Original communication

FORAMINA OF THE POSTERIOR CRANIAL BASE: A STUDY OF ADULT INDIAN SKULLS

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RESUMEN

Introducción: Las foraminas craneales son los únicos puntos de entrada a un cráneo que, de otra manera, permanecería cerrado. La evaluación de estas foraminas es una parte muy importante para el diagnóstico médico y debería ayudar al clínico en su enfoque quirúrgico a esta delicada región. El presente estudio se centra en las foraminas de la base posterior del cráneo incluyendo los pares de fosas yugulares, el agujero estilomastoideo, el canal hipogloso; el impar agujero magno y otras foraminas auxiliares tales como el agujero mastoideo y el canal condíleo posterior. Material y Método: El estudio se llevo a cabo en 50 cráneos adultos, secos y macerados, pertenecientes todos ellos al subcontinente indio. Para ello se utilizó un calibre vernier con una precisión de 0.01 mm. Resultados: Se obtuvo una amplia variación en las dimensiones de la fosa yugular. La diferencia máxima bilateral en el mismo cráneo fue de 6.72 mm. La bóveda y la septación incompleta existían en un 20% de los cráneos. El tamaño del agujero estilomastoideo osciló entre 0.9-5.3 mm. Una de las 100 foraminas estudiadas se mostró estenosada. La duplicación se vio en el 4% de los cráneos. Las septaciones en el canal hipogloso se produjeron exclusivamente en el aspecto endocraneal y se observó bilateralmente en un 4% y unilateralmente en un 20% de los cráneos. En uno de los cráneos se encontró occipitalización del atlas. La salida del agujero magno estaba deformada y estenosada. Este fue el único cráneo con un índice en el agujero magno menor de 1. El agujero mastoideo estuvo presente bilateralmente en un 74% y unilateralmente en un 16% de los cráneos, mientras que las cifras correspondientes para el canal condíleo posterior fueron de 62% y 26% respectivamente.

Palabras clave: *foraminas craneales, base posterior del cráneo, cráneos humanos.*

ABSTRACT

Introduction: Cranial foramina are the only portals to an otherwise closed cranium. Evaluation of these foramina is an important part of diagnostic medicine and would aid the clinician in his surgical approach to this complicated region. The present study is of foramina in the posterior cranial base including the paired jugular foramen, stylomastoid foramen, the hypoglossal canal; the unpaired foramen magnum and accessory foramina such as the mastoid foramen and the posterior condylar canal. Materials and Method: The study was done on 50 dried, macerated, adult human skulls, all belonging to the Indian subcontinent, using a vernier caliper with a precision of 0.01 mm. Results: There was wide variation in the dimensions of the jugular foramen. The maximum bilateral difference within the same skull was 6.72mm.Dome and incomplete septation coexisted in 20% skulls. The size of stylomastoid foramen ranged from 0.9-5.3 mm. One out of the 100 foramina studied showed a stenosed foramen. Duplication was seen in 4% skulls. Septations in the hypoglossal canal were exclusively on the endocranial aspect and were seen bilaterally in 4% and unilaterally in 20% skulls. In one skull there was occipitalisation of the atlas. The magnum outlet was distorted and stenosed. This was the only skull with a 'foramen magnum index' less than 1. The mastoid foramen was present bilaterally in 74% and unilaterally in 16% skulls while the corresponding figures for the posterior condylar canal were 62% and 26% respectively.

Key words: *cranial foramina, posterior cranial base, human skulls, variations*

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Received: 4 February, 2011. **Revised**: 25 February, 2011. **Accepted**: 17 March, 2011.

INTRODUCTION

The base of the skull is a complicated region with a number of foramina providing the only portals of access to the otherwise closed cranium. When one considers the delicate neurovascular structures that traverse their narrow confines, knowledge of the variations of these foramina become an important part of diagnostic medicine and an aid to the evaluation of radiologic films. Apart from clinicians, the study of the foramina is important to anthropologists as these foramina have dramatically changed in size and shape in the course of evolution. The positional change of the foramen magnum from the posterior aspect of the occiput in quadrupeds, to the base of the skull in bipeds, is an indicator of the transformation in habitual posture and locomotory pattern of the individual. Also, interestingly, the size of the hypoglossal canal, being much larger in the modern human than in the African apes, could be related to the origin of the human vocal behaviour (Kay et al, 1998).

