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Facial nerve canal dehiscence: evaluation of a new middle ear dissection technique and digitalized image analysis

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SUMMARY

The tympanic segment (TS) of the facial nerve (FN) runs in a protective bony canal in the medial wall of the middle ear. Facial nerve canal dehiscence (FND) represents a breach in the bony canal covering the FN. Full exposure of the TS greatly aids visualisation and therefore the gross investigation of middle and inner ear pathologies, but the existing literature provides minimal guidance on dissection and measurement techniques. The aim of this study was to develop a dissection approach for the middle ear, investigate the incidence of FND in fresh- frozen and embalmed cadavers, and finally, to grade/measure FND using a digitalized image analysis software (ImageJ). Twenty-two temporal bones were investigated (59% [n = 13] were fresh-frozen [six males, seven females], and 40% [n = 9] embalmed [six males, three females]). Dissection was conducted in the anatomy teaching laboratory of the University of Edinburgh (regulated by the Human Tissue [Scotland] Act 2006). Dissection and analysis procedure involved five main stages: preparation, exposure, sectioning of the horizontal segment, grading of the canal's dehiscence, and measurement and analysis. The overall dehiscence rate was 41% (n = 9): 23% (n = 3) in fresh-frozen cadavers and 66% (n = 6) in embalmed cadavers. Of 22 temporal bones, 36% were graded as fully dehisced in different locations. Our dissection successfully achieved full exposure of both the medial wall of the middle ear and the FN's TS. Analysis of the curved TS was performed with ImageJ software and allowed a more accurate measurement of the TS's length and any associated FND. Attaining a clear and systematic dissection approach for the middle ear is of fundamental importance for future anatomical research that investigates FND, as well as for the provision of teaching materials in the form of anatomical specimens.

Key words: Middle ear – Facial nerve – Canal dehiscence – Tympanic segment – Image analysis – Dissection

INTRODUCTION

The incidence of iatrogenic, facial nerve (FN) injury is rare, although its occurrence can be devastating to patients. The incidence of FN palsy has been shown to increase when canal dehiscence is present (Lin et al., 2004). Facial nerve canal dehiscence (FND) can be influenced by various factors,

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such as abnormal development or pathologies that either directly or indirectly affect the integrity of the FN's bony canal (Choi et al., 2014; Genc et al., 2014; Gülüstan et al., 2014).

Although the risk of iatrogenic facial paralysis reported in the literature ranges from 0.6% to 3.6%, in primary and revision mastoid surgeries, the frequency of FN injury ranges from 4% to 10% (Wiet, 1982; Schuring, 1988). The majority of iatrogenic FN palsy incidences are often undetected during surgery. Green et al. (1994) reported that in 79% of patients the surgeon did not identify a FN injury at the time of injury.

Among many techniques utilized to study FND, merely three apply a dissection-based approach—none of which have clearly reported a detailed description of how these approaches were taken (Beddard and Saunders, 1962; Mollica, 1962; Kharat et al., 2009).

The present study demonstrates the anatomy of the middle ear, the tympanic segment (TS) of the FN, FND, and proposes etiological factors that may induce FND. This study aims to address the question of incidence of FND in grossly dissected fresh-frozen and embalmed cadaveric specimens utilizing a newly-developed dissection approach and a digitalized image analysis.

MATERIALS AND METHODS

Twenty-two temporal bones were dissected, of which thirteen (59%) were collected from fresh-frozen cadavers (six male and seven female) and nine (41%) from embalmed cadavers (six male and three female). The mean age of the specimens at death was 78 years. Laboratory-based dissection was conducted in the anatomy teaching laboratory of the University of Edinburgh (regulated by the Human Tissue [Scotland] Act 2006) to investigate the FN's TS and any potential bony canal dehiscence. Due to the limited guidance available in the literature regarding the optimal approach to dissecting the middle ear, three dissection techniques were trialed to identify an approach that could achieve full middle ear exposure with complete preservation of the FN's TS.

Detailed below, the chosen method of dissection involved five main stages: preparation, exposure, sections of the horizontal segment, grading of the canal's dehiscence and measurement and analysis.

Compete lateral approach

The complete lateral approach attempted to achieve complete exposure of the middle ear from a lateral approach, including the complete dissection of the bony external auditory meatus (EAM), mastoid bone, and squamous part of the temporal bone. This approach yielded the most favourable results, because it facilitated the full lateral exposure of the middle ear, provided a wide angle for obtaining photos for analysis, promoted clear visualization of the FN's TS, and proved less likely to result in damage to the specimens.

