과

35 명의 환자들에서 측정한 평균 와우 길이, 길이 A, 길이 B 는 각각 36.20mm, 8.67mm, 5.73mm 였다. 와우 길이와 전극의 삽입 깊이각 사이에는 통계적으로 의미있는 상관성이 없었다 ($r = -0.2333$, $P > 0.05$). 와우 길이와 길이 A ($r = -0.7643$, $P < 0.0001$), 와우 길이와 길이 B ($r = -0.7118$, $P < 0.0001$) 사이에는 통계적으로 의미 있는 음의 상관관계가 관찰되었다. 관찰자 사이의 신뢰도를 평가했을 때, 대개 높은 급내상관계수 (와우 길이, 0.864; 길이 A, 0.862; 길이 B, 0.529; 전극 삽입 깊이각, 0.958)를 보였다.

결론

수술 전 촬영한 TBCT 에서 측정한 와우의 크기, 특히 기저부의 직경 및 길이가 전극의 삽입 깊이각과 통계적으로 의미있는 상관성을 보였다. 수술 전 TBCT 을 이용한 와우의 크기 측정 및 전극 삽입 깊이각의 예측이 인공와우 이식술 시 각각의 환자에게 맞는 길이의 전극을 선택하고, 환자의 잔류 청력을 보존할 수

있도록 전극 삽입 깊이를 정확히 조절하는 데 도움을 줄 것으로 보인다.

주요어 : 인공와우 이식술, 와우 길이, 측두골 전산화 단층촬영, 삽입 깊이각
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