Analysis of mastoid portion of facial nerve course in temporal bone using computed tomography

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ABSTRACT:
Introduction: The facial nerve (FN) follows a complex route in the temporal bone. Successful temporal bone surgery requires knowledge of its course which can be achieved using imaging methods such as computed tomography. This investigation aims to analyze the FN course in its mastoid portion and second genu and the frequency of its atypical course.

Material and methods: This is a retrospective study that enrolled 104 CT scans of temporal bones of patients followed up in the outpatient clinic of the Otorhinolaryngology Department of Dentistry Faculty of the Medical University of Warsaw between 2020 and 2022. FN courses were classified as straight, bulging, or letter “S”-like. Other parameters estimated:

- position of the second genu according to the prominence of the lateral semicircular canal (classified as lateral, medial, or middle) and its distance from a line adjacent to the lateral semicircular canal was measured;
- the distance between the short process of the incus and the outermost point of the second genu;
- the course of the mastoid portion of FN and the location of SG in comparison to the tympanic portion of n. VII. The course was later classified as lateral, medial, or middle.

Results: Among the 104 assessed temporal bones, the course of the mastoid portion of FN was classified as bulging in 47 cases (45.2%). Straight and letter “S”-like courses were present in 41 (39.4%) and 16 (15.4%) cases, respectively. Deviation of the second genu according to the prominence of the lateral semicircular canal was medial in 86 cases (82.7%), and middle in 4 cases (3.8%). In the rest, second genu was paramedian to the prominence of the lateral semicircular canal. The mean distance between the short process of the incus and the outermost point of SG was 4.9 mm (±0.73 mm). The mastoid portion was located laterally, medially, and in the middle of the tympanic portion plane in, respectively, 4.8%, 83.7%, and 11.5%. The second genu was located laterally, medially, and in the middle of the tympanic portion plane in 1.9%, 73.1%, and 25%, respectively. In conclusion, seven temporal bones (6.7%) of five patients presented with a lateral displacement of FN in relation to the established anatomical landmarks.

Conclusions: Although the atypical course of FN, including the lateral displacement of the mastoid portion, is rare, screening for it is crucial before surgical exploration.

KEYWORDS: facial nerve, mastoid, iatrogenic injuries, anatomy

ABBREVIATIONS
BG – bulging course group
CT – computed tomography
FN – facial nerve
LSGCC – lateral semicircular canal
SG – second genu
SLG – “S”-like course group
STG – straight course group

INTRODUCTION
The course of the facial nerve (FN) in the temporal bone is complicated and exhibits a high inter-individual variability. Successful temporal bone surgery requires knowledge of its course and major anatomical landmarks which can pose a difficulty for young otorhinolaryngologists. Iatrogenic facial palsy is one of the most severe complications after ear surgery as it affects facial expression and appearance but also has a devastating effect on the social, psychological, and economic aspects of the affected person’s life. The incidence of iatrogenic FN injury during otologic surgeries varies between 0.6% and 3.6% with an increase in revision surgeries [1]. Mastoidectomy is considered to be a major risk factor among other otologic procedures [2] such as middle ear surgery, as well as parotid gland tumor resection, temporomandibular joint surgery, and facial nerve tumour resection [3]. Ryu et al. report that 28.5% of iatrogenic injuries during mastoid surgeries occurred in the mastoid portion, 28.5% in the second genu, and 43% in the tympanic portion of n. VII [1]. Mostly, injuries occur while drilling and using sharp tools [4].
Meticulous analysis of the FN course is fundamental before ontological surgery and should be performed using imaging techniques such as computed tomography (CT) or magnetic resonance imaging. CT is a relatively accessible, cheap, safe, and quick option for FN course evaluation as it shows the Fallopian canal throughout the whole temporal bone. CT is also a preferred method of evaluation of bony structures of the temporal bone: the labyrinthine, tympanic cavity, FN course and mastoid process segments [3, 5]. Additionally, young surgeons should learn to respect major anatomical landmarks and their relation to the FN canal in the temporal bone – those include the prominence of the lateral semicircular canal (LSCC) and incudal fossa. This rigorous approach guides a surgeon through the temporal bone, allows to avoid intraoperative FN injury, and enables better surgery outcomes.

This investigation aims to analyze the FN course in its mastoid portion and second genu pointing to the frequency of its atypical course.