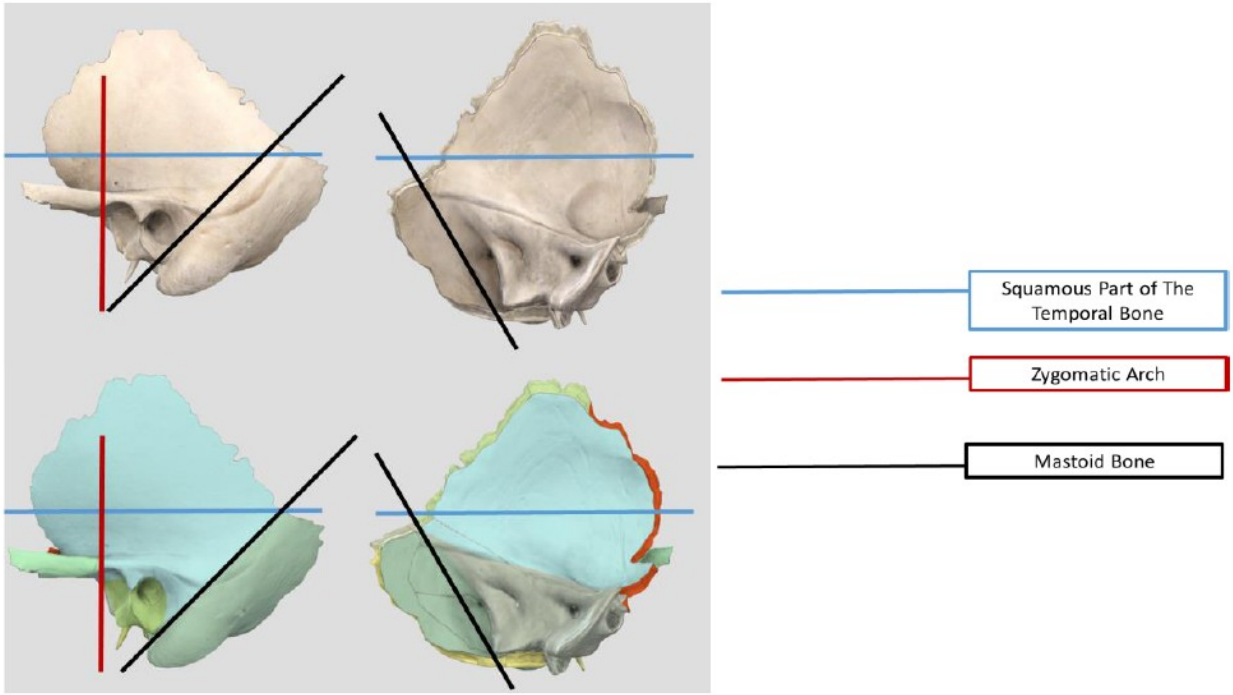

Fig 1. Schematic representation of the anterior and posterior views of the temporal bone. Colored lines represent the cut lines pursued in preparing the temporal bone for exposure. Red line: zygomatic arch cut line. Blue line: squamous part of the temporal bone cut line. Black line: mastoid bone cut line.

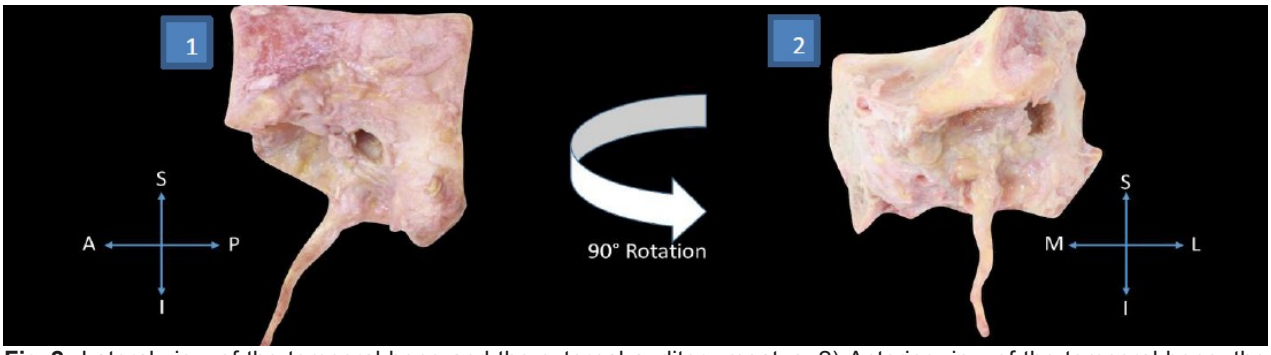

Fig 2. Lateral view of the temporal bone and the external auditory meatus. 2) Anterior view of the temporal bone; the external auditory meatus appears laterally.

The first stage: preparation

Twenty-two hemisected heads were dissected to prepare the temporal bones for exposure. Dissection was initiated by firstly removing the scalp and, thereafter, the skin and fascia from over the zygomatic arch and mandible (Fig. 1). Preparing the temporal bone for middle ear exposure involved four stages of dissection, which are represented by the lines in Fig. 1.

The zygomatic arch and mandible

Dissection of the zygomatic arch and mandible involved a number of stages. (1) The masseter muscle was dissected and reflected to define the mandible's borders and ramus. (2) The temporalis muscle was then dissected and reflected inferiorly from its attachment to the superior temporal line. (3) Using a medical electric saw (Medezine 5000, Sheffield, UK), the zygomatic arch was cut both anteriorly—as closely to the orbit as possible—and posteriorly, near the anterior border of the mandible's head. (4) After reflecting the zygomatic arch, the mandible was cut vertically along the middle of the ramus down inferior to the mandible's angle, thus separating it into anterior and posterior halves. (5) The posterior part of the mandible was removed, and the infratemporal fossa was exposed (Fig. 2).

