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Facial nerve course in the temporal bone: Anatomical relationship between the tympanic and mastoid portions for safe ear surgery

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ABSTRACT

Objective: Avoidance of iatrogenic injury to the facial nerve is crucial during ear surgery. The anatomical relationship between the tympanic portion of the facial canal (FC) and the mastoid portion of the facial nerve was analyzed using multi-slice computed tomography (CT) scans to avoid iatrogenic facial nerve injury.

Methods: In total, 364 ears of 351 patients who underwent CT scans were enrolled. The 364 ears were divided into two groups: 281 ears with middle ear inflammation (MEI) and 83 ears without middle ear inflammation (non-MEI). The anatomical relationship between the tympanic portion of the FC and mastoid portion of the facial nerve was analyzed on multi-slice CT images. The ears were categorized into three subgroups based on the course of the mastoid portion of the facial nerve to the tympanic portion of the FC: ("lateral running course", LRC), "on the tympanic line course" (OL), and "medial running course" (MRC). The proportions of ears in each subgroup were compared between the MEI and non-MEI groups.

Results: Overall, 15% of ears were categorized as LRC, 30% were OL, and 55% were MRC. In the MEI group, the proportions of LRC, OL, and MRC ears were 17%, 32%, and 51%, respectively, whereas they were 7%, 24%, and 69% in the non-MEI group. The proportion of LRC ears in the MEI group was significantly higher than that in the non-MEI group.

Conclusions: Especially in patients with MEI, a more LRC for the facial nerve increases the risk of facial nerve injury during posterior tympanotomy or canal wall down mastoidectomy. The course of the facial nerve in the temporal bone should be evaluated before surgery on multi-slice CT images.

1. Introduction

The incidence rate of facial palsy following middle ear surgery varies from 0.2% to 3.6% [1–5]. Ryu et al. reported that 43% of iatrogenic facial nerve injuries during mastoid surgery occurred in the tympanic portion, 28.5% in the second genu and 28.5% in the mastoid portion [6]. The injuries in the second genu and mastoid portion of the facial nerve occurred while drilling bones during posterior tympanotomy or mastoidectomy, which are essential techniques for middle ear surgery and cochlear implant, in contrast to those in the tympanic portion which occurred without drilling (removal of cholesteatoma or manipulating the facial nerve itself) [6]. The

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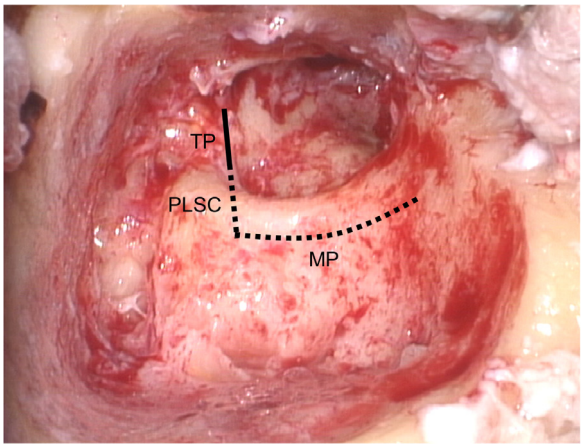

Fig. 1. Presumed running course of the mastoid portion (MP) of the facial nerve during surgery. Right ear. Canal wall down has been performed with reference to the running course of its tympanic portion (TP). Solid line indicates the directly visible section of the TP. Dotted lines indicate the MP and TP of the facial nerve buried in bone tissue. PLSC, prominence of the lateral semicircular canal.

other paper also reported that the most common procedure complicating iatrogenic facial nerve injury was mastoidectomy [7]. Thus, posterior tympanotomy and mastoidectomy involve the risk of direct facial nerve injury, and surgeons must carefully consider the running course of the facial nerve in the temporal bone during surgery. Because the facial nerve runs in the facial canal (FC), which is surrounded by bone tissue, the facial nerve itself in the middle ear (particularly its mastoid portion) is not visible directly when the middle ear cavity is initially opened. The course of the facial nerve can be revealed by the step-by-step drilling of surrounding bone tissue. However, the drilling site may be in very close proximity to the facial nerve, and surgeons often realize the facial nerve course only after its exposure. In a previous chart review study, in 79% of 22 patients with iatrogenic facial nerve paralysis after otologic surgery, facial nerve injury was not recognized by the surgeon in the operating room [8].

