VIA MEDICA

ORIGINAL ARTICLE

Folia Morphol.
Vol. 80, No. 1, pp. 97–105
DOI: 10.5603/FM.a2020.0019

ISSN 0015–5659
eISSN 1644–3284
journals.viamedica.pl

Variations in the morphology of stylomastoid foramen: a possible solution to the conundrum of unexplained cases of Bell's palsy

S.K. Ghosh, R.K. Narayan

Department of Anatomy, All India Institute of Medical Sciences, Phulwarisharif, Patna, Bihar, India

[Received: 12 January 2020; Accepted: 2 February 2020]

Background: Stylomastoid foramen is the terminal part of facial canal and is the exit gateway for facial nerve from skull base. We hypothesized that anatomical variations of this foramen could be a risk factor for the injury of facial nerve resulting in unilateral facial nerve paralysis or Bell's palsy. Hence the present study was conducted to study the variations in size and shape of stylomastoid foramen in dry adult human skulls.

Materials and methods: The study was conducted on 37 dry adult human skulls of unknown age and sex. High resolution images of the skulls under study were processed by ImageJ software and observations were undertaken.

Results: Total eight variations of stylomastoid foramen were observed in terms of shape. The common variants were round, oval and square (present in 83.79% skulls on right side and 81.07% skulls on left side), whereas the rare variants were triangular, rectangular, serrated, bean-shaped and irregular. It was noted that stylomastoid foramen were associated with extensions (45.95% skulls) and also adjacent foramen (18.92% skulls). Exclusively unilateral observations included bifurcation of foramen (16.22% skulls), foramen situated deep inside skull groove (5.41% skulls) and foramen interrupted by bony spur (2.7% skulls). No significant differences were observed between the mean diameters (antero-posterior and transverse) of the stylomastoid foramen.

Conclusions: The unilateral variations along with rare variations in terms of shape such as serrated, bean-shaped and irregular foramen (which were also unilateral findings) could be potential risk factors towards injury of facial nerve at the point of exit from skull base leading to Bell's palsy. (Folia Morphol 2021; 80, 1: 97–105)

Key words: stylomastoid foramen, variations, risk factor, injury, facial nerve, Bell's palsy

INTRODUCTION

The facial nerve or the VIIth cranial nerve leaves the cranial cavity by travelling through a Z-shaped bony canal known as the facial or Fallopian canal. The facial nerve lies in the tympanic cavity within the facial canal and leaves the skull via stylomastoid foramen [5]. The stylomastoid foramen is the termination of facial canal and is a curved aperture located in the middle of the base of styloid and the mastoid process of the temporal bone, on the inferior aspect of the petrous temporal bone. The foramen along with the facial nerve also transmits the stylomastoid artery, a branch of posterior auricular artery [19]. The facial canal is approximately 3 cm long and is divided into three

Address for correspondence: Dr. S.K. Ghosh, Department of Anatomy, 3rd Floor, Academic Building, All India Institute of Medical Sciences, Phulwarisharif, Patna, Bihar-801507, India, tel: +91-8867502575, +91-8017541980, fax: +91-11-4157-1111, e-mail: drsanjib79@gmail.com

parts, labyrinthine, tympanic and mastoid. Available literature suggests anatomical difference between the luminal size of facial canal along its entire length and diameter of facial nerve, which predisposes nerve to compression in varied conditions leading to neuritis and clinically presenting as ipsilateral facial palsy called as Bell's palsy [1, 12, 22].

Unilateral facial nerve paralysis is most commonly (70%) caused by Bell's palsy. It is an acute onset of temporary weakness in facial muscles, which mostly occurs due to swelling or inflammation of ipsilateral facial or VIIth cranial nerve [4, 6]. For centuries, the acute onset, temporary, unilateral facial palsy was considered idiopathic and hence the diagnosis was that of exclusion of the known aetiologies. However, in recent literature it has been hypothesised that the inflammatory response to infection (commonly to herpes simples virus type I) induces oedema of the facial nerve. Consequently the nerve being entrapped in the un-yielding, tortuous bony facial canal becomes ischaemic due to the increment of the endoneural pressure and compression of the neural vasculature. Hence, the swelling evidently leads to axonal degeneration and cessation of nerve conduction [7, 10, 25].