The squamous part of the temporal bone

Externally and anteriorly to the EAM, a vertical cut was made approximately 1–2 cm anterior to the temporomandibular joint. Superiorly, this cut separated the temporal region from the frontal region and the face, extending inferiorly through the infratemporal fossa. Internally, the cut line passed

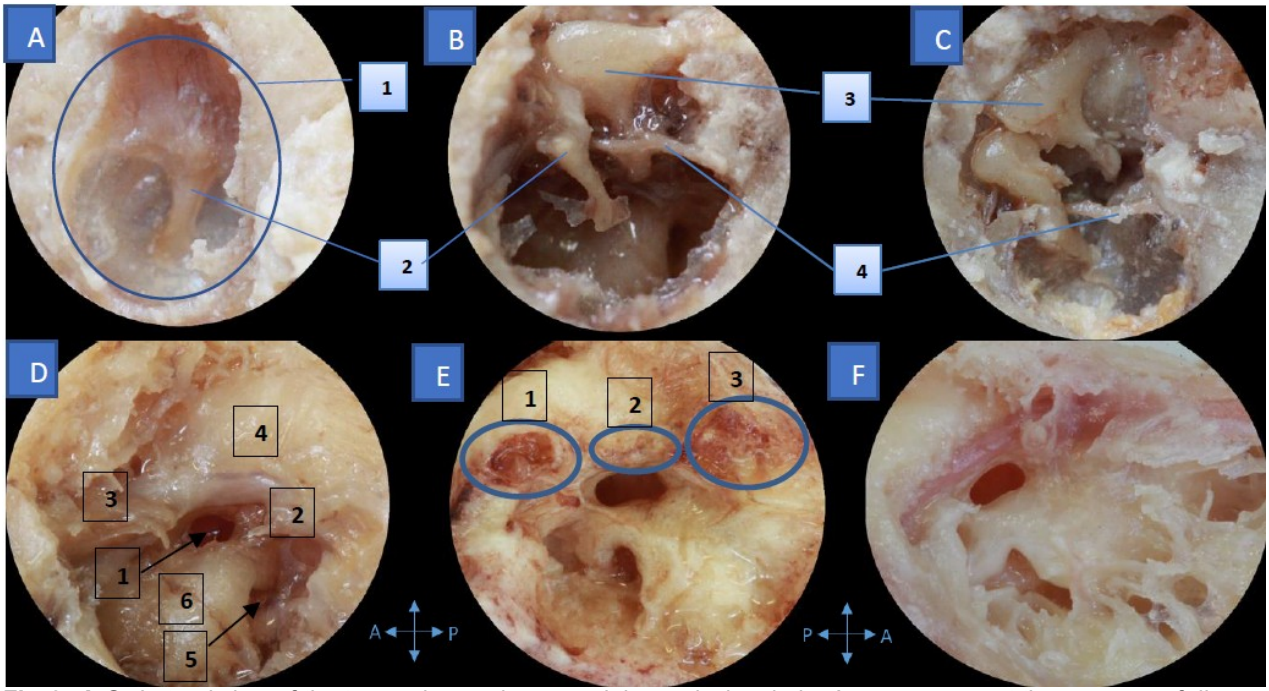

Fig 3. A-C: Lateral view of the tympanic membrane and the ossicular chain. Arrows represent the progress of dissection: 1. The tympanic membrane, 2. Lateral process of the malleus (exposed and pressed on the tympanic membrane), and 3. Short limb and articulation surface of the incus, 4. Corda tympani D-F: Lateral view of the medial wall of the middle ear with ossicular chain removed. D. (1) Oval window, (2) Pyramidal process, (3) Cochleiform process, (4) Lateral semicircular canal, (5) Round window, and (6) Cochlear promontory. E. (1) Dehiscence at the area of pyramidal process and lateral semicircular canal, (2) Dehiscence at the area of oval window, and (3) Dehiscence at the area of the cochleiform process and the geniculate ganglion. F. Intact facial nerve.

anteriorly to the arcuate eminence to the middle cranial fossa, aiming to preserve the petrous part of the temporal bone (Fig. 1).

The mastoid bone

The mastoid bone was then cut in an oblique line to the posterior cranial fossa. Externally, the cut started from the auricular fissure up to the squamous suture –superiorly- and then continued in a plane passing through the middle of the supramastoid crest. Internally, the cut line passed posteriorly to the arcuate eminence to the posterior cranial fossa, again aiming to preserve the petrous part of the temporal bone (Fig. 1).

The temporal segment (superior to the EAM)

A horizontal cut line was made 3–5 cm superior to the EAM to separate the temporal bone (Fig. 1) and prepare it for exposure.

The second stage: exposure of the middle ear

The external auditory meatus

Using the tympanic membrane as a landmark, the EAM was cut in a sagittal plane along its external surface from anterior to posterior (Fig. 2). Using an electric medical autopsy saw (Medezine 5000), multiple cuts were then made to reach the tympanic membrane in an aim to shorten the EAM and reach the middle ear (Fig. 3 A-C). After adequate exposure, the tympanic membrane was then reflected and the ossicular chain carefully removed. Consequently, the middle ear was therefore exposed in a complete lateral view (Fig. 3 D-F). The C-shaped tympanic ring was then drilled using a high-speed multi-tool (DREMEL 4300-3/45, Dremel, Racine, WI, USA) to increase visualization of the middle ear (Fig 3 D-F).