The present study consisted on collection and analysis metrical and non-metrical data of foramina in the posterior part of the cranial base in adult human skulls, all originating from the Indian sub-continent. Any abnormal findings were noted and all the observations were compared with those documented in literature. Variations amongst foramina, as a result of skulls belonging from different racial groups, is a fascinating concept and has been kept in mind while discussing the comparative analysis of past and present data.

MATERIALS AND METHODS

A convenient sample of fifty, dried, macerated, unsexed, adult human skulls, all from the Indian subcontinent, were collected from Bharati Vidyapeeth Deemed University, Medical and Dental colleges, Pune, India. All the skulls were recent, belonging to the latter half of the twentieth century. The skulls were observed for any damage and only those in good condition were selected.

A vernier caliper with a precision of 0.01 mm was used to measure the diameters on the exocranial aspect of the regular paired foramina connecting the posterior cranial fossa with the base of the skull. These foramina included the paired jugular, stylomastoid and the hypoglossal canal, and the unpaired foramen magnum. The medio-lateral and the antero-posterior diameters for the jugular, stylomastoid, and hypoglossal canal were measured. It may be noted that these two diameters were perpendicular to each other. For the foramen magnum, the maximum transverse and the antero-posterior (in the sagittal plane) diameters were recorded. If any foramen was found to be too narrow to be measured by the vernier caliper, its dimensions were judged by whether it allowed an endodontic instrument (K file) number 80 to pass through it. The distances from the medial edge of the paired foramina to the mid-sagittal plane were also measured. To minimize error, each measurement was taken twice by the same observer and, in case of any discrepancy; the mean of the two values was noted. The linear measurements have been given in millimetres. Bilateral differences between each of the measurements were statistically analyzed using the *t* test, and were considered significant at $p<0.05$.

Nonmetrical data, such as the presence of dome in the jugular foramen and septation in both the jugular foramen and the hypoglossal canal were noted. The frequency of occurrence of accessory foramina such as the mastoid foramen and the posterior condylar canal was recorded. Any deviation in shape, size, septation or any other abnormality was also noted. The size of the foramen for the purpose of comparison was taken as the product of its medio-lateral and the antero-posterior diameters.

RESULTS

The following observations were recorded while studying the foramina in the posterior region of the cranial base in adult human skulls.

The medio-lateral diameter of the jugular foramen ranged between 9 mm and 21.4 mm with a mean of 15.59 +/-2.64 mm and 13.83 +/-4.94 mm on the right and left sides respectively while the maximum antero-posterior diameter (perpendicular to the medio-lateral axis of the foramen) ranged between 4.1mm and 13.6 mm with a mean of 9.02 +/-1.79 mm on the right side and 7.73 +/-1.79 mm on the left. The largest sized foramen noted in the present study measured 20.5 × 11.58 mm while the smallest was 13.4 × 4.1mm. The greatest variance in dimensions of this bilaterally present foramen within the same skull was as much as 6.3 mm for the medio-lateral diameter and 6.72 mm for antero-posterior diameter. In both cases, the dominant foramen was right sided. The dome of the jugular foramen was present bilaterally in 29 (58%) skulls and unilaterally in 14 (28%) and 4 (8%) skulls on the right and left sides respectively. Complete septation of the jugular foramen was observed in a total of 5 (10%) skulls of which, in 3 (6%) skulls it was bilateral and in 2 (4%) skulls it was seen to be unilaterally present (one each on the right and left sides). Incomplete septation was a more frequent event and was seen in 18 (36%) skulls of which in 9 (18%) it was present bilaterally and in 2 (4%) and 7 (14%) skulls it was unilateral on the right and left sides respectively. Thus complete septation was observed in 4 (8%) right sided and in 4 (8%) left sided foramina and the corresponding figures for incomplete septation were 11 (22%) and 16 (32%) respectively. Dome and incomplete septation coexisted in 10 (20%) right sided foramina and 13 (26%) left sided ones. The distance of the foramen from the mid-sagittal plane ranged between 16.2 mm and 27.22 mm. The mean distance was 21.32 mm and 21.07 mm for the right and left sides respectively. Bilateral asymmetry and size dominance of the foramen is indicated in table 1.