Surgeons should have a deep knowledge of the temporal bone, and can use the following techniques to avoid iatrogenic facial nerve injury during middle ear surgery: 1. With reference to the thin wall of the tympanic portion of the FC lateral to the facial nerve (which can be detected without drilling after tympanotomy), drilling bone tissue around the mastoid portion of the facial nerve can proceed to a depth equivalent to that of the tympanic portion of the FC (Fig. 1). 2. The prominence of the lateral semicircular canal is both lateral and superior to the second geniculate of the facial nerve; it is safe to drill the bone to a similar depth as the prominence (Fig. 1). 3. A facial nerve electric stimulator is useful during surgery. Notably, however, the course of the facial nerve varies and should be evaluated preoperatively in each patient.

Recently, multi-slice computed tomography (CT) equipment has been developed; the use of this equipment is essential for preoperative diagnosis of ear disease, because it can distinguish among the fine structures of the temporal bone. Multi-slice CT is advantageous in that its images can be viewed on the monitor display in axial, coronal, and sagittal orientations, providing information regarding three-dimensional anatomy. In particular, surgeons can understand the course of the facial nerve by tracing it on the display from the labyrinthine portion to stylomastoid foramen.

In the present study, the running course of the facial nerve was evaluated on multi-slice CT images of the temporal bone. We investigated the anatomical relationship between the tympanic portion of the FC and the mastoid portion of the facial nerve. Additionally, we analyzed the difference in course of the facial nerve between patients with and without middle ear disease, and considered potential applications of the results of this study for ear surgery.

2. Materials and Methods

2.1. Materials

This study enrolled 364 ears of 351 patients (158 males, 193 females; mean age, 53.9 years [range: 11–85 years]) who underwent multi-slice CT imaging for ear surgery for consecutive 68 months in our department. Because the mastoid cell system grows vigorously until approximately 10 years of age [9,10], candidates for this study were aged ≥ 11 years; children who had otitis media with effusion were excluded. The 364 ears were divided into two groups: ears with middle ear inflammation (MEI) and ears without middle ear inflammation (non-MEI). The MEI group consisted of 281 ears with conditions such as cholesteatoma, chronic otitis media, tympanosclerosis, and adhesive otitis media. The non-MEI group consisted of 83 ears with conditions such as otosclerosis, facial palsy, perilymphatic fistula, and acoustic tumour (Table 1).

2.2. Measurements

This study evaluated the anatomical relationship of the tympanic portion of the FC and mastoid portion of the facial nerve in the context of a posterior tympanotomy, or the canal wall down procedure, while viewing the tympanic portion of the FC during surgery. First, we evaluated the left-right symmetry of CT images based on the locations of the internal auditory canal, lateral semicircular canal, cochlea, and incudomalleal joint. Subsequently, we detected the tympanic portion of the facial nerve on axial CT images and outlined its lateral bony wall (lateral wall of the FC) on the display, because this wall can be easily detected after tympanotomy or atticoantrotomy (Fig. 2A). This line on the FC is considered to be similar to the course of the tympanic portion of the facial nerve, because of the thinness of the canal in this part: in some cases, the tympanic portion of the facial nerve can be visible through the dehiscence of the FC. In cases where the tympanic portion was slightly curved on images, we chose the portion of the canal immediately dorsal to the cochleariform process, where it can most easily be detected during surgery. Next, we traced the second genu and mastoid portion of the facial nerve to the level of the inferior boundary of the cochlea (basal turn) on caudal sequential CT images assuming the posterior tympanotomy and canal wall down

Table 1
Primary disease in ears with and without middle ear inflammation (MEI).

Ears with middle ear inflammation (MEI)	N = 281
cholesteatoma	135
chronic otitis media	118
tympanosclerosis	9
adhesive otitis meida	7
cholesterol granuloma	3
postoperative cavity problem	3
others	6

Ears without middle ear inflammation (non-MEI)	N = 83
otosclerosis	25
facial palsy	18
perilymph fistula	12
trauma	11
acoustic tumor	7
others	10