The middle ear

Photos for analysis were taken using a Canon EOS 60D 18MP Digital SLR camera with a 100-mm EF Ultrasonic 1:2:8USM Canon Macro Lens. Following full exposure and using a tripod stand, photos were taken at a 90-degree angle with the oval window at the photo centre. A 10-mm scale was included with each specimen.

Landmarks of the FN's TS

The FN's TS is located from the geniculate ganglion (anteriorly) to the second genu (posteriorly). The cochleiform process serves as a surgical landmark for the geniculate ganglion's identification, where the anterior part of the FN's TS lies slightly above and medially to the ganglion (Mansour et al., 2013; Standring, 2015). The second genu is located below and medially to the dome of the lateral semicircular canal; posteriorly, it lies closely to the pyramidal eminence (Spector and Ge, 1993; Mansour et al., 2013). Therefore, to maintain constant measurement, the geniculate ganglion was identified by a vertical line from the anterior border of the cochleiform process, while the second genu was identified by a vertical line from the posterior border of the pyramidal process up to the lateral aspect of the lateral semicircular canal's dome.

An initial examination was performed by inspecting the canal for any breach in continuity or visible gaps and then by physically checking the canal's integrity through palpation with a metallic surgical instrument.

Table 1. The third stage: the sections of the tympanic segment of the facial nerve. The sections and location of the FN horizontal segment*; geniculate ganglion, TS, and the second genu

Table 1. The sections and location of the FN horizontal segment*; geniculate ganglion, TS, and the second genu

Section	The geniculate ganglion and the cochleiform process	Above the oval window	The second genu and the pyramidal process
Description	From the first genu to the anterior border of the oval window	As above	From the second genu to the posterior border of the oval window

*The horizontal segment represents the canal from the Geniculate ganglion to the second genu.

Table 2. The fourth stage: categorizing/grading canal dehiscence. Description of each grading category used for the analysis

Table 2. Description of each grading category used for the analysis

Category	Completely intact fallopian canal	Minor partial dehiscence	Major partial dehiscence	Exposed FN
Description	FN is completely protected, with no observable gaps or discontinuity in the bony canal	Thinning of the bony canal, involving less than half the canal's width	Thinning of the bony canal, involving more than half the canal's width	A segment or the complete length of the bony canal is absent; FN is either protruded or covered only by its sheath

The fifth stage: measurement and analysis

Measurements were performed using the image-processing program IMAGEJ (US National Institutes of Health, Bethesda, MD, USA), which enables the accurate measurement of computerized images following predetermined calibration. The FN's TS was identified manually by referring to the aforementioned landmarks and the FN canal's length; any bony canal dehiscence was then measured and graded based on the aforementioned four-stage criteria (Table 2), and its location was identified based on the segments described in Table 1.

Statistical analysis

Data were analysed using the MedCalc statistical software (version 18.6). Frequency distribution was presented in numbers and percentages for categorical variables, while continuous variables were described by the mean and standard deviation. The Chi-square test was applied to determine whether or not a relationship existed between categorical variables, and a p-value < 0.05 was considered statistically significant.

Validation of measurements and analysis

Measurements were validated by measuring the overall length of the FN's horizontal segment and the lengths of dehiscence (based on location) ten times each. The mean of each repetition was reported in the results chapter as the measurement of choice.

RESULTS

Laboratory results

The mean age of the specimens was 78 years (range: 46-93 years). The temporal bones were bilateral in the majority of both the fresh-frozen and normally embalmed groups, with the exception of two unilateral specimens in both groups (Table 3.1).

The length of any dehiscence (mm) was measured and the minimum, maximum, and mean lengths determined. Dehiscences occurring in the cochleiform process and geniculate ganglion area had a mean length of 3.10 mm (range: 2.0-5.8 mm). The mean dehiscence length in the oval window and TS area was 2.15 mm (range: 1.2-2.8 mm), and the pyramidal process and second genu area presented a mean dehiscence length of 2.7 mm (range: 1.1-4.6 mm) (Table 3.2).

The incidence of FND was measured based on its location within the horizontal segment. The incidence of dehiscence in the cochleiform process and geniculate ganglion, oval window and TS, and pyramidal process and second genu areas were 27.2%, 36.3%, and 36.3%, respectively (Table 3.3).

The overall dehiscence rate was 41% across nine cadavers, of which 23% (n = 3) were fresh-frozen and 66% (n = 6) embalmed specimens (Table 3.4).

Table 3.1. Demographics

	Sample size	Fresh-frozen	Embalmed	Side (left/right)	Mean age
Male	12	6	6	L:6/R:6	80.5
Female	10	7	3	L:4/R:6	75.1
Total	22	13	9	L:10/R:12	78

Table 3.2. Measurements of dehiscence lengths (mm) in the sites of the FN horizontal segment

Measurements	C.P. & G.G.	Oval window & tympanic segment	P.P. & 2nd genu
Mean	3.10	2.15	2.75
Maximum	5.84	2.89	4.63
Minimum	2.01	1.153	1.14

C.P.: cochleiform process; G.G.: geniculate ganglion; P.P.: pyramidal process

Table 3.3. Incidence of FND in total sample size (n = 22)

Location	No.	%	Total non-dehisced N (%)
C.P. & G.G.	6	27.27%	16 (72.72%)
Oval window & tympanic segment	8	36.36%	14 (63.63%)
P.P. & 2nd genu	8	36.36%S	14 (63.63%)

C.P.: cochleiform process; G.G.: geniculate ganglion; P.P.: pyramidal process

Incidence of dehiscence based on sex

When stratified by sex, FND was found in two of ten (20%) female specimens in the cochleiform process and geniculate ganglion area only, as well as in four of ten (40%) female specimens in the other two areas (i.e., oval window and TS as well as the pyramidal process and second genu areas). The rate of FN dehiscence in male temporal bones was 33.33% (n = 4) in all areas of the FN's horizontal segment (Table 3.5).