The compression of an inflamed facial nerve has previously been explained on the basis of irregularity between the lumen size of the un-yielding facial canal and the neve width [3, 13]. However, the sporadic reports on the variation of size and shape of the stylomastoid foramen [17, 18], which can also have clinical implications in unexplained cases of facial nerve palsy, have never been discussed with regards to compression of the nerve. Hence the present study was conducted with an objective to study the variations in size and shape of the stylomastoid foramen in dry adult human skulls.

MATERIALS AND METHODS

The study was conducted in the Department of Anatomy at All India Institute of Medical Sciences, Patna, India. Prior to the onset of the study, we obtained ethical approval from the Ethics Committee of the above mentioned institution. The study was conducted on 37 dry human skulls of unknown age and sex and all the bones were procured from the bone bank of the Department of Anatomy. It was ensured that all selected skulls were without any evident deformity or sign of injury.

At the onset high resolution digital images (horizontal and vertical resolutions: 300 dpi) of the of the norma basalis of human skulls under study were taken along with a 15 cm ruler (Faber-Castell's grip ruler) with the help of Canon EOS 1300D 18MP digital single-lens reflex camera (utilising 18–55 mm lens). While taking the images of the skulls, uniformity was ensured with respect to sharpness, noise, dynamic exposure (exposure range), tone reproduction, contrast and colour accuracy of the images. Moreover it was ensured that for every image the distance between the skull and the lens of the camera remained uniform. Prior to undertaking the images the skulls were kept on a flat surface and stabilised appropriately. The images were then uploaded to an image processing software, ImageJ (1.52p version, 2019), for measurements. The images were converted with the help of the software to 8-bit colour and grayscale for proper analysis, the scale for measurement was set with the help of the grip ruler in the image and the values obtained were tabulated. All measurements were undertaken by two observers to reduce chances of error. Each measurement was taken twice by one observer and the final data were obtained as an average of the 4 measurements undertaken by the 2 observers. Finally mean and standard deviation was computed when data from all the skulls under study were available. Foramen's dimension was taken in two planes, maximum medio-lateral or transverse dimension and maximum antero-posterior dimension for both the right and left sides.

Ethical clearance

The authors hereby declare that the study was conducted only after approval had been obtained from the Ethical Committee of All India Institute of Medical Sciences, Patna whose guidelines are in accordance with the Declaration of Helsinki (1964) and all subsequent revisions.

Statistical analysis

Data was analysed using SPSS version 20.0 for Windows (SPSS Inc., Chicago, IL, USA). Paired t test was used to compare the left and right sides with the t value and $p < 0.05$ considered significant. Quantitative data are represented as mean ± standard deviation (SD) in the manuscript.

RESULTS

We observed a total of eight types of variations with respect to the shape of the stylomastoid foramen in the human skulls included in the present study (Figs. 1–3). The most common variant observed was the round

Figure 1. The common variants of stylomastoid foramen in terms of shape; **A.** Round stylomastoid foramen; **B.** Square stylomastoid foramen; **C.** Oval stylomastoid foramen. All the variants of foramen are shown as arrow marked area in the figures.