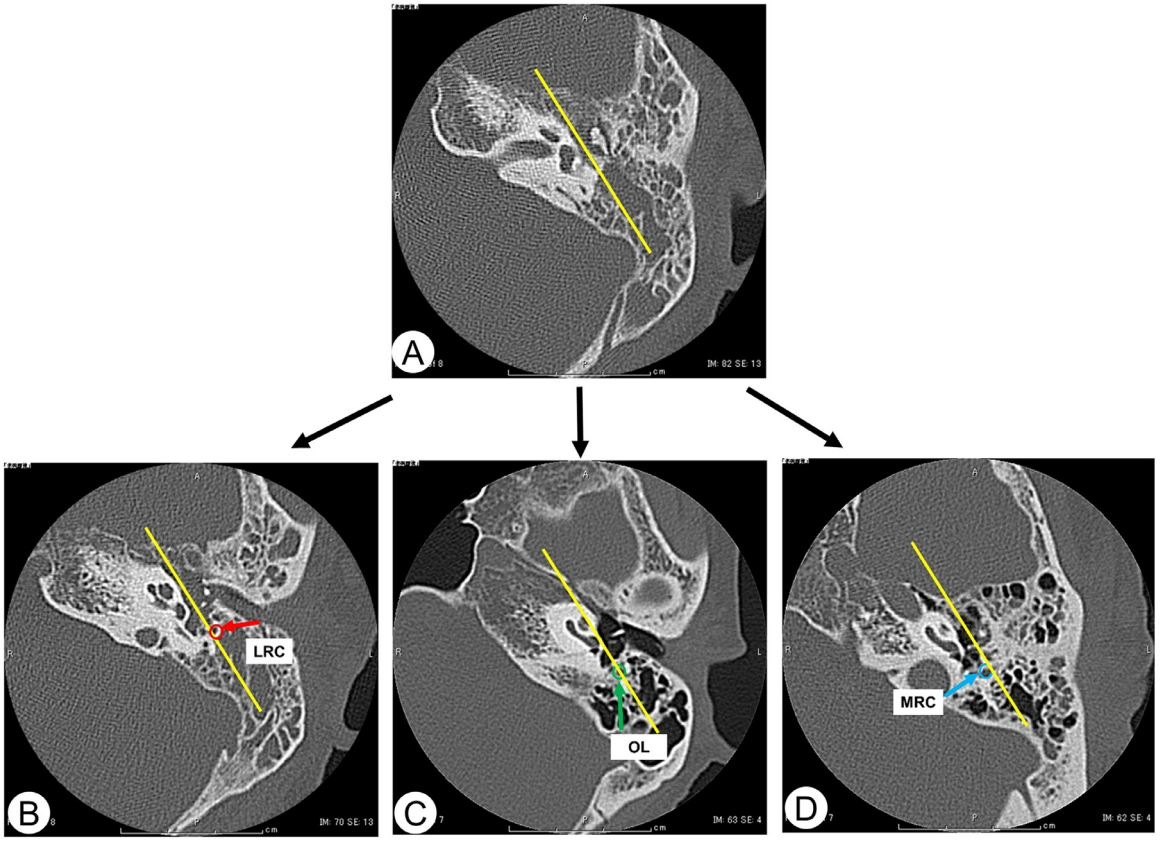

Fig. 2. Classification of the running course of the mastoid portion of the facial nerve. **A.** The tympanic portion of the facial nerve is detected in an axial computed tomography (CT) image and a line is drawn on the lateral wall of the facial canal (FC) on the display. Next, the MP of the facial nerve is traced in sequential caudal CT images while the line is kept on the display. **B.** "Lateral running course" (LRC) group. The MP (red circle and arrow) runs lateral to the TP of the FC, although this may be brief. **C.** "On the tympanic portion line course" (OL) group. The MP (green circle and arrow) runs nearly on the residual line of the TP of the FC. **D.** "Medial running course" (MRC) group. The MP (blue circle and arrow) always runs medial to the TP of the FC.