Incidence of dehiscence based on grade and location

Among all samples with dehiscence in the cochleiform process and geniculate ganglion area, two (9%) FN canals were graded as 'exposed' in that the FN appeared fully exposed. In the same area, two specimens (9%) were graded as 'major partial dehiscence' and two others (9%) as 'minor partial dehiscence'. Dehiscence found in the oval window and TS area was graded as 'exposed' in three (13.6%) specimens, as 'major partial dehiscence' in one (4.5%), and as 'minor partial dehiscence' in four (18%).

Among the FNs with total dehiscence in the pyramidal process and second genu area, three (13.6%) were graded as 'exposed', two (9%) as 'major partial dehiscence', and three (13.6%) as 'minor partial dehiscence' (Table 3.6).

Incidence based on specimen side

The overall incidence of FND in the right-sided temporal bones in the cochleiform process and geniculate ganglion area was five (22.6%), six (27.2%) in the oval window and TS area, and five (22.7%) in the pyramidal process and second genu area.

The left-sided temporal bones presented a dehiscence rate of merely one (4.5%) in the cochleiform process and geniculate ganglion area, a rate of three (9%) in the oval window and horizontal segment area, and a rate of three (13.6%) in the pyramidal process and second genu area (Table 3.7).

Table 3.4. Measurements of dehiscence lengths (mm) in the sites of the FN horizontal segment

Type	Overall dehiscence	Dehiscence in multiple areas	Non-dehisced	Total dehiscence
Fresh-frozen	3/13 (23%)	3/13 (23%)	3 (23%)	9/22 (41%)
Embalmed	6/9 (66%)	4/9 (44.4%)	6 (66%)	

Table 3.5. Incidence of FND in total sample, based on sex

Location	Male No. Total (%)	Female No. Total (%)	Total No. Overall sample (%)
C.P. & G.G.	2/10 (20%)	4/12 (33.33%)	6/22 (27.27%)
Oval window & tympanic segment	4/10 (40%)	4/12 (33.33%)	8/22 (36.36%)
P.P. & 2nd genu	4/10 (40%)	4/12 (33.33%)	8/22 (36.36%)

C.P.: cochleiform process; G.G.: geniculate ganglion; P.P.: pyramidal process; Chi-square test results of the incidence of FND between males and females: P = 0.87; Appendix, Table 2

Table 3.6. Incidence and percentage of dehiscence based on grade and location

	Location		
Grade	C.P. & G.G. N (%)	Oval window & tympanic segment N (%)	P.P. & 2nd genu N (%)
Exposed	2 (9%)	3 (13.6%)	3 (13.6%)
Major partial dehiscence	2 (9%)	1 (4.5%)	2 (9%)
Minor partial dehiscence	2 (9%)	4 (18%)	3 (13.6%)

C.P.: cochleiform process; G.G.: geniculate ganglion; P.P.: pyramidal process

Table 3.7. Incidence of dehiscence based on specimen side and location

Side	Location				
	C.P. & G.G. N (%)	Oval window & tympanic	P.P. & 2nd Genu	Non-dehisced N (%)	Total N (%)
Left ear	1 (4.5%)	2 (9%)	3 (13.6%)	7 (31.8%)	10 (45.4%)
Right ear	5 (22.7%)	6 (27.2%)	5 (22.7%)	6 (27.2%)	12 (54.5%)

C.P.: cochleiform process; G.G.: geniculate ganglion; P.P.: pyramidal process; Chi-square test results of the incidence of FND between the left and right-side: P = 0.353; Appendix, Table 1

Table 3.8. Incidence of dehiscence based on type of specimen preservation method

Type	No. of non-dehisced specimens	No. of dehisced specimens	Total
Fresh-frozen	10 (76.9%)	3 (23%)	13 (59%)
Embalmed	3 (33.3%)	6 (66%)	9 (43%)

Dehiscence was demonstrated by three of the thirteen (23%) dissected fresh-frozen temporal bones and six of the nine (66%) dissected embalmed specimens (Table 3.8).