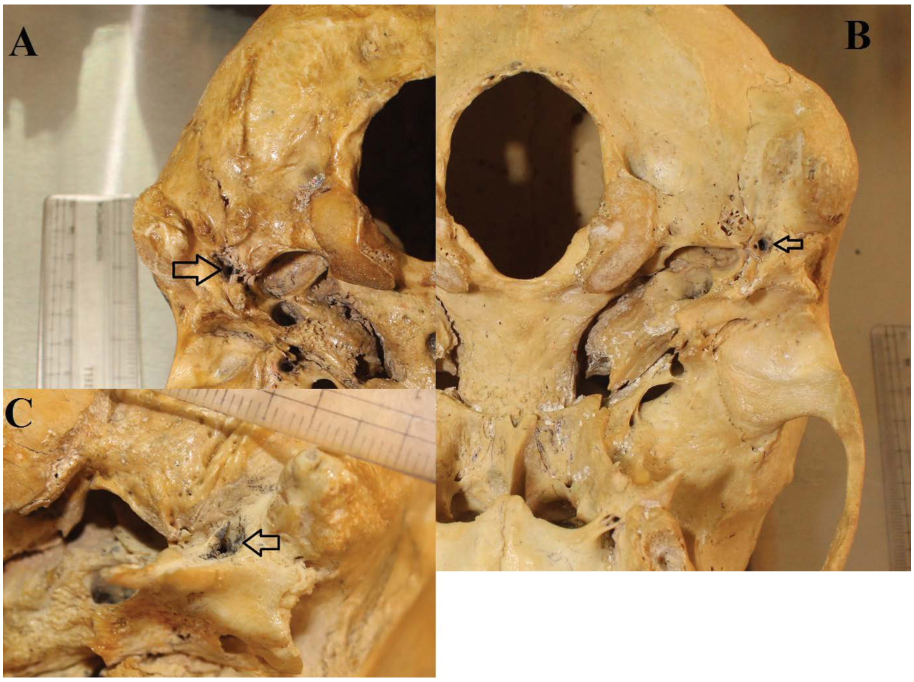

Figure 2. The uncommon variants of stylomastoid foramen in terms of shape; **A.** Triangular stylomastoid foramen; **B.** Rectangular stylomastoid foramen; **C.** Irregular stylomastoid foramen. All the variants of foramen are shown as arrow marked area in the figures.

shaped foramen which was noted in 20 (54.05%) skulls on left side and in 17 (45.95%) skulls on right side, respectively. Oval shaped foramen was the next common variant on the left side and was observed in 9 (24.32%) skulls. However, on the right side, square shaped foramen was the next common variant and was observed in 8 (21.62%) skulls, with oval shaped foramen noted in 6 (16.22%) skulls under study (Tables 1, 2).

In 17 (45.95%) skulls under study, the stylomastoid foramen along with its original shape had an extension (Fig. 4). Extension of the foramen was observed bilaterally in 5 (13.51%) skulls. Overall extension of the foramen was observed in 22 cases (bilateral in 5 skulls and unilateral in 12 skulls). Among the eight variations of shape of the stylomastoid foramen reported in the present study, only oval foramen (15/22; 68.18%) and round foramen (7/22; 31.82%) were associated with extensions. It was noted that oval foramen was usually associated with antero-posterior extensions (13/15; 86.67%) and round foramen

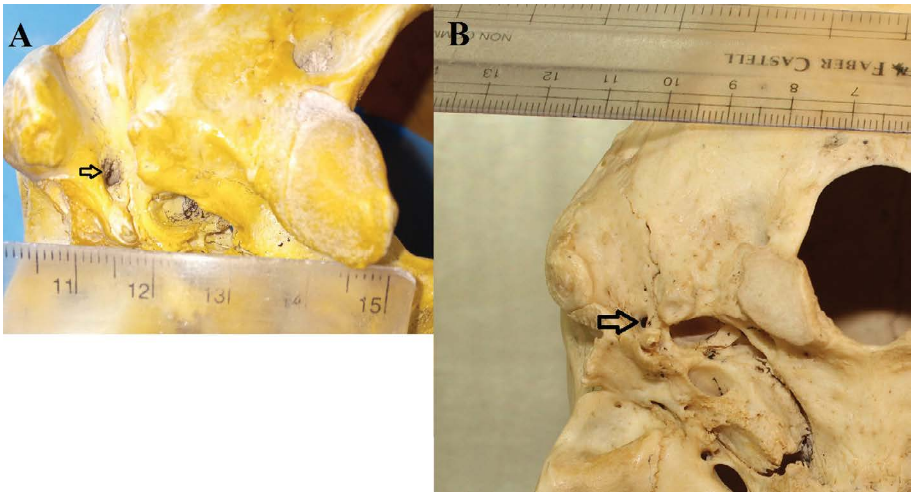

Figure 3. The uncommon variants of stylomastoid foramen in terms of shape; **A.** Serrated stylomastoid foramen; **B.** Bean-shaped stylomastoid foramen. Both the variants of foramen are shown as arrow marked area in the figures.