**MATERIALS AND METHODS**

**MATERIALS**

This retrospective study enrolled 104 ears (55 left ears, 49 right ears) of 79 patients (37 male and 42 female; mean age: 59 years ±20.9 [range 19–90]) followed up in the outpatient clinic of the Otorhinolaryngology Department of the Dentistry Faculty of the Medical University of Warsaw between 2020 and 2022. Those patients underwent a CT scan of temporal bones due to reasons shown in Tab. I. Exclusion criteria were the ipsilateral presence of chronic/acute otitis media, otogenic temporal and intracranial complications, temporal bone trauma, neoplasms of the temporal bone, history of otologic surgeries, congenital and acquired temporal bone malformations, or age below 18 years. If only one ear was subject to exclusion criteria, the contralateral ear was still included in the study if no contraindications were found. CT scans were evaluated by two young researchers and were later double-checked by an experienced otorhinolaryngologist.

**Methods**

This study evaluated the following anatomical features of the FN course in the temporal bone:

1. The mastoid portion of the FN course was classified as one of three following subtypes: bulging, straight, or letter “S”-like. It was assessed using the coronal plane of a CT scan. The bulging subtype was described as having a part along its course laterally displaced in comparison to the vertical mastoid segment (Fig. 1.). The letter “S”-like course, was classified as having two parts along the vertical segment displaced laterally and/or medially so that it resembles the letter “S” (Fig. 2.). The straight subtype was classified as having no displacements along its vertical portion (Fig. 3.);

2. The deviation of the second genu according to the prominence of the lateral semicircular canal was assessed on the coronal plane CT scans. After the second genu of FN (SG) and LSCC were identified, a vertical line perpendicular to LSCC was drawn. SG location was classified as lateral, medial, or in the drawn line – examples are shown in Fig. 4. If the location was described as medial or lateral, we measured the displacement (in mm). The measurement was made between the vertical adjacent line and the closest point of the bony canal of SG – in case of a medial displacement, outermost, and in case of a lateral displacement, innermost (Fig. 5.).

3. By using CT reconstruction techniques, we measured the distance between the short process of the incus and the outermost point of SG. After the outermost point of SG was localized and marked in the coronal plane of CT, the end-point of the short process of the incus was traced and marked on the horizontal plane of CT. With imaging reconstruction techniques, the distance between those points was measured (in mm). Fig. 6. presents the measurement;

4. The course of the mastoid portion of FN and the location of SG were assessed in relation to the tympanic portion of FN. In horizontal plane CT, the tympanic portion of FN was detected and a line was drawn along it. In case the tympanic portion was slightly curved, we drew the line through the middle of the endpoints of this part. Next, SG and the mastoid portion of FN were detected. With the outline of the tympanic portion still on the display, we classified whether the SG/mastoid part of n. VII was located laterally, medially, or “on the line” with the tympanic course. For SG assessment, if the location was described as medial or lateral, we measured the displacement (in mm). The measurement was made from the closest part of the bony canal (if medial, outermost; if lateral, innermost), to the line passing through the tympanic portion (Fig. 8.).

**Apparatus and software for measurements**

Computed tomography scans were obtained by a 128-slice CT scanner (Philips Ingenuity Core 128; 80kV; 80-140kVp; 20-655mA; matrix, 512*512). The axial images were 0.625-mm-thick sections and the helical images were 0.67 mm thick. All images were displayed using Exhibeon software.

**Data analysis**

For statistical analysis, STATISTICA 13.3 (TIBCO Software Inc., Palo Alto, CA, USA) was used to analyze the data. The P-value significance level was considered as 0.05. Shapiro–Wilk test was applied to test the distribution of the data. The groups classified according to the course of the mastoid portion of FN (bulging, straight or letter “S”-like) were compared using the unpaired two-sample Student’s t-test for quantitative data, and Pearson’s chi-squared test or Fisher’s exact test to determine whether there is a statistically significant difference between the expected and the observed frequencies among the groups.

**Ethics approval**

This retrospective study was conducted in accordance with the Declaration of Helsinki. The Institutional Review Board at the Medical University of Warsaw was informed about the study (Approval Number: AKBE/236/2022) and the requirement for written informed consent from each patient was waived.
RESULTS

The assessed CT scans of temporal bones presented with a wide range of heterogeneous FN courses. Among the 104 temporal bones, the course of the mastoid portion of FN was classified as bulging in 47 cases (45.2%). Straight and letter “S”-like courses were present in 41 (39.4%) and 16 (15.4%) cases, respectively. For further analysis, the temporal bones were divided into 3 groups based on the course of the mastoid portion of FN: I – the bulging group (BG), II – the straight course group (STG), and III – the “S”-like course group (SLG).

