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RESEARCH ARTICLE

A Morphological study of Shapes, Overlapping of Occipital Condyles and the Anterior Tubercle of Foramen Magnum in Human Skull with Comparison in Adolescent, Adult and Foetal age and in Males and Females

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Abstract

Introduction: Foramen Magnum (FM) transmits many important structures. Standard literature states this foramen to be roughly oval shaped. However, recent researches suggest that the FM can of varied shapes. The FM can be overlapped by occipital condyles causing hindrance for the traversing structures. Rarely the FM shows a tubercle at its anterior end, which can also cause problems for the traversing structures.

Aim of study:

1. To observe different shapes of the FM and their frequency
2. To observe frequency of overlapping of occipital condyles on the FM
3. To observe the frequency of a rare tubercle at the anterior end of FM

Materials and methods: 181 adult skulls (known sex) and 54 foetal skulls (total 235), were studied from different medical institutes in India. These skulls were arranged in Foetal (A), Adolescent Female (B-f), Adolescent Male (B-m), Adult Female (C-f) and Adult Male (C-m) groups.

Results: The FM had the following shapes overall (percentage wise) Circular 13.2%, Oval 16.6%, Egg Shaped 18.3%, Rhomboid 14%, Pentagonal 5.95%, Hexagonal 15.3%, Heptagonal 4.6%, and Irregular 11.9%

Overall, the occipital condyles overlapped the FM in 21.27% cases; most frequently in oval shaped FM. Given, percentage wise occurrence for each group: A group- 00%, B-f group- 23.07%, B-m group- 15.9%, C-f group- 44.1%, and C-m group- 28.5%

10.63% of the FM had the anterior tubercle, most frequent in oval shaped FM. Given, percentage wise occurrence in each group: A group- 00%, B-f group- 15.38%, B-m group- 13.63%, C-f group- 14.7%, and C-m group- 11.6%

INTRODUCTION

Foramen magnum (FM) is the largest and very important bony foramen at the base of human skull. The FM transmits many important structures and it is a subject of interest for many researchers. Standard literature quotes the FM to be oval shaped [1]. The FM however, shows different morphology in each individual skull, and reportedly, it has different outlines of shapes ranging from round to polygonal or even irregular. This study focuses on the analysis of the different shapes of FM in different age groups. This study also focuses on the incidences of overlapping of the adjoining occipital condyles on the FM. Furthermore, this study reports the frequency of occurrence of a tubercle rarely seen on the anterior end of FM, (which may be the ossified apical ligament of dens of axis vertebra).

Aim and objectives of Study:

This study of the FM has three objectives;

1. To observe different shapes of the FM and the frequency of their occurrence
2. To observe the relation of the occipital condyles with the FM (occurrence of overlapping of occipital condyles on the FM)
3. To observe the occurrence of a rare tubercle seen at the anterior end of FM (at the point of attachment of the apical ligament of the dens of axis vertebra)

The objectives were used to achieve the following aims,

1. To compare the foetal, adolescent male and female, and adult male and female to determine the prevalence of a particular morphological shape in a particular group
2. To study the frequency of overlapping of FM by the occipital condyles and prevalence of such overlapping in different FM shapes, in foetal, adolescent and adult age, and in both the sexes.
3. To study the frequency of appearance of the anterior tubercle in the FM and its prevalence in different shapes of FM, in foetal, adolescent and adult age, and in both the sexes

This knowledge about the morphological shapes of the FM shall be useful for Anatomists, Anthropologists, Radiologists, Surgeons and Forensic Experts.

Materials and Method:

For this study, 181 adult dry skulls of known sex and 54 foetal skulls of unknown sex were studied (total 235 skulls). The skulls studied were categorised into Five groups labelled as A, B-f, B-m, C-f and C-m. The group containing foetal skulls was labelled as A Group. Second and third group were adolescent groups of skulls of age between 13 years to 25 years, these groups were labelled as group B-f for female skulls, and group B-m for male skulls. The fourth and fifth group were of Adult skulls of age ranging from 25 years to 60 years and above, these groups were labelled as group C-f for female skulls and group C-m for male skulls. The morphology of the FM, its relation with the occipital condyles and the regularity of occurrence of the anterior tubercle at the anterior end of FM was observed in each of these skulls and the base of each of these skulls was photographed for the records by using a digital camera.

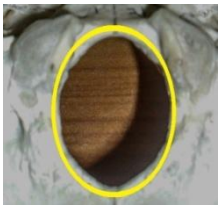
Observations:

The following photographs show the various shapes observed in the FM.

Photographs:

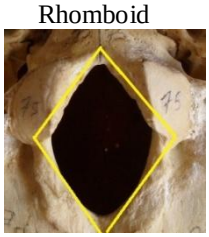
Circular

Oval



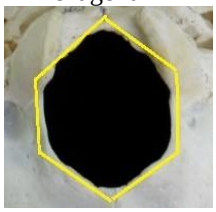
Egg Shaped

Rhomboid

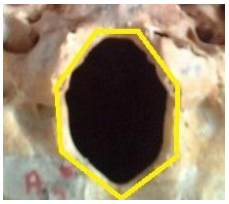


Pentagonal

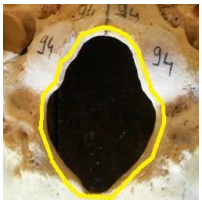
Hexagonal



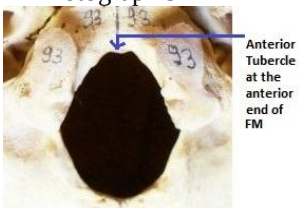
Heptagonal



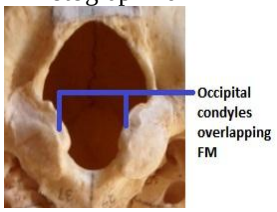
Irregular



Photograph 9



Photograph 10



The observations are presented in tabulated format as below;

Table no. 1 Shows observation of group wise occurrence of different shapes

Shapes / Groups	Circular	Oval	Egg Shaped	Rhomboid	Pentagonal	Hexagonal	Heptagonal	Irregular	Total Skulls Observed
A group (Foetal)	17	