Table 1. Details of the shape of stylomastoid foramen and associated findings in the human skulls under study

Identification no. of skull	Location of foramen (side of skull)	Shape of foramen	Extensions when present (with direction)	Adjacent foramen when present (with direction)
1	Left	Oval	Antero-posterior	—
	Right	Oval	Antero-posterior	—
2	Left	Round	—	Anterior
	Right	Round	—	—
3	Left	Square	—	—
	Right	Round	Medial	—
4	Left	Round	Anterior	—
	Right	Round	Medial	—
5	Left	Round	—	—
	Right	Round	—	Anterior
6	Left	Round	—	—
	Right	Round	—	Anterior
7	Left	Round	—	—
	Right	Triangular	—	—
8	Left	Round	—	—
	Right	Square	—	—
9	Left	Round	Antero-medial	—
	Right	Serrated	—	—
10	Left	Round	—	—
	Right	Square	—	—
11	Left	Round	—	Anterior
	Right	Irregular (d/t bony spur projecting from posterior aspect of styloid process)	—	—
12	Left	Oval (bifurcated)	Antero-posterior	—
	Right	Round	—	—
13	Left	Round (situated deep inside the tympano-jugular groove)	—	—
	Right	Round (situated deep inside the tympano-jugular groove)	—	—
14	Left	Oval	Antero-posterior	—
	Right	Round	—	—

→

Table 1. (cont.) Details of the shape of stylomastoid foramen and associated findings in the human skulls under study

Identification no. of skull	Location of foramen (side of skull)	Shape of foramen	Extensions when present (with direction)	Adjacent foramen when present (with direction)
15	Left	Round	Lateral	—
	Right	Round	Medial	—
16	Left	Round	—	—
	Right	Square	—	—
17	Left	Oval	Antero-posterior	—
	Right	Square	—	—
18	Left	Round	—	—
	Right	Square	—	—
19	Left	Oval	Antero-posterior	—
	Right	Square	—	—
20	Left	Triangular	—	—
	Right	Rectangular	—	—
21	Left	Round	—	—
	Right	Oval	Medio-lateral	—
22	Left	Round	—	Medial
	Right	Round	—	—
23	Left	Serrated	—	—
	Right	Square (bifurcated)	—	—
24	Left	Bean-shaped	—	—
	Right	Round	Medial	—
25	Left	Round	—	—
	Right	Round	—	—
26	Left	Triangular (bifurcated)	—	—
	Right	Round	—	—
27	Left	Serrated	—	—
	Right	Oval	Antero-posterior	—
28	Left	Round	—	—
	Right	Round	—	—
29	Left	Round	—	—
	Right	Rectangular	—	Medial
30	Left	Rectangular	—	—
	Right	Triangular (bifurcated)	—	—
31	Left	Round	—	—
	Right	Round	—	Lateral
32	Left	Round	—	—
	Right	Round	—	—
33	Left	Oval	Antero-posterior	—
	Right	Oval	Medio-lateral	—
34	Left	Rectangular (bifurcated)	—	—
	Right	Oval (bifurcated)	Antero-posterior	—
35	Left	Oval	Antero-posterior	—
	Right	Square	—	—
36	Left	Oval	Antero-posterior	—
	Right	Round	—	—
37	Left	Oval	Antero-posterior	—
	Right	Oval	Antero-posterior	—

Table 2. Variations in the shape of stylomastoid foramen as observed in the present study