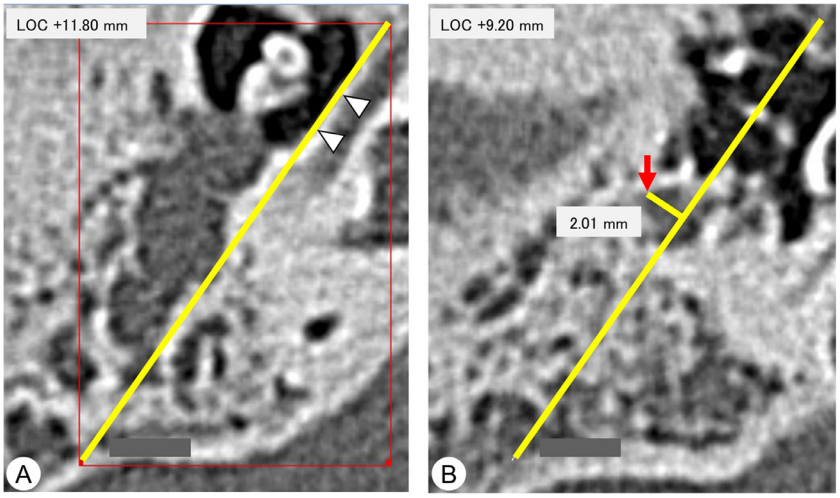

Fig. 3. Measurement of the most lateral part of the mastoid portion of the facial nerve in the LRC group. **A.** A line (yellow line) is drawn on the lateral wall of the tympanic portion (TP) of the FC (arrowheads). The location shows 11.80 mm. **B.** Image of the most lateral part of the MP of the facial nerve (arrow). The distance (short yellow line) between the most lateral part of the MP and the remained TP line is measured (2.01 mm). The location shows 9.20 mm, indicating that the most lateral part of the MP is located 2.60 mm (11.80 mm minus 9.20 mm) caudal to the line of TP.

technique while the outline of the lateral bony wall remained on the display. We classified these ears into three subgroups: 1. "Lateral running course" (LRC) group: the mastoid portion of the facial nerve runs lateral to the tympanic portion of the FC, including those cases where this lateral course is short (Fig. 2B); 2. "On the tympanic line course" (OL) group: the mastoid portion runs nearly on the remaining line of the tympanic portion of the FC (Fig. 2C); 3. "Medial running course" (MRC) group: the mastoid portion of the facial nerve always runs medial to the tympanic portion of the FC (Fig. 2D). After classification, we compared the proportions of ears in these three subgroups between MEI and non-MEI ears.

Next, we evaluated the characteristics of the LRC patients, who are at risk of facial nerve injury during posterior tympanotomy or canal wall down mastoidectomy, with reference to the tympanic portion of the FC. The perpendicular distance between the remaining line of the tympanic portion of the FC and the most lateral part of the mastoid portion of the facial nerve was measured. Then, the caudal distance from the tympanic portion of the FC to the most lateral part of the mastoid portion of the facial nerve was also measured (Fig. 3).

2.3. Apparatus and software for measurements

Multi-slice CT images (0.5-mm thick with a slice interval of 0.2, 0.25, or 0.3 mm) were collected (Aquilion ONE^{TM}; Canon Medical Systems Corp., Otawara, Japan). Axial scans were parallel to the orbitomeatal line (outer canthus of the eye to external auditory canal). The imaging data were transferred to a Vitrea Workstation (Canon Medical Systems Corp.) using the hospital intranet. The measurements were performed on bone images (window level, 600 Hounsfield units [HU]; window width, 4,500 HU) using EX-V software (ver. 1.11; FUJIFILM Medical Co. Ltd., Tokyo, Japan) on the display of the terminal computer of the electronic medical records system.

2.4. Data analysis

The number of the LRC, OL, and MRC groups were compared using chi-squared test. In the LRC group, MEI ears and non-MEI ears were compared in terms of the degree of lateralization of the facial nerve using Student's *t*-test after confirming these normal distribution and homoscedasticity. Statistical analysis was performed using JMP Pro software (version 14.2.0). P values <0.05 were deemed to be statistically significant.

2.5. Ethical approval

All procedures performed in studies involving human participants were approved by the Ethics Committee of Osaka Medical College (#2713). Informed consent was obtained in the form of opt-out on the website of our department and outpatient office in accordance with our IRB approval.

3. Results

3.1. Course of the mastoid portion of the facial nerve to the tympanic portion of the facial canal

Among the 364 ears, 55 (15%) were classified into the LRC group, 109 (30%) into the OL group, and 200 (55%) into the MRC group.

3.2. Course of the facial nerve in ears with/without middle ear inflammation

Among the 281 ears with MEI, the percentages in the LRC, OL, and MRC groups were 17%, 32%, and 51%, respectively. Among the 83 non-MEI ears, the percentages in the LRC,

Table 2
Running course with and without (MEI).

	LRC	OL	MRC
MEI (N=281)	49 (17%)	89 (32%)	143 (51%)
non-MEI (N=83)	6 (7%)	20 (24%)	57 (69%)

MEI, middle ear inflammation; LRC, lateral running course; OL, on the tympanic portion line; MRC, medial running course.