Location of the second genu according to the prominence of the lateral semicircular canal was assessed as medial in 63 cases (60.6%). The mean displacement measured from a vertical line adjacent to LSCC to the outermost point of the bony canal for medial deviation was 1.4 mm (±0.60 mm). Three cases presented as located in the drawn line. In 38 cases (36.5%), the bony canal of FN was adjacent to the line perpendicular to LSCC and was described as paramedian – in most cases the nerve was located medially to the line, whereas in two cases the lateral displacement was observed.

The mean distance between the short process of the incus and the outermost point of SG was 4.9 mm (±0.73 mm) [range: 3–6.9 mm] and the differences between the groups (BG, STG, SLG) were not statistically significant (Tab. II.).

Tab. I. Reasons for temporal bone CT scans in patients enrolled in this study.

<table>
<thead>
<tr>
<th>REASON FOR CT SCAN</th>
<th>NO OF CT SCANS</th>
</tr>
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<tbody>
<tr>
<td>Neoplasm in the temporal bone (suspected or confirmed)</td>
<td>7</td>
</tr>
<tr>
<td>Chronic otitis media</td>
<td>4</td>
</tr>
<tr>
<td>Otitis media</td>
<td>6</td>
</tr>
<tr>
<td>Post-otologic surgery check-up</td>
<td>5</td>
</tr>
<tr>
<td>Acute otitis media</td>
<td>6</td>
</tr>
<tr>
<td>Otitis externa</td>
<td>4</td>
</tr>
<tr>
<td>Choleastatoma</td>
<td>4</td>
</tr>
<tr>
<td>Osteomyelitis</td>
<td>1</td>
</tr>
<tr>
<td>Chronic rhinosinusitis</td>
<td>8</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>3</td>
</tr>
<tr>
<td>Post – sinus surgery check-up</td>
<td>1</td>
</tr>
<tr>
<td>Mastoiditis</td>
<td>5</td>
</tr>
<tr>
<td>Neoplasm of the parotid gland</td>
<td>2</td>
</tr>
<tr>
<td>Temporal bone trauma</td>
<td>1</td>
</tr>
<tr>
<td>Other/Not specified</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td>104</td>
</tr>
</tbody>
</table>

Tab. II. The differences in the mean distance between the short process of the incus and the outermost point of SG for groups with a distinct course of the mastoid portion of FN. BG – bulging course group; STG – straight course group; SLG – “S”-like course group; SD – standard deviation.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>MEAN VALUE ± SD (MM)</th>
<th>PAIRWISE COMPARISON</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG</td>
<td>4.77 ±0.64</td>
<td>BG vs STG: p = 0.139</td>
</tr>
<tr>
<td>STG</td>
<td>5.01 ±0.83</td>
<td>STG vs BG: p = 0.139</td>
</tr>
<tr>
<td>SLG</td>
<td>5.00 ±0.67</td>
<td>SLG vs BG: p = 0.232</td>
</tr>
</tbody>
</table>

Fig. 1. Bulging course of the mastoid segment of FN (left ear).

Fig. 2. “S”-like course of the mastoid segment of FN (left ear).

Fig. 3. Straight course of the mastoid segment of FN (left ear).
The location of SG to the tympanic portion of FN was assessed as “in the line” in 26 temporal bones (25%). In 76 cases (73.1%) it was located medially and only in 2 temporal bones (1.9%) it was situated laterally to the tympanic portion extension. The displacement measured for medially located SG from the outermost part of the bony canal to the line passing through the tympanic portion was 0.3 (±0.62) mm; however, most of the cases were actually paramedian and the measurement was 0 mm. Two cases assessed as lateral presented with the tangential course to the line drawn through the tympanic portion of FN and thus they were also described as paramedian.

The course of the mastoid portion of FN in 12 cases (11.5%) was on the line drawn along the tympanic portion. Most temporal bones (83.7%) presented with the medial course, whereas only in 5 cases (4.8%) the nerve was located laterally to the tympanic portion of FN. The lateral displacement was observed only in patients with a straight course of the mastoid portion of FN.

We also checked if there is any relationship in the distance between the short process of the incus and the outermost point of SG and lateral displacements in the area of SG or the mastoid segment. However, any relationships were not statistically significant (P>0.05).