Serial number	Shape of foramen	Location on the skull (side)	
		Right	Left
1	Round	17 (45.95%)	20 (54.05%)
2	Oval	6 (16.22%)	9 (24.32%)
3	Square	8 (21.62%)	1 (2.7%)
4	Triangular	2 (5.41%)	2 (5.41%)
5	Rectangular	2 (5.41%)	2 (5.41%)
6	Serrated	1 (2.7%)	2 (5.41%)
7	Bean-shaped	0 (0%)	1 (2.7%)
8	Irregular	1 (2.7%)	0 (0%)

were usually associated with medial extensions (4/7; 57.14%). It was also observed that in case of oval foramen, extensions were more common on the left side (9/15; 60%); however, for round foramen extensions were more on the right side (4/7; 57.14%). Bilateral occurrence of extensions were more common in case of oval shaped foramen (3/5; 60%) (Tables 1, 3).

It was noted that the stylomastoid foramen was associated with an adjacent foramen in 7 skulls (7/37; 18.92%) under study (Fig. 4). The adjacent foramen, when present was always found unilaterally and in most cases (4/7; 57.14%) it was located anterior to the actual foramen. Moreover it was observed on the right side in 4 skulls (4/7; 57.14%) and on the left side in 3 skulls (3/7; 42.86%), respectively (Table 1). Notably it was observed in 6 skulls (6/37; 16.22%) under study that the stylomastoid foramen was bifurcated (Fig. 5). Foramen with bifurcation was found in four variants of stylomastoid foramen in terms of shape (oval, triangular, rectangular and square) and was always a unilateral occurrence. It was also observed that in 2 skulls (2/37; 5.41%) the foramen (round in shape) was situated deep inside the tympano-jugular groove (Fig. 5). In one of the skulls under study, the stylomastoid foramen was partially obstructed by the presence of a bony spur projecting from posterior aspect of styloid process (Fig. 5, Table 1).

Measurements of dimensions of the stylomastoid foramen revealed that the mean antero-posterior diameter were more than the mean transverse diameter on both sides of the skull; however, the difference was not statistically significant. Moreover mean values of both the diameters (antero-posterior and transverse) were more on the left side of the skull; however, the difference was again not statistically significant (Table 4).

Figure 4. Additional morphological features of stylomastoid foramen; **A.** Round stylomastoid foramen showing medial extension; **B.** Round stylomastoid foramen with adjacent foramen on medial side. Both the features are shown as arrow marked area in the figures.

Table 3. Distribution of extensions of stylomastoid foramen as observed in the skulls under study

No. of skulls where extension observed	Distribution in the skulls			Distribution according to shape of foramen			
17	Bilateral	Unilateral		Oval		Round	
				15		7	
	5	12		Right side	Left side	Right side	Left side
		Right side	Left side	6	9	4	3
		5	7				