Asymmetry ≥1mm				Asymmetry ≥2mm				Asymmetry ≥5mm			
In medio-lateral diameter		In Antero-posterior diameter		In medio-lateral diameter		In antero-posterior diameter		In medio-lateral diameter		In antero-posterior diameter	
74%		72%		44%		52%		10%		12%	
Dominance		Dominance		Dominance		Dominance		Dominance		Dominance	
Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
64%	10%	56%	16%	42%	2%	42%	10%	10%	nil	10%	2%

Table 1: Bilateral asymmetry and dominance in size of the jugular foramen (given as a percentage of 50 skulls) in the present study.

Asymmetry ≥0.5mm		Asymmetry ≥1mm		Asymmetry ≥2mm	
66%		26%		4%	
Right Dominance	Left Dominance	Right Dominance	Left Dominance	Right Dominance	Left Dominance
52%	14%	20%	6%	4%	nil

Table 2: Bilateral asymmetry and dominance in size of the stylomastoid foramen (given as a percentage of 50 skulls) in the present study.

The medio-lateral diameter of the stylomastoid foramen in the present study of 99 foramina was found to range between 0.9 mm and 5.3 mm. One foramen had a pin hole sized exocranial orifice which was too narrow to be measured by the vernier caliper. This foramen allowed the passage of an endodontic instrument (K file), number 80 (fig. 1). The mean diameter (excluding the stenosed foramen) was 2.91 +/-0.91 mm (right) and 2.52 +/-0.61 mm (left). Duplication of the foramen was observed in 2 (4%) skulls unilaterally. The distance of the foramen from the mid-sagittal plane ranged between 32.46 mm and 47 mm. The mean distance was 40.7 mm and 40.13 mm for the right and left sides respectively. Bilateral asymmetry and size dominance of the foramen is indicated in table 2.

The medio-lateral diameter of the hypoglossal canal ranged between 2.66 mm and 10.9 mm with a mean of 5.53 +/-1.16 mm and 5.45 +/-1.1mm on the right and left sides respectively. The antero-posterior diameter ranged between 2.7 mm and 8.14 mm with a mean of 4.36 +/-1.39 mm on the right side and 4.39 +/-1.3 mm on the left. The largest sized foramen measured 7.4 × 8.14 mm while the smallest was 2.66 × 3.7 mm. Septations were seen bilaterally in only 2 (4%) skulls and unilaterally in 6 (12%) on the right side and 4 (8%) on the left. These bony septations were all on the endocranial aspect and did not traverse the entire depth of the canal so as to be evident at the exocranial end. The distance of the foramen from the mid-sagittal plane ranged between 13 mm and 22 mm. The mean distance was 16.80 mm and 16.68 mm for the right and left sides respectively. Bilateral asymmetry and size dominance of the hypoglossal canal is indicated in table 3.

Figure 1: Stenosed stylomastoid foramen allowing the passage of an endodontic instrument (K file), number 80

Dimensions of the jugular foramen, hypoglossal canal and the stylomastoid foramen of the two sides were statistically analyzed using the paired *t* test and considered significant at $p<0.05$. While the p value for the medio-lateral diameter of the right and left jugular foramina was 2.64, for the antero-posterior diameter it was 0.002. The corresponding values of the hypoglossal canal were 0.78 and 0.71 respectively, while that of the medio-lateral diameter of the stylomastoid foramen was 0.004. Thus the bilateral difference in dimensions was significant only for the antero-posterior diameter of the jugular foramen and the medio-lateral diameter of the stylomastoid foramen.

Figure 2: Deformed magnum outlet due to occipitalised atlas.

