The Importance of Carotid–Cochlear Interval in the Etiology of Hearing Loss

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Abstract Carotid–cochlear interval (CCI) is the minimal distance between petrous segment of internal carotid artery (ICA) and basal turn of cochlea. Pulsations of the ICA might create fluid pressure changes and direct stimulation of hair cells on the basilar membrane of basal turn of cochlea which is responsible for mid-tone frequencies. The purpose of this study was to investigate whether CCI has a role in the etiology of mid-tone hearing loss and to obtain reference measurements of CCI on MRI. A total of 117 subjects were consecutively enrolled into this retrospective study during a 4 month period. All examinations were performed on a 1.5 T MRI system. The images were transferred to the workstation and reformatted. The CCI was measured on reformatted 3D FIESTA images. The audiologic findings were correlated. We reviewed the temporal MRI studies of 90 consecutive patients [M/F: 48/42, Mean age 45.6 ± 16.6 (10–78)]. As a total 180 sides were evaluated. The CCI ranged from 0 to 9 mm. The CCI didn't exhibit a significant association with subject age or gender. There were no significant differences between readers or sides. There were statistically significant correlation between CCI and level of frequency and degree of hearing loss ($p = 0.004$ and $p = 0.002$). The knowledge of CCI is essential prior to otosurgical procedures. There was linear correlation among CCI and level of

frequency and degree of hearing loss. CCI of the group including all types of middle frequency hearing loss was longer compared to the normal group.

Keywords Hearing loss · Cochlea · Internal carotid artery · Magnetic resonance imaging

Introduction

Carotid–cochlear interval (CCI) is the minimal distance between the petrous segment of the internal carotid artery (ICA) and basal turn of cochlea. At the petrous apex level ICA courses in a bony framework called carotid canal. This canal harbors areolar tissue, a venous plexus, and post-ganglionic sympathetic nerves in addition to internal carotid artery [1]. The small distance between internal carotid artery and basal turn of cochlea might lead to potential for injury to the carotid artery during improper placement of the electrode in cochlear implantation procedure. It is also critical in a cochlear drill out procedure in cases of labyrinthitis ossificans [2].

Pulsations of the internal carotid artery might create fluid pressure changes and direct stimulation of hair cells on the basilar membrane [3]. Most of the basal turn is responsible for mid-tone frequencies. This might result in mid-tone sensorineural hearing loss. To the best of our knowledge, this is the first clinical study looking to the possible relationship between CCI and audiometric findings. Dehiscence of bony basal canal of cochlea was first reported in a 63 year old patient who presented with tinnitus and the audiogram demonstrated mild mid-high frequency hearing loss. There was bilateral dehiscence of the bony septum separating the basal turn of cochlea from the contiguous carotid canal on temporal CT exam [4].

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Our aim was to investigate whether CCI had a role in the etiology of mid-tone sensorineural hearing loss and to obtain reference measurements of CCI on MRI for surgeons and neuroradiologists. For this reason we correlated the findings with audiometric results.

Methods

Subject Population

A total of 117 subjects [M/F:52/65; Mean age: 46 ± 17 (10–81)] were consecutively enrolled into this retrospective study during a 4 month period (from January to April 2008). They were admitted to our Ear, Nose and Throat Clinic due to hearing loss, Bell's palsy, tinnitus and vertigo. The subjects with a normal otoscopic examination were included into the study. Subjects with acute and chronic otitis media, otitis media with effusion, tumor, metastasis, metabolic disorder that might destroy temporal bone anatomy were excluded from the study. The subjects on drug therapy that might affect bone marrow were not included to the study. As a result, 27 subjects were not included due to the exclusion criteria.

Imaging Parameters

All examinations were performed on a 1.5 T whole body MRI system (Excite, General Electrics, Milwaukee, Wisconsin) with a 33 mT/m maximum gradient capacity. The imaging protocol consisted of axial 3D FIESTA (TR, 4.8 ms; TE, 1.4 ms; slice thickness, 0.5 mm; FOV, 18×18 cm; matrix, 352×192 ; NEX, 4). The images were transferred to an Advantage Workstation 4.0 (GE Medical Systems) and reformatted. The other routine sequences of temporal MRI study included axial T1 W, T2 W and post-contrast axial and coronal T1 W sequences. 0.2 ml/kg gadolinium was used as contrast agent.

Image Analysis

Images were independently reviewed by 2 examiners (two attending physicians), blinded to the clinical status of the patient and indication for MRI. The minimal distance between the basal turn of cochlea and internal carotid artery was determined on reformatted 3D FIESTA images using electronic calipers on both sides.