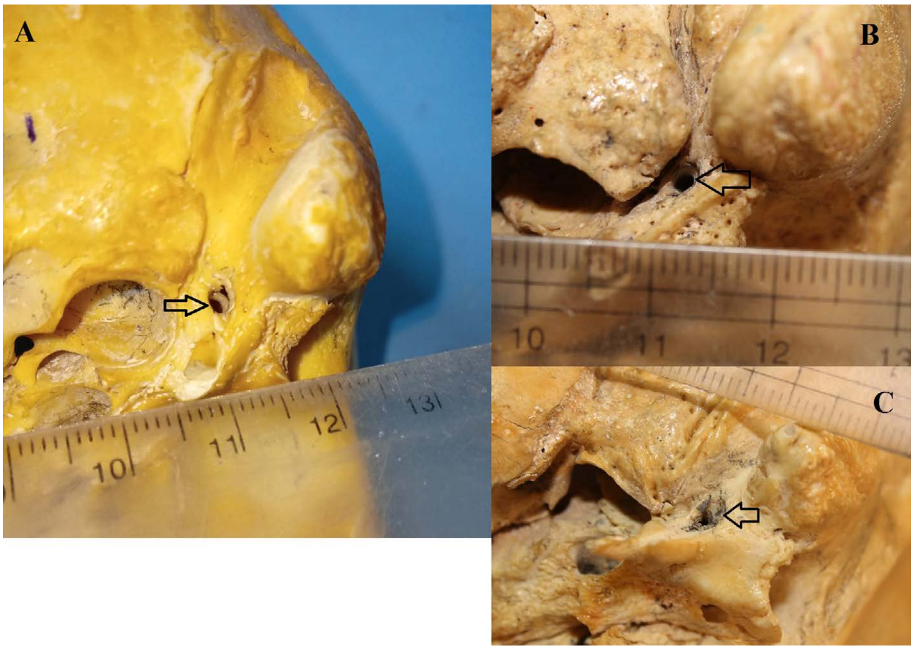

Figure 5. Exclusive unilateral features of stylomastoid foramen; **A.** Bifurcated oval foramen; **B.** Round foramen situated deep inside tympano-jugular groove; **C.** Irregular foramen with a bony spur projecting from posterior aspect of styloid process. All the features are shown as arrow marked area in the figures.

Table 4. Dimensions of the stylomastoid foramen as observed in the present study

Measurement values	Transverse diameter [mm]		Antero-posterior diameter [mm]	
	Right	Left	Right	Left
Mean ± standard deviation	2.02 ± ± 0.62	2.23 ± ± 0.57	2.21 ± ± 1.01	2.34 ± ± 0.64
p value	0.43		0.50	
Maximum	3.26	3.78	5.76	3.95
Minimum	0.85	1.08	0.98	1.13

DISCUSSION

Idiopathic acute onset unilateral facial paralysis is commonly referred to as Bell's palsy [4]. Available literature suggests that herpes simplex virus (HSV-1) infection and subsequent oedema within the facial nerve attributed to inflammatory response as the possible aetiology of Bell's palsy in most cases [10, 15]. Nevertheless, researchers in recent times have tried to explore beyond the popular hypothesis and attempted to unravel other possible factors behind Bell's palsy [14, 16]. A trigger to this effect is the paradox that HSV-1 infection is relatively common whereas Bell's palsy is rather uncommon [22]. Researchers have tried to focus on the measurements related to the tortuous and uncompromising bony facial canal based on the hypothesis that anatomical variations within this canal could possibly lead to compression of the facial nerve eventually culminating as Bell's palsy [2, 8, 24]. Stylomastoid foramen is the termination of the facial canal and is the exit gateway for the facial nerve from skull base [19]. Variations in the dimensions (shape and size) of stylomastoid foramen could possibly have a significant influence in explained cases of Bell's palsy. There are considerable lacunae in the existing literature with regards to the anatomical details of stylomastoid. Hence the present study was undertaken to throw light on the variations in the size and shape of stylomastoid foramen.

There have been previous studies (conducted with the help of computed tomography and three dimensional models) on the anatomy of the facial canal and a recent study (on dry adult human skulls) was also conducted on the morphometry of the stylomastoid foramen [9, 11, 17, 20, 23]. However, to the best of our knowledge the present study is the first to explore the size and shape of stylomastoid foramen in dry adult human skulls. In this study as many as eight variations with regards to the shape of stylomastoid foramen were observed (Tables 1, 2). As noted in the present study, based on its shape, stylomastoid foramen can be broadly classified as common and rare variants. Whereas round, oval and square constitutes the common variants (present in 83.79% skulls on right side and 81.07% skulls on left side, respectively) shape wise triangular, rectangular, serrated, bean-shaped and irregular constitutes the rare variants of the stylomastoid foramen (Figs. 1–3, Table 2). It may be suggested that rare variants such as serrated (due to sharp edges), bean-shaped (due to narrow concave margin) and irregular stylomastoid foramen could interfere with the smooth exit of facial nerve and thereby could have a bearing on unilateral injury of the nerve.