DISCUSSION

No previous dissection-based investigations in the literature clearly describe the method by which a complete view of the course of the FN's TS is achieved. In addition, other dissection-based methods have been limited to surgical techniques that provide neither a clear lateral view of the full course of the FN nor an angle that enables accurate measurement of its length, such as in mastoidectomy procedure (Beddard and Saunders, 1962; Kharat et al., 2009). Kharat et al. (2009) exposed the FN through a simple mastoidectomy procedure and then took measurements with malleable steel wire, although this technique did not provide a complete lateral view of the FN's TS and is prone to inaccuracy. Beddard and Saunders (1962) briefly mention their dissection method by referring to the tools utilized rather than the process by which the dissection was performed (Table 4). Variation in FND has become well-established in the literature since it was first reported by Adam et al. (1894). Possible etiology of canal dehiscence can be related to disease that involves inflammatory and destructive pathologies, such as chronic otitis media— with or without cholesteatoma—or may be due to non-pathological factors, such as surgically induced trauma. Kaplan (1960) reports that heredity, a persistent stapedial artery, and the inhibition of canal wall formation can play a role in FND. Further study of the various factors and etiologies of facial canal dehiscence is essential for understanding the incidence and location in which the FN is most vulnerable in order to avoid post-operative FN injury.

Non-pathologic etiologies

In a histological study of 1,000 temporal bones conducted by Moreano et al. (1994), facial canal dehiscence was identified in 56% (n = 560), wherein merely five cases had a persistent stapedial artery—all of which were associated with canal dehiscence in the oval window area. The authors further reported that, although the number of occurrences was small compared to the sample size, the data supported that this remnant vessel may be an etiological factor in canal dehiscence. Heredity, on the other hand, has been implicated in bilateral facial canal dehiscence (Guild, 1949).

The canal wall formation process is a well-studied factor that can affect dehiscence of the FN canal. Spector and Ge (1993) report that the (in-utero) ossification process of the TS of the FN starts from two ossification centres: anterior at 24 weeks and posterior at 26 weeks of gestation. The oval window region represents the fusion area of the two ossification centres; therefore, all incidences of dehiscence in this area are possibly secondary to the failure of the ossification process. Nevertheless, Declau et al. (1991), who investigated the role of intra- membranous ossification in the facial canal's formation at different sites of the TS, suggested that the inner and outer connective tissues are responsible for the location and time sequence of the ossification process, and that the distribution of epithelial–mesenchymal tissue interaction can explain the presence and location of dehiscence. Interestingly, these results correspond with the high incidence of dehiscence reported at the oval window and geniculate ganglion area (Moreano et al., 1994).

Table 4. Incidence of dehiscence of the facial nerve canal in gross dissection studies

Reference	Approximate % of overall dehiscence (tympanic & mastoid)	Approximate % of G.G., TS & 2nd G dehiscence	Gender distribution (male:female)	Sample size	Method of investigation
(Kharat, Golhar and Patil, 2009)	12% (n = 3)	12% (n = 3)	NR	(n = 25)	Gross dissection (embalmed)
(Beddard and Saunders, 1962)	25% (n = 14)	25% (n = 14)	NR	(n = 52)	Gross dissection (fresh-frozen)
(Mollica, 1962)	25% (n = 16)	NR	NR	(n = 64)	Gross dissection

G: genu; G.G.: geniculate ganglion; NR: not reported

This table illustrates the incidences of (1) overall dehiscence of the fallopian canal (tympanic and mastoid segments) and (2) the horizontal segment represented by the G.G., TS, and second genu. The literature was grouped according to the investigation method and then sub-grouped based on whether or not the included samples were associated with a pathology—specifically, an inflammatory or degenerative disease.

Pathological etiologies

Pathological factors can play a major role either in exacerbating existing canal dehiscence or in causing facial canal dehiscence to occur. In the following sections, these disease pathologies will be discussed in terms of the disease's relation to bony resorption, as well as how the disease's progression pattern (e.g., cholesteatoma) can affect or exacerbate the effects of the disease, the coexistence of pathologies, and other early dehiscence indicators.

The presence of bony resorption pathologies

Based on FND detected intraoperatively in surgery for cholesteatoma and chronic otitis media, the incidence of dehiscence has been reported to be between 6% and 33.3% for otitis media (Selesnick and Lynn-Macrae, 2001; Bayazit et al., 2002), and 17% as a result of exposure secondary to cholesteatoma (n = 1024) (Sheehy et al., 2014). For both cholesteatoma and otitis media, Choi et al. (2014) reported an incidence of 38.6% (n = 82) among a total sample of 212.

Most incidences of facial canal dehiscence reported during the surgical for cholesteatoma are located in the oval window area (Selesnick and Lynn-Macrae, 2001; Lin et al., 2004). This finding validates the current understanding of the growth patterns of cholesteatomas located near the FN's TS, in which case the TS's invasion is likely to occur early on in the disease process (Bayazit et al., 2002; Lin et al., 2004). This additionally includes thinning that might be present at the oval window area, due to problems with development, increasing the TS's vulnerability (Spector and Ge, 1993).

Coexisting pathologies and early dehiscence indicators

FND during cholesteatoma and chronic otitis media are usually associated with other coexisting incidences of dehiscence in the tympanic cavity, which can be utilized as early TS dehiscence indicators. In a surgical observation study, Bayazit et al. (2002) reported that the most common pathology to coexist with facial canal dehiscence was a labyrinthine fistula. Genc et al. (2014) reported that the rates of scutum defect (a lateral epitympanic wall) were 29.22% (45/154). In the same study, facial canal dehiscence was present in 55.55% of the patients with and 8.25% of patients without a scutum defect. A scutum defect is a significant finding for predicting the extent of the existing pathology and the potentially associated facial canal dehiscence. A further risk indicator that increases the risk of facial canal dehiscence in cholesteatoma cases by about 4.7 times is the presence of a semi-circular canal fistula. Preoperative imaging and the identification of a fistula should alert the surgeon of possible FND (Magliulo et al., 2011).