The antero-posterior diameter of the foramen magnum ranged between 28.04 mm and 37.9 mm with a mean of 33.35 mm while the maximum transverse diameter ranged between 22.3 mm and 30.96 mm, with a mean of 27.69 mm. The largest and smallest foramina in 49 skulls had the dimensions of 28.88 x 37 mm and 22.3 x 28.04 mm respectively. In one skull, occipitalization of the atlas resulted in a highly stenosed and deformed foramen whose antero-posterior and maximum transverse diameters were 25 mm and 26.8 mm respectively (fig. 2). In 49 skulls, the foramen magnum index (FMI) calculated as the ratio of the antero-posterior and the maximum transverse diameters of the foramen, was found to be more than 1.2 in 26 (53.06%) and less than 1.1 in 6 skulls (12.24%) indicative of oval and circular shaped foramina respectively. In the remaining 17 skulls (34.7%) it was between 1.1 and 1.2. The skull with an occipitalized atlas was the only skull with an index less than 1 (0.93).

Asymmetry ≥1mm				Asymmetry ≥2mm			
In medio-lateral diameter- 42%		In antero-posterior diameter-20%		In medio-lateral diameter-12%		In antero-posterior diameter-6%	
Dominance		Dominance		Dominance		Dominance	
Right 26%	Left 16%	Right 10%	Left 10%	Right 4%	Left 8%	Right 2%	Left 4%

Table 3: Bilateral asymmetry and dominance in size of the hypoglossal canal (given as a percentage of 50 skulls) in the present study.

Mastoid foramen is an inconstant foramen and in this study, its bilateral presence was observed in 37 (74%) skulls and unilateral presence in only 8 (16%) skulls (right side -12%, left side - 4%). In the remaining 5 (10%) skulls it was absent. Multiple mastoid foramina (from 2 to a maximum of 4) were seen in 14 (28%) skulls. These were bilateral in 8% and unilateral in 10% on right and left sides each.
The posterior condylar canal, another inconstant foramen, was observed bilaterally in 31 (62%) skulls and unilaterally in 13 (26%) skulls (right- 16%, left- 10%). In the remaining 6 (12%) skulls it was absent. Duplication of the foramen was seen in one skull on right and in three skulls on left side.

DISCUSSION

The shape and size of the jugular foramen is obviously related to the size of the internal jugular vein and the presence or absence of a prominent superior jugular bulb (Sturrock, 1988). The difference in size of the two internal jugular veins is already visible in the human embryo at the 23 mm stage and is probably a consequence of the different patterns of development of the right and left brachiocephalic veins (Hatiboglu and Anil, 1992). Since the textbooks classically describe the superior sagittal sinus as draining into the right transverse sinus, it would be expected that the right foramen would invariably be larger than the left (Sturrock 1988). However, there is a wide variation in the anatomy of the intracranial venous sinuses (Woodhall, 1939, Surendrababu et al, 2006) and this would account for the variation in the size of the foramen. An interesting view propounded by Glassman (1992) is that the larger size of the foramen could be linked to handedness. The formation of this foramen between two adjacent bones and the important neurovascular structures that traverse it, further complicate its anatomy and make it important from the surgical viewpoint. In the present study both the mediolateral as well as the antero-posterior diameters were found to vary within a very wide range with the mean of both diameters greater on the right side (table 4). Similar observations have been made by Ekinci and Unur (1997) and Aydinlioglu et al (2001). Idowu (2004) however, found the mean length of the foramen to be marginally greater on the left side (table 4).
Regarding the dominance in the size of the foramen, Sturrock (1988) found in his study, the

right foramen larger in 68.6% and the left larger in 23.1%. In the remaining 8.3% they were bilaterally symmetrical. The corresponding values in the study conducted by Hatiboglu and Anil (1992) were 61.6%, 26% and 12.4% while in the study by Patel and Singel (2007) the values were 60.4%, 15.4% and 24.2% respectively. However none have indicated the exact numerical value while considering bilateral asymmetry. In the present study, asymmetry of more than 1mm, 2mm and 5mm were considered for labeling a foramen dominant. Right dominance was seen in a significantly greater number of skulls (table 1).

The dome is a special feature of the jugular foramen and is linked to the presence of the superior bulb of the internal jugular vein. In the study conducted by Sturrock (1988) and Hatiboglu and Anil (1992), as well as in the present study, similar readings were recorded as to the unilateral and bilateral presence of the dome (table 5). These results, however, are different from those of Patel and Singel (2007) who observed the bilateral presence of the dome in a much lower percentage of skulls whereas the unilateral presence in their study was of more frequent occurrence (table 5).

Diameters		Ekinci and Unur (1997)	Aydinlioglu et al (2001)	Idowu (2004)	Present study
Medio-lateral (in mm)	Mean-right	15.70	13.70	13.90	15.59
	Mean -left	15.00	12.30	14.11	13.83
	Range	—	—	9.20-20.20	9-21.40
Antero-posterior (in mm)	Mean -right	8.30	12.20	10.22	9.02
	Mean -left	7.30	10.90	9.57	7.73
	Range	—	—	6.80-14.40	4.10-13.60

Table 4: Comparative analysis (of past and present data) of the dimensions of the jugular foramen.

Presence of:		Sturrock (1988)	Hatiboglu and Anil (1992)	Idowu (2004)	Patel and Singel (2007)	Present Study
Dome	Bilateral	53.90%	49%	-	21.00 %	58.00%
	Unilateral-right	30.10%	36.60%	-	38.50%	28.00%
	Unilateral-left	6.40%	4.60%	-	14.30%	8.00%
Septation-complete	right	3.20%	5.60%	7.50%	23.10%	8.00%
	left	3.20%	4.30%		17.60%	8.00%
Septation-incomplete	right	1.30%	2.60%	-	49.50%	22.00%
	left	10.90%	19.60%	-	59.30%	32.00%

Table 5: Comparative analysis (of past and present data) of the presence of dome and septation in the jugular foramen.

An occasional fibro-osseous septum may be found between the jugular spine of the temporal bone and that of the occipital bone separating the posterlateral pars venosa and the anteromedial pars nervosa compartments of the jugular foramen. The presence of such complete or incomplete septations was found to be variably present in the observations made by different researchers. Observations by Sturrock (1988) and Hatiboglu and Anil (1992) tally, however, they differ widely from those of Patel and Singel (2007) (table 5). The observations made in the present study are intermediate to those made by Sturrock (1988) and Patel and Singel (2007) (table 5). Patel and Singel (2007) have ascribed the reason for such variation to the different geographical areas from which the skulls were obtained. However, majority of the skulls studied by Sturrock (1988) and all the skulls observed in the present study were also from the Indian subcontinent and thus such a conclusion could not be authenticated.

The stylomastoid foramen is a small foramen opening at the base of the temporal bone between the styloid and mastoid processes. Berge and Bergman (2001) found the mean dimensions to be 1.66 × 1.56 mm ranging between 1.07 × 1.07 mm and 2.5 × 2 mm. In the present study, where the medio-lateral diameter of the foramen was measured, the mean on the right side was 2.91 mm and on the left was 2.52 mm. The dimensions ranged between 0.9 mm and 5.3 mm barring one left sided foramen which was too narrow to be measured by the vernier caliper and allowed the passage of endodontic instrument (K file) number 80 (fig. 1). Such a stenosed facial canal might have led to compressive effects on the 7th cranial nerve with resultant ipsilateral paresis of the muscles developing from the mesoderm of the second branchial arch. Unfortunately the clinical history of the patient was not available. Thus the range in the medio-lateral dimensions of the foramen in the present study was much wider than those observed by Berge and Bergman (2001). Even in the frequency of bilateral asymmetry, the results of Berge and Bergman (2001) and the findings in the present study are very different. While they found the foramen consistently symmetric and recorded bilateral asymmetry (difference ≥0.5 mm) in only 1% of skulls we noted the same in as many as 66% of skulls (right dominance in 52% and left dominance in 14% of skulls). Such wide variations could possibly be due to the different populations studied. In the present study, in two skulls (4%), the foramen was duplicated unilaterally on the left side. This could be a result of a congenital bifurcation of the infratemporal segment of the facial nerve which has been reported (Glastonbury et al, 2003) and when present is important to recognize in patients being evaluated for congenital ear malformations. Celik et al, (1997) during their examination of cranial bones, found an interesting variation of this foramen. Instead of being entirely present within the temporal bone, it was in the form of a sulcus which formed a canal after articulation with the occipital bone. Such a finding was not seen in the present study.

The hypoglossal canal has a wide range in size and is often asymmetric. Streit (1903) (as cited by Berge and Bergman, 2001) and Berge and Bergman (2001) found the width (medio-lateral diameter) of the canal varied between 3 - 12 mm and 3 - 10 mm respectively. In the present study the medio-lateral diameter was found to lie within a narrower range of 2.70 - 8.14 mm with a mean of 4.36 mm and 4.39 mm on the right and left sides respectively. The largest and smallest sizes of the canal observed by Berge and Bergman (2001) on the exocranial aspect were 10 × 5 mm and 3 × 2.5 mm respectively and the corresponding figures in our study were 7.4 × 8.14 mm and 2.66 × 3.7 mm respectively. Occasional presence of septation on the endocranial aspect of the canal which would separate the meningeal artery from the hypoglossal nerve was noted by both Berge and Bergman (2001) and Muthukumar et al, (2005) with similar results. Berge and Bergman (2001) found such septation to be present in 4% skulls bilaterally, 8% skulls on the right side and 20% skulls on the left side (total 32% skulls). Muthukumar et al, (2005) noted such septations in 30% skulls while we observed the same in 24% skulls (12% on right side, 8% on left side and 4% bilaterally). Berge and Bergman (2001) found spicules present on the exocranial aspect infrequently. This was not observed in the present study. A unique finding observed by Berry and Berry (1967) and Berry (1975) was duplication of the canal in 7.0 - 27.4% and 2.0 - 22.7% respectively, depending on the population studied. They concluded that such variations were a result of the different populations studied which ranged from North and South America, Burma, Nigeria, Palestine, Egypt and North India. Interestingly, such a variation was not seen in any skull in our study despite the skulls belonging to the Indian population.

In the present study, although the distances of the regular, paired foramina from the mid sagittal plane were highly variable, the mean distance for each foramen was almost identical for the right and left sides. A comparison of the values for these distances was made between the right and left sides using the paired *t* test and no significant difference was found at $p<0.05$ ($p= 0.64$, 1.1 and 0.32 for the jugular foramen, stylomastoid foramen and the hypoglossal canal respectively). Hence we conclude there is relative bilateral symmetry of the base of the adult human cranium.

The dimensions of the foramen magnum are of great significance because of the structures transmitted through it. Various researchers have recorded the dimensions of the foramen in both antero-posterior and transverse planes. The mean antero-posterior diameter recorded by Lang (1991) (as cited by Berge and Bergman, 2001), Sendemir et al (1994), Berge and Bergman (2001) , Muthukumar et al (2005), Gruber et al (2009) and Tubbs et al (2010) were 35.33 mm, 35.6 mm, 34 mm , 33.3 mm, 36.6 mm and 31 mm respectively, while the mean of the maximum transverse diameter observed by the same workers were 29.67 mm, 29.9 mm, 29 mm, 27.9 mm, 31.1 mm and 27 mm respectively. In the present study the mean antero-posterior and transverse diameters were 33.5 mm and 27.69 mm respectively. Thus it is interesting to note that although the dimensions of this foramen are within a very wide range in the different ethnic groups studied by the various researchers, the mean diameters for all (except those documented by Gruber et al in 2009 and Tubbs et al in 2010) remain fairly constant.

In one skull out of the fifty studied, we noted a bony fusion between the atlas and the margins of the foramen magnum causing the foramen outlet to be highly distorted, misshapen and stenosed (transverse diameter was 26.8 mm, antero-posterior diameter was 25 mm and the "foramen magnum index" was 0.93) (fig. 2). This being the only skull with an index less than 1, we conclude that unless deformed for any reason, the antero-posterior diameter of the foramen magnum is always greater than the maximum transverse diameter of the same foramen. The clinical outcome of such a lack of an atlanto-occipital joint coupled by the compression effect on the spinal medulla would have been interesting to note but for the lack of clinical report on the case. Such an occurrence is known to be rare and is probably due to disruption in the separation of the caudal and cranial parts of the first sclerotome (Saini et al, 2009). A spinal cord compression in these cases would be a certainty if the sagittal diameter of the canal behind the odontoid process was less than 14mm (Greenberg, 1968). This condition is interestingly associated with a low hair line, torticollis and an abnormally short neck with restricted movements - such features should thus alert the chiropractic physician of the possible underlying congenital anomaly and accordingly modify manipulative care of the upper cervical region (McKechnie, 1994).

Murshed et al (2003) in their study of computerized tomographic images of 110 normal subjects noted the various shapes of the foramen magnum to be oval (8.1%) egg shaped (6.3%), round (21.8%), tetragonal (12.7%), pentagonal (13.6%), hexagonal (17.2%) and irregular (19.99%). However the above shapes seem to be classified on subjective assessment. Muthukumar et al (2005) calculated a "foramen magnum index" as the ratio of antero-posterior and maximum transverse diameters. If such an index was greater than 1.2, this would mean an oval foramen. Based on such an index, he found 46% of the foramina studied to be oval, while in the present study, 26 of 49 skulls (53.06%) had an index greater than 1.2 and could thus be classified as oval. It may be added that both the above figures apply to the Indian population.

Boyd (1930), in a study of 1500 skulls, found the mastoid foramen to be present bilaterally in 34.4% skulls, absent bilaterally in 31.9% and present unilaterally in 16.1% and 17.6% on the right and left sides respectively. The corresponding values in the observations made by Berge and Bergman (2001) were 89%, 1%, 6%, 4% while those in the present study were 78%, 6%, 12% and 4%. There is thus a wide variation seen in different populations. Multiple foramina were noted by Berge and Bergman (2001) in 8% of skulls while such a phenomenon was noted in 28% of skulls in the present study (8% bilaterally and 10% each on the right and left sides unilaterally).Thus in terms of presence of the foramen our observations are close to those of Berge and Bergman (2001). However, multiple foramina were seen in a much larger number in our study. The corresponding values in one parameter make it difficult to conjecture that the variation in the other parameter is a result of different ethnic races the skulls belong to.

Posterior condylar canal is an inconstant foramen which Boyd (1930) considered the largest emissary foramen. He found this foramen to be present bilaterally in 46.6% skulls, absent in 23.1% and unilaterally present in 16.5% and 13.8% on the right and left sides respectively. The corresponding values observed by Berge and Bergman (2001) were 54%, 10%, 21% and 15% and in our study were 62%, 12%, 16% and 10%. Ethnicity being the cause of variation in its presence has been demonstrated in the study by Berry and Berry (1967) and Berry (1975) who reported a patent canal in 13.3% to 70.5% and 14.6% to 57.7% depending on the population studied. Berge and Bergman (2001) found the foramen duplicated in 4% of skulls and triplicate in less than 1% of skulls. In the present study the foramen was found duplicated in 8% of skulls (2% on right side and 6% on left side) but not triplicate in any skull.

In conclusion, it was interesting to observe that in a comparative analysis of past and present data, apart from some variations, many of our findings were comparable with those recorded by others. It is also notable that, in some parameters of the jugular foramen, our observations were similar to those made by Sturrock (1988) and Hatiboglu and Anil (1992) but different from those noted by Patel and Singel (2007). Since the latter also conducted their study on the Indian population, such a variation could not be ascribed to ethnicity. Thus, though there is evidence that the incidence of some variations may increase or decrease depending on the population studied (Boyd, 1930; Berry and Berry, 1967; Berry, 1975), we could not define such a distinct pattern in the present study and thus conclude that foraminal variants are not related to the ethnic origin of the skull and any variations noted were purely incidental.

ACKNOWLEDGEMENTS

Dr Rodrigo Carrera Redondo, Lecturer in Spanish, Institute of Foreign Languages, University of Pune, India; for Spanish translation.

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