In conclusion, seven temporal bones (6.7%) of five patients presented with a lateral course of the mastoid portion/SG in at least one assessed point (versus prominence of the LSCC or tympanic portion of FN). The cases are presented in Tab. III. Lateral displacements were minor because the bony canal of FN was adjacent to the comparative line (paramedian). Furthermore, the displacements were present in every type of the FN course (BG, STG, SLG).
DISCUSSION

The FN, the seventh cranial nerve, plays many important functional roles, some of which are crucial in everyday life. Being able to express emotions via facial movements or the ability to produce tears are just some examples. Without proper nerve function, phenomena such as impaired lacrimation, hyperacusis, altered speech and defective functioning of the nasal valve can occur, and the quality of the patient’s life worsens [6]. What is worth considering, FN follows a complex course through the temporal bone. Understanding its anatomy remains crucial to avoid iatrogenic FN damage, especially when it is surrounded by pathologic tissues, such as cholesteatoma. Iatrogenic FN palsy is a rare but severe complication of various otologic procedures and its incidence ranges between 1% and 4% in primary procedures and from 3.7% to 10% in revision procedures [1]. CT imaging is commonly used in evaluating the FN course and the spatial relationships between FN and its neighboring structures [7–12].

Various studies present different sites of FN damage during ear surgery, including tympanic or mastoid segment and second genu [1, 13, 14]. Authors list the dehiscence of the bony canal in the tym-
panic portion of n. VII, lateral displacement of the mastoid portion of FN and displacement of the second genu as the most common causes of iatrogenic nerve injury [12]. Atypical FN course increases the risk of iatrogenic FN injury during otologic procedures, such as mastoid surgery or cochlear implant surgery, regardless of the surgeon’s experience [5]. In our study, we focused on checking the variations in the location of the second genu and mastoid segment. Our analysis, based on 104 CT images of temporal bones, revealed that in 8 cases (7.7%) the lateral displacement in at least one evaluated point was encountered.

The imaging of the bony canal of FN on a CT scan can provide a surgeon with basic information on possible surgical risks. Firstly, we performed a visual classification of the course of the mastoid portion of FN on coronal CT scans. Interestingly, less than half of temporal bones (39.4%) presented with the straight course, whereas most cases presented with the deviated course along the mastoid portion. What was observed during the assessment was the fact that in most cases of bulging, the whole mastoid portion was situated medially and therefore the risk of surgical damage remained decreased. We found no data regarding the distribution of the bulging or the “S”-like course and thus we cannot compare our data with other studies regarding the CT assessment of the FN course. However, Yadav et al. in a cadaver study found that a lateral hump or postero-lateral bulge below the horizontal semicircular canal was present in 20% of cases, and in 12% it was lateral to the prominence of the horizontal semicircular canal [15].

Another measurement was the deviation of the second genu in relation to the prominence of the lateral semicircular canal, inspired by the study of Du et al. [12]. We also used coronary CT scans to identify the prominence of LSCC and SG and to access the location of SG in relation to the vertical line adjacent to the prominence of LSCC. Contrary to the previous study, in cases displaced medially or laterally, we decided to measure the distance between the drawn line and the closest point of the bony canal of SG, not the middle of the nerve. Therefore, it is impossible to compare our measurements and those reported by Du et al. However, we could use 1.76 ±0.27 mm as the width of intact SG reported by Celik et al. [16]. Du et al. showed that the heights of SG above LSCC in the medial-to-lateral dimension measured on coronary CT images varied from -2.9 to 2.9 mm. In our study, the distance varied from -2.6 to 0 mm and even considering the mean width of SG, our cases were not so laterally displaced as in a study of Du et al. Moreover, Du et al. reported that 27.7% of patients had a lateral displacement of the second genu above the prominence of LSCC, whereas in our study we identified only two cases (1.9%) when the nerve was situated paramedially on the lateral side. The difference in the number may come as a result of different patients’ age, demographic, or exclusion criteria, as all patients in the quoted research needed mastoidectomy. We arrived at a different conclusion than Du et al. Ultimately, the bulging subtype of the FN course can be also present if the second genu does not deviate laterally. Thus, according to our research, we cannot use the lateral deviation of SG as an indicator of the bulging course of FN.

We also explored a parameter that is not researched sufficiently in current literature – the distance between the short process of the incus and the outermost point of the second genu of FN – if there is any relationship in the distance between the short process of the incus. The endpoint of the short process of the incus is pointing towards the fossa incudis. This is a major anatomical landmark in ear surgery that informs the surgeon about the medial proximity of the mastoid portion of FN and its SG. Using reconstruction techniques of CT scans, we measured the distance between the short process of the incus and the outermost point of the second genu – the mean distance was 4.9 mm (range: 3 mm–6.9 mm). The results show great variability; however, surgeons should give special attention in cases where the distance is particularly small to estimate drilling time and force.