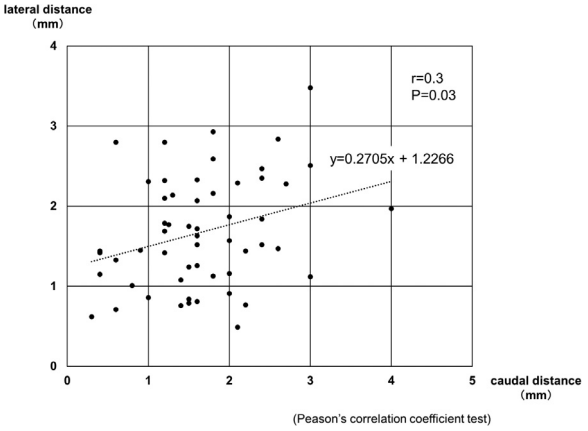

Fig. 4. Anatomical relationship between the lateral and caudal distances of the mastoid portion of the facial nerve to the FC tympanic portion in the LRC group.

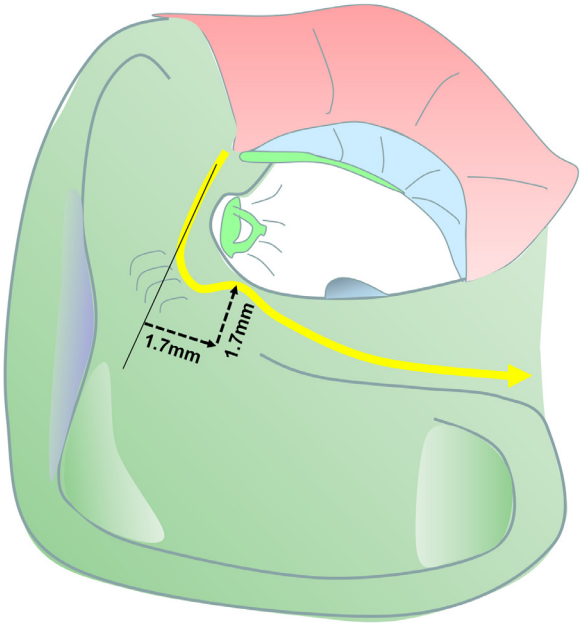

Fig. 5. Mean running course of the MP of the facial nerve to the TP of the FC in the LRC group. The mean caudal and lateral distances from the most lateral part of the MP to the TP were both 1.7 mm.

OL, and MRC groups were 7%, 24%, and 69%, respectively. Statistical analysis revealed that the percentage of LRC group MEI ears (17%) was significantly higher than that in non-MEI ears (7%; p = 0.02) (Table 2).

3.3. Detailed analysis of LRC group

The relationship between the caudal and lateral distance from the tympanic portion of the FC to the most lateral part of the mastoid portion of the facial nerve is shown in Fig. 4. The lateral distance was 0.5–3.5 mm (mean, 1.7 mm) and the caudal distance was 0.3–4.0 mm (mean, 1.7 mm) (Fig. 5). There was a weak positive correlation between these distances (r = 0.3). In terms of the degree of lateralization, there was a tendency for the facial nerve to run more laterally in ears with MEI (mean, 1.6 mm) than in non-MEI ears (mean 1.2 mm); however, the difference was not statistically significant (p=0.07).4.

4. Discussion

Avoidance of iatrogenic injury to the facial nerve is crucial during ear surgery. The lateral bony wall of the FC tympanic portion is initially detectable during surgery, and is a good landmark for the mastoid portion of the facial nerve during canal wall down mastoidectomy or posterior tympanotomy. However, the relationship between the tympanic and mastoid portions of the facial nerve in the surgical view has not been clearly elucidated.

According to our analysis of 364 ears on CT images, the MRC, OL, and LRC groups constituted 55%, 30%, and 15% of the ears, respectively. Furthermore, 17% of the MEI ears were categorized into the LRC subgroup, which was a significantly higher proportion versus the non-MEI ears (7%). Because the canal wall down technique and posterior tympanotomy are predominantly used to treat patients with middle ear inflammatory disease, approximately one-sixth of patients with MEI are at risk of facial nerve injury or exposure during these procedures if the surgeon drills to remove bone tissue from around the mastoid portion of the facial nerve, with reference to the visible lateral wall course of the tympanic portion of the FC. Otologists should be aware of the risk of facial palsy, especially during surgery for middle ear inflammatory disease, and we recommend that the course of the facial nerve be checked in each patient before surgery on multi-slice CT images.

It remains unknown as to why the mastoid portion of the facial nerve runs more lateral in MEI versus non-MEI ears. One potential explanation is as follows: the facial nerve and FC are divided into three portions in the temporal bone (labyrinthine, tympanic, and mastoid). In terms of postnatal development of the facial nerve and canal, the lengths of

the labyrinthine and tympanic portions in infants are nearly equivalent to those of adults [11,12]. In contrast, the mastoid portion of the facial nerve and canal lengthen with age. In infants, the stylomastoid foramen, where the facial nerve exits from the temporal bone, is located superior to its position in adults, and lies deeper relative to the tympanic ring than in adults [13,14]; the extratemporal facial nerve begins to course superficially and anteriorly immediately after exiting the stylomastoid foramen, such that the chorda tympani nerve diverges from the facial nerve below the stylomastoid foramen [11,13]. In adults, during the three-dimensional development of the mastoid, the mastoid portions of the FC and nerve lengthen; the stylomastoid foramen then shifts inferiorly and medially, while the extratemporal course of the facial nerve assumes a deeper position [13,14]. These findings suggest that the course of the mastoid portion of the facial nerve could be influenced by the degree of postnatal mastoid development. Otitis media with effusion can affect the development of the mastoid and mastoid cells in children [15,16]; persistent or repetitive otitis media with effusion in childhood can lead to poor development of the mastoid, thus resulting in potential middle ear inflammatory diseases in adulthood (e.g., cholesteatoma or adhesive otitis media). It is likely that persistent or recurrent otitis media with effusion in childhood suppresses mastoid development, which might result in the lateral course of the facial nerve predominantly observed in ears with MEI.

In our LRC group, the most lateral part of the mastoid portion of the facial nerve was revealed from the tympanic portion of the FC by a distance of 0.5–3.5 mm laterally (mean, 1.7 mm) and 0.3–4.0 mm caudally (mean, 1.7 mm); it was in close proximity to the second genu of the facial nerve (Fig. 5). Fujita et al. analyzed the development of the mastoid portion of the facial nerve and reported no change in length between the second genu and the bifurcation point of the stapedial branch (mean, 0.20 mm in adults), where it is close to the mean of the most lateral part of the mastoid portion in our study. In contrast, prolongation was present between the second genu and the bifurcation point of the chorda tympani (mean, 11.00 mm in adults) or stylomastoid foramen (mean, 15.02 mm in adults) [11]. As we mentioned previously, the stylomastoid foramen in infants is superior to the bony external auditory canal, and the extratemporal course of the facial nerve passes anteriorly after exiting the stylomastoid foramen; the nerve runs immediately inferior to the bony external auditory canal [13,14]. The stylomastoid foramen shifts in an inferior (and deeper) direction during the course of development of the mastoid. If the development of the mastoid is suppressed by MEI in childhood, the mastoid portion of the FC may lengthen insufficiently with age, while distortion at the point directly caudal from the second genu acts as a fulcrum. This may resemble the most frequent and mild anomaly of the facial nerve course, as reported by Fowler [17] and Nager [18]: a posterior and lateral bulge immediately beneath the prominence of the lateral semicircular canal. However, this is speculative, and a more detailed analysis is needed to fully understand the relationship between mastoid development and the course of the facial nerve.

In 1981, Fisch reported that the diameter of the mastoid portion of the FC was 1.48 mm [19]. Nakashima also analyzed it in greater detail via computer-aided 3-D reconstructions and reported that the mediolateral diameter was 2.02 mm in adults [20]. According to our data, the mastoid portion of the facial nerve shifted laterally by a mean of 1.7 mm (up to 3.5 mm) relative to the tympanic portion of the FC in the LRC group. These shifts are equivalent to 0.8–2.4 times the diameter of the FC in the mastoid portion, and otologists should be aware that this large lateral deviation of the facial nerve is possible, especially in ears with MEI.

5. Conclusions

The mastoid portion of the facial nerve runs to the tympanic portion of the FC via various courses. The facial nerve runs more lateral in the mastoid portion in MEI versus non-MEI ears, thus this increasing the risk of facial nerve injury during posterior tympanotomy or canal wall down mastoidectomy. Multi-slice CT images are useful to identify variations in the course of the facial nerve. To avoid iatrogenic facial palsy, we strongly recommend preoperative evaluation of the facial nerve course in the temporal bone on multi-slice CT images.

Declaration of Competing Interest

The authors have no conflicts of interest to declare.

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