Iatrogenic trauma

The risk for iatrogenic facial paralysis is reported to range from 0.6% to 3.6%, and in primary and revision mastoid surgery, the frequency of FN injury is 4% to 10% (Wiet, 1982; Schuring, 1988). In a review of 22 patients who had sustained an iatrogenic FN injury, the procedures most commonly associated with this injury included mastoidectomy (55%), tympanoplasty (14%), and exostoses removal (14%), with the TS being the most common area of injury. Surprisingly, in 79% of patients, FN injury was not detected at the time of injury (Green et al., 1994).

Length and location of the TS of the FN

Nikolaidis et al. (2009) reported that the average length of the TS of the FN was 10.97 mm when the TS is divided into a proximal segment (geniculate ganglion to the posterior edge of the cochleiform process) and a distal segment (posterior edge of the cochleiform process to the tympanic cavity's posterior wall, at the level of the pyramidal eminence). The proximal and distal segment's average lengths were reported to be 5.25 mm and 5.72 mm, respectively. According to our measurements, the TS's mean length is 11.46 mm (range: 9.04-16.13 mm), which is 0.49 mm greater than that previously published by (Nikolaidis et al., 2009).

Incidence of FND

In this study, dehiscence was identified in 9 of the 22 (41%) temporal bones dissected. The incidence in our study is higher than that reached in other gross dissection studies, such as those of Beddard and Saunders (1962) - which indicates a 25% incidence of dehiscence (14/52) - and Kharat et al., 2009), which reports an incidence of 12% (3/25).

Although we have recorded cases in which the FN was exposed, no nerve bulging was observed. According to (Beddard and Saunders, 1962), the absence of an exposed FN's bulging beyond the limits of the bony canal is likely due to the cadaver's post-mortem state; in living patients, this outward bulging is common. The length of the dehiscence found above the oval window ranged from 1.15-2.89 mm, which is similar to the results of (beddard and Saunders, 1962), who report that the smallest defects recorded above the oval window are about 2 mm long.

Additionally, in this study, the incidence of FND based on sex was 22.7% in males and 18.1% in females, although this difference was not statistically significant (P = 0.87). Our results are in accordance with those of Lin et al. (2004), who reported a 34% incidence in a male group and 32.8% in a female group. According to Moody and Lambert (2007), dehiscence is more common in extreme age, which might be attributable to bone resorption pathology in older age and incomplete ossification in the neonatal period. This may explain the higher incidence found in our study, wherein the majority of individuals (14/22) were

older than seventy years of age at death.

In terms of the dehiscence incidence between sides, we found an incidence of 27.2% on the right side and 13.6% on the left; the difference was not statistically significant (P = 0.35). Moreano et al. (1994) report a 76.3% incidence of bilateral facial canal dehiscence, which was considered the rule rather than the exception. Our results contradict this finding, as we found only one case of bilateral FND. These results suggest that factors associated with randomized sampling (e.g., age and gender) do not clearly explain the cause of the large variability of incidences reported.

The data extracted from our sample size was sufficient for obtaining statistical relationships; however, the sample size was a limitation when age and ethnicity were compared because the majority of our sample population were of Caucasian origin older than 70 years of age. This indicates a study limitation in obtaining statistical comparisons between our findings and that of other similar studies. Limited information regarding the cadavers' medical histories was also factor that might have played a role in the degree of dehiscence detected if the specimens had been collected from an individual who had previous ear pathology, such as cholesteatoma. However, evidence of this was not detected during the dissection of any of the temporal bones. The dissection approach was limited in accessing the FN's mastoid segment because its course completely embeds it into the mastoid bone.

CONCLUSION

Anatomical laboratories lack prosected human teaching specimens that clearly illustrate the middle ear anatomy. Previous dissection-based research investigating FND provides minimal guidance on how this was achieved. Our gross dissection results have utilized both a newly-developed approach for middle ear exposure, as well as the IMAGEJ program for taking TS measurements. The importance of this research may lie in the provision of a systemic methodology that can be employed in future anatomical research, as well as the provision of dissection technique that aids in producing teaching material for the middle ear in the form of anatomical specimens. The incidence of FND was 41% (9/22 specimens) and, among all methods of investigation examined, the gross anatomy dissection method suggests superiority in yielding surgically relevant data.

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APPENDIX

Chi-Square Test Results

Chi-Square Test Table 6.1

Classification X	Side
Classification Y	Presence of Total Dehiscence

	Side		
Presence_of_total_Deh	L	R	
0	7	6	13 (59.1%)
1	3	6	9 (40.9%)
	10 (45.5%)	12 (54.5%)	22

Chi-squared test

Chi-squared	0.862
DF	1
Significance level	P = 0.3533
Contingency coefficient	0.194

Chi-Square Test Table 6.2

Classification X	Sex
Classification Y	Presence of Total Dehiscence

	Sex		
Presence_of_Deh	F	M	
0	8	7	15 (68.2%)
1	4	3	7 (31.8%)
	12 (54.5%)	10 (45.5%)	22