One of the conducted assessments was the classification of the course of the mastoid portion of the tympanic portion of FN, proposed by Ozaki et al. [8]. Our results showed that only in 5 temporal bones (4.8%) the mastoid segment was situated laterally to the line drawn through the tympanic portion, whereas Ozaki et al. reported that among 364 ears, 15% presented with the lateral course. The reason for this disproportion remains unknown. A possible explanation may be the group size. However, another possible reason is that we included temporal bones without pathologies, malformations, or history of surgery, whereas Ozaki et al. assessed two groups: one with middle ear inflammation and the other without inflammation, but with other pathologies (otosclerosis, trauma, acoustic tumors, etc.). Ozaki et al.

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**Tab. III.** Cases with the course classified as lateral in any of the measured points: SG—second genu, FN—facial nerve.

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<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>female</td>
<td>left</td>
<td>bulging</td>
<td>3.6</td>
<td>paramedian (lateral)</td>
<td>medial</td>
<td>paramedian (lateral)</td>
</tr>
<tr>
<td>2*</td>
<td>70</td>
<td>male</td>
<td>left</td>
<td>straight</td>
<td>5.2</td>
<td>paramedian (lateral)</td>
<td>lateral</td>
<td>paramedian (lateral)</td>
</tr>
<tr>
<td>3*</td>
<td>70</td>
<td>male</td>
<td>right</td>
<td>straight</td>
<td>4.9</td>
<td>paramedian (medial)</td>
<td>lateral</td>
<td>medial</td>
</tr>
<tr>
<td>4**</td>
<td>82</td>
<td>male</td>
<td>left</td>
<td>straight</td>
<td>4.2</td>
<td>medial</td>
<td>lateral</td>
<td>medial</td>
</tr>
<tr>
<td>5**</td>
<td>82</td>
<td>male</td>
<td>right</td>
<td>straight</td>
<td>4.5</td>
<td>medial</td>
<td>lateral</td>
<td>medial</td>
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<tr>
<td>6</td>
<td>62</td>
<td>male</td>
<td>right</td>
<td>straight</td>
<td>5.6</td>
<td>medial</td>
<td>lateral</td>
<td>paramedian (medial)</td>
</tr>
<tr>
<td>7</td>
<td>36</td>
<td>male</td>
<td>left</td>
<td>bulging</td>
<td>4.3</td>
<td>paramedian (lateral)</td>
<td>medial</td>
<td></td>
</tr>
</tbody>
</table>

* One patient. ** One patient
suggest that otitis media with effusion can cause alterations in postnatal mastoid development, influencing the FN course. Haber et al. suggest that an atypical FN course is more common in patients with inner ear malformations, however, such patients were excluded from our research [5].

Lastly, we tried to complete the classification by the assessment of the deviation of SG in relation to the tympanic segment of FN. This measurement was also not inspired by previously published studies. What is interesting, only in two cases SG was classified as situated laterally, but they were in fact lateral paramedian.

There were several limitations to our study. To begin with, the number of included patients was low in comparison to other similar studies. However, the group size was determined given the multiple assessments we performed. Secondly, we included only healthy temporal bones, without any pathological condition. Thus, the performed assessment was more accurate. Nevertheless, we are aware that the analysis of the FN course is critical for temporal bones with underlying conditions being the indications for surgical procedure. Therefore, we are not able to discuss if the complete assessment of the FN course is possible in every preoperative situation due to the limited visibility or destruction of FN or other structures using only CT scans.

To summarize, we identified 7 temporal bones (6.7%), which presented with lateral displacements and therefore could pose a risk of iatrogenic injury of FN during surgery. Interestingly, these temporal bones belonged to five patients – two patients had both ears with laterally displaced FN, whereas for the other four patients we were unable to assess the second temporal bone because of the exclusion criteria. It is impossible to apply all presented parameters before each mastoid surgery, however, surgeons should be able to read CT scans and notice warning signs of atypical FN course. Even though it seems that the number of patients with displaced mastoid portion of FN is relatively small, it is not insignificant and these patients require more careful planning of surgery.

CONCLUSIONS

Careful analysis of the course of FN before otological surgery is essential in carrying out successful surgery without minimizing complications such as iatrogenic FN palsy. Although the lateral displacement of the mastoid portion and SG of FN is a rare occurrence, screening for it is crucial. Computed tomography is the easiest option to visualize the course of FN in the temporal bone. There is a substantial need for a standardized FN course assessment system before mastoid surgery using imaging techniques.

REFERENCES