It was noted with interest that the stylomastoid foramen could be associated with extensions and adjacent foramen. In the present study, 17 skulls were associated with extensions of the stylomastoid foramen having both bilateral and unilateral incidence (Fig. 4). It was further observed that only round and oval shaped foramen (more common variants) were associated with extensions. Moreover the oval variants were more commonly (68.18% cases) associated with extensions as compared to round ones (31.82% cases). Notably extensions in oval variations of the foramen were commonly (86.67% cases) associated with antero-posterior orientation, whereas round foramen were usually associated with medial (57.14% cases) extensions (Table 3). In 7 skulls included in the present study, we observed that the stylomastoid foramen was associated with an adjacent foramen which was always unilateral in incidence (Fig. 4). Notably in most cases (57.14%) the adjacent foramen was situated anterior to the actual foramen (Table 1). On the basis of previously reported literature it may be suggested that extensions of the stylomastoid foramen and presence of adjacent foramen could be the allowance for the entry of stylomastoid artery (branch of posterior auricular artery) which is a normal anatomical companion of the facial nerve [19, 21]. In terms of size, it was observed that mean antero-posterior diameter was more than the mean transverse diameter; however, the difference was not statistically significant (Table 4). Hence it may be concluded that size of the stylomastoid foramen could be of little importance when considering the risk of facial nerve injury while passing through the stylomastoid foramen.

A notable observation was that 6 (16.22%) skulls under study had bifurcated stylomastoid foramen and this was always unilateral in occurrence (Fig. 5). Bifurcation when present was observed in oval shaped foramen (common variant) in 40% cases and in triangular, rectangular and square shaped foramen (rare variants) in the remaining 60% cases. In 2 skulls, the foramen (round shaped) were situated deep inside the tympano-jugular groove (Fig. 5). In 1 skull, the stylomastoid foramen was partially obstructed by a bony spur (Fig. 5, Table 1). Overall in 9 (24.32%) skulls as discussed above, the anatomical details of the stylomastoid foramen could possibly interfere with the smooth exit of the facial nerve from the skull base. In other words, in these skulls the facial nerve was at the risk of injury while coming out of the stylomastoid foramen. Moreover in each of the 9 skulls, the observation was unilateral, which could lead to unilateral facial nerve palsy or Bell's palsy.

Limitations of the study

The present study has its inherent limitations as it is a single centre study conducted on a small number of dry human skulls. Nevertheless the findings reported could be considered as baseline information which may serve as a platform for future research. Knowledge about the variations in the shape of the stylomastoid foramen along with associated details such as presence of extensions of the foramen and existence of adjacent foramen could be useful during clinical interventions pertaining to facial nerve at the exit point from skull base. The most notable findings of the present study are the anatomical details of the stylomastoid foramen (bifurcated foramen, deeply situated foramen and presence of bony spur) which could be the cause of unilateral facial nerve lesion leading to Bell's palsy. Hence it may be opined that the findings of the present study do support the hypothesis that other than HSV-I infections, the aetiology of Bell's palsy could also partly be attributed to anatomical variations of stylomastoid foramen which is the terminal point of facial canal.

CONCLUSIONS

In the present study which was conducted on dry adult human skulls, eight variations of stylomastoid foramen were observed in terms of shape. The common variants were round, oval and square, whereas the rare variants were triangular, rectangular, serrated, bean-shaped and irregular. It was noted that stylomastoid foramen at times were associated with extension and even an adjacent foramen. It is quite possible that these entities are meant for the passage of stylomastoid artery which normally accompanies the facial nerve through the stylomastoid foramen. Variations of stylomastoid foramen, which were exclusively unilateral such as bifurcated foramen, presence of bony spur, deeply situated foramen within a groove were also observed. These unilateral variations along with rare variations in terms of shape such as serrated, bean-shaped and irregular foramen (which were also unilateral findings) could be potential risk factors towards injury of facial nerve at the point of exit from skull base leading to Bell's palsy. No significant differences were observed between the mean diameters (antero-posterior and transverse) of the stylomastoid foramen thus limiting their role for any possible injury to the facial nerve.

Acknowledgements

The authors express heartfelt gratitude to all the residents and faculty members of the Department of Anatomy, All India Institute of Medical Sciences, Phulwarisharif, Patna, India for their unconditional support throughout the study. We are grateful to the authorities of All India Institute of Medical Sciences, Phulwarisharif, Patna, India for their kind cooperation during the course of this study.

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