Chi-squared test

Chi-squared	0.027
DF	1
Significance level	P = 0.8703
Contingency coefficient	0.035

Chi-Square Test Table 6.3

Classification X	Sex_1
Classification Y	Presence of Dehiscence in C.P and G.G_

	Sex_1		
Presence_in_C.P_and_G.G	F	M	
0	8	8	16 (72.7%)
1	4	2	6 (27.3%)
	12 (54.5%)	10 (45.5%)	22

Chi-squared test

Chi-squared	0.467
DF	1
Significance level	P = 0.4945
Contingency coefficient	0.144

Chi-Square Test Table 6.4

Classification X	Side_1
Classification Y	Presence of Dehiscence in C.P and G.G_

	Side_1		
Presence_in_C.P_and_G.G	L	R	
0	9	7	16 (72.7%)
1	1	5	6 (27.3%)
	10 (45.5%)	12 (54.5%)	22

Chi-squared test

Chi-squared	2.632
DF	1
Significance level	P = 0.1047
Contingency coefficient	0.327

Chi-Square Test Table 6.5

Classification X	Gender_2
Classification Y	Presence of Dehiscence in area of Oval window

	Gender_2		
Presence_in_Oval_window	L	R	
0	8	6	14 (63,6%)
1	4	4	8 (36,4%)
	12 (54,5%)	10 (45,5%)	22

Chi-squared test

Chi-squared	0.100
DF	1
Significance level	P = 0.7518
Contingency coefficient	0.067

Chi-Square Test Table 6.6

Classification X	Side_2
Classification Y	Presence of Dehiscence in area of Oval window

	Side_2		
Presence_in_Oval_window_1	L	R	
0	8	6	14 (63.6%)
1	2	6	8 (36.4%)
	10 (45.5%)	12 (54.5%)	22

Chi-squared test

Chi-squared	2.025
DF	1
Significance level	P = 0.1547
Contingency coefficient	0.290

Chi-Square Test Table 6.7

Classification X	Sex_3
Classification Y	Presence of Dehiscence in area of _P.P and 2nd_Genu

	Gender_3		
Presence_in_P.P_and_2nd_Genu	F	M	
0	8	6	14 (63.6%)
1	4	4	8 (36.4%)
	12 (54.5%)	10 (45.5%)	22

Chi-squared test

Chi-squared	0.100
DF	1
Significance level	P = 0.7518
Contingency coefficient	0.067

Chi-Square Test Table 6.8

Classification X	Side_3
Classification Y	Presence of Dehiscence in area of _P.P and 2nd_Genu

	Side_3		
Presence_in_P.P_and_2nd_Genu_1	L	R	
0	7	7	14 (63.6%)
1	3	5	8 (36.4%)
	10 (45.5%)	12 (54.5%)	22

Chi-squared test

Chi-squared	0.306
DF	1
Significance level	P = 0.5800
Contingency coefficient	0.117

Table 6.9. Summary of data collected from overall (n = 22) specimens dissected

Specimen number/ Fresh-frozen	Side	Sex	Ag e	Average Total Length (mm)	Horizontal segment of facial nerve				
					C.P & G.G (mm)	Oval window & tympanic segment (mm)	P.P & 2nd Genu (mm)	Total De-hiscence (mm)	% Dehiscence
1.	R	F	81	11.898	3.571 (Major)	2.893 (Minor)	3.104 (Major)	9.568	80.42%
2.	R	F	70	11.93	0	0	0	0	0.00%
3.	L	F	70	10.522	0	0	0	0	0.00%
4.	L	M	93	11.483	0	0	0	0	0.00%
5.	R	M	93	16.132	5.845 (Exposed)	1.687 (Exposed)	4.635 (Exposed)	12.167	75.42%
6.	L	F	89	11.08	2.54 (Exposed)	2.468 (Exposed)	3.679 (Exposed)	8.687	78.40%
7.	R	F	89	13.808	0	0	0	0	0.00%
8.	R	M	86	12.729	0	0	0	0	0.00%
9.	L	M	86	9.041	0	0	0	0	0.00%
10.	R	F	92	10.875	0	0	0	0	0.00%
11.	L	F	92	11.544	0	0	0	0	0.00%
12.	R	M	92	10.911	0	0	0	0	0.00%
13.	L	M	92	11.529	0	0	0	0	0.00%
Specimen number/Embalmed									
14.	R	M	53	9.28	0	2.066 (Exposed)	0	2.066	22.26%
15.	L	M	53	10.426	0	0	0	0	0.00%
16.	R	F	76	13.211	2.014 (Minor)	2.576 (Minor)	1.149 (Minor)	5.739	43.44%
17.	R	F	46	10.774	2.097 (Minor)	2.589 (Minor)	1.495 (Minor)	6.181	57.37%
18.	L	F	46	9.49	0	0	0	0	0.00%
19.	R	M	68	10.808	0	0	0	0	0.00%
20.	L	M	68	10.933	0	0	3.647 (Exposed)	3.647	33.36%
21.	R	M	91	11.084	2.583 (Major)	1.153 (Major)	2.749 (Major)	6.485	58.51%
22.	L	M	91	12.687	0	1.782 (Minor)	1.604 (Minor)	3.386	26.69%

Cochleiform process (C.P), Geniculate ganglion (G.G), pyramidal process (P.P)