Analysis of Audiometric Findings

Subjects were grouped as normal and sensorineural hearing loss. According to the frequency of hearing loss, they were classified as normal, low (<1,000 Hz), middle (1,000–4,000 Hz), high (>4,000 Hz), mid-high (>1,000 Hz) and

all (all frequencies). In addition, the subjects were grouped into three according to the frequency of hearing loss as Group 1 (normal), Group 2 (mid, mid-high and all frequencies) and Group 3 (low and high frequencies). Group 2 includes all types of middle frequency hearing loss when Group 3 includes the rest. According to the degree of hearing loss, they were classified as normal (0–20 dB), mild (20–40 dB), moderate (40–60 dB), high (60–80 dB), very high (80–100 dB) and total (>100 dB).

Statistical Analysis

Statistical analysis was performed by Statistical Package for Social Sciences (SPSS) 11.5 software (SPSS Inc., Chicago, IL, United States). Whether the ICA measurements were normally distributed or not was determined by using Kolmogorov–Smirnov test. Continuous variables were expressed as mean $\pm$ standard deviation.

Median ICA values were evaluated by Mann–Whitney *U* test or Kruskal–Wallis test according to the number of independent groups. When the *p* value from Kruskal–Wallis test statistics is statistically significant Conover's non-parametric multiple comparison tests were used to know which group differ from which others. Whether the difference between left and right sides in median ICA levels was statistically significant or not was evaluated by Wilcoxon Sign Rank test.

Degrees of association between continuous and ordinal variables were calculated by Spearman's rho correlation coefficient.

Intra-class Correlation Coefficient (ICC) and 95 % Confidence Intervals' were also calculated for determining interobserver agreement level. A *p* value less than 0.05 was considered statistically significant.

Results

The temporal MRI studies of 90 consecutive patients were included into the study [M/F: 48/42, Mean age 45.6 ± 16.6 (10–78)]. A total of 180 sides were evaluated. The CCI value ranged from 0 to 9 mm (Fig. 1a–g). The mean distance was 2.31 ± 1.34 mm for females and 2.28 ± 1.47 mm for males. There was no statistically significant difference between genders (*p* = 0.719). The CCI measures didn't exhibit a statistically significant relationship with subject age (*r* = −0.072 and *p* = 0.338). There was no statistically significant difference between sides (*p* = 0.762). The interobserver agreement between two readers for the same subject was 0.990 (0.987–0.993) and it was statistically significant (*p* < 0.001).

The CCI in subjects with hearing loss was longer compared to the normal group (*p* = 0.014) (Fig. 2; Table 1).

There was statistically significant relationship between the degree of hearing loss and CCI ($p = 0.002$). According to the degree of hearing loss, the CCI in normal group was significantly small when compared both to ‘very high’ and ‘total’ groups ($p = 0.008$ vs $p < 0.001$). The CCI in ‘mild’ and ‘moderate’ level hearing loss was small when compared to total hearing loss ($p = 0.012$ vs $p < 0.001$). In addition, the CCI of ‘moderate’ level hearing loss was significantly small compared to ‘very high’ hearing loss ($p = 0.012$).

There was no statistically significant difference between groups according to the frequency of hearing loss into six as normal, low, middle, high, mid-high, all and CCI ($p = 0.077$) (Fig. 3). When the cases were classified into three as Group 1, 2 and 3, there was statistically significant difference among CCI of groups ($p = 0.041$) (Fig. 4; Table 2). The CCI of Group 2 was longer compared with Group 1 ($p = 0.017$). There were statistically significant correlations among CCI and level of frequency and degree

Fig. 1 3D reconstruction shows *right* CCI to measure 0 mm (a) with normal audiogram findings (b) in a 36-year-old male patient with complaints of vertigo. 3D reconstruction shows *left* CCI to measure 0.6 mm (c) and *right* CCI to measure 1.7 mm (d) in a 45-year-old female with complaints of vertigo. The corresponding audiogram

demonstrates normal findings on both sides (e). 3D reconstruction shows *left* CCI to measure 9 mm (f) in a 61-year-old male patient with complaints of tinnitus. The audiogram demonstrates mild hearing loss in all frequencies on the *left side* (g)

Fig. 2 Graph of CCI among groups with hearing loss and normal hearing. The difference between groups is significant ($p = 0.014$)

Table 1 The findings when the subjects were grouped as normal, low, middle, mid-high, high and all according to the frequency of hearing loss

Hearing loss freq	<i>n</i>	Mean	Std deviation	Median	Minimum	Maximum
Normal	78	1.98	1.06	1.70	0.00	6.50
Low	2	2.40	0.42	2.40	2.10	2.70
Middle	12	1.90	1.52	1.52	0.00	6.20
Mid-High	26	2.46	1.43	2.06	0.28	5.60
High	10	2.41	0.90	2.36	1.40	4.20
All	52	2.76	1.79	2.26	0.51	9.00
Total	180	2.30	1.41	1.93	0.00	9.00

of hearing loss ($r = 0.213$ and $p = 0.004$, $r = 0.230$ and $p = 0.002$) (Table 3).

Discussion

The petrous apex contains important neuronal, vascular, and labyrinthine structures in a small area. It is essential to have a through knowledge of the anatomy prior to surgeries involving this region [5]. Basal turn of the cochlea is most vulnerable to injury, in oppose to the apex and middle turns which are protected beneath the geniculate ganglion. Although very rare, damage to the internal carotid artery might lead to devastating injury [2]. In our study, the CCI ranged from 0 to 9 mm. No statistically significant relationship was observed between CCI and age or gender.

Fig. 3 Graph of CCI among groups (normal, mild, moderate, high, very high and total) according to the degree of hearing loss. The difference between groups is significant ($p = 0.002$)

Fig. 4 Graph of CCI among groups according to the frequency of hearing loss. The difference between groups is significant ($p = 0.041$)

The bony wall between otic capsule and carotid canal has been reported to be as thin as 0–0.2 mm on CT studies [2–6]. Dehiscence of the bony canal has been reported [3, 4]. Unfortunately, it is impossible to comment on the integrity of bone on MRI. This remains to be one of the limitations of our

Table 2 The findings when subjects were grouped into three according to the frequency of hearing loss

Hearing loss	<i>n</i>	Mean	Std deviation	Median	Minimum	Maximum
Group 1	78	1.98	1.06	1.70	0.00	6.50
Group 2	90	2.56	1.66	2.10	0.00	9.00
Group 3	12	2.41	0.82	2.36	1.40	4.20
Total	180	2.30	1.41	1.93	0.00	9.00

Table 3 The correlations graphics of CCI and type, frequency and degree of hearing loss

Variable pairs	Correlation coefficient	<i>p</i> value
CCI-frequency of hearing loss	0.213	0.004
CCI-degree of hearing loss	0.230	0.002

study. But reformatted 3D FIESTA images enable direct and accurate visualization of ICA and basal turn of cochlea in three dimensions. It is also quite reliable and replicable to measure the CCI on a workstation. The average carotid–cochlear distance measured in the dissected specimens was 4.3 ± 0.8 mm [7]. It ranged from 0.4 to 7.0 mm [8] and 0.5 to 1.125 mm [9]. Significantly smaller distances have been found in children <4 years (1.17 ± 0.63 cm) than in patients >5 years (1.89 ± 1.19 cm) [5]. In our study, the mean distance was 2.31 ± 1.34 mm for females and 2.28 ± 1.47 mm for males. There was no statistically significant difference among genders. The CCI was significantly smaller in males than in females [5] or no association [3] was shown in different studies. The cause of this variable nature of results might be the number of specimens in the group, racial or population variability, or differences between the methods used. We didn't find statistically significant difference on both sides, similar to recent studies [3, 5].

In our study, the CCI in subjects with hearing loss was longer compared to the subjects with no hearing loss. There was no statistically significant difference between CCI of groups containing normal and sensorineural type hearing loss. When we grouped the subjects according to the frequency of hearing loss into six as normal, low, middle, high, mid-high and all, there was no statistically significant correlation with CCI. However, when the subjects were classified into three as Group 1 (normal), Group 2 (the group including all types of middle frequency hearing loss) and Group 3 (the others), there was statistically significant difference among CCI level of groups. The CCI of Group 2 was longer compared with Group 1. The above findings were unexpected. We believe further studies are needed on the subject. In addition, there was statistically significant

relationship among the degree of hearing loss and CCI ($p = 0.002$). There were statistically significant correlation between CCI and level of frequency and degree of hearing loss ($p = 0.004$ and $p = 0.002$).

Our findings clearly don't support the earlier hypothesis that pulsations of the closer internal carotid artery might create fluid pressure changes and direct stimulation of hair cells on the basilar membrane. But, we didn't obtain CT exam which is a limitation to show the dehiscence. It should be noted that, in the prior studies which might support this hypothesis, there was dehiscence of bony canal at least on one side [3, 4].

Attention to CCI might prevent inadvertent carotid artery injury during otosurgical procedures including cochlear implantation. No statistically significant relationship with CCI and age or gender was observed. There was linear correlation between CCI and level of frequency and degree of hearing loss. The CCI of the group including all types of middle frequency hearing loss was longer compared to the group with subjects with no hearing loss. These findings were unexpected and didn't support the hypothesis that pulsations of the closer internal carotid artery might create fluid pressure changes and direct stimulation of hair cells on the basilar membrane.

Conflict of Interest The authors declare that they have no conflict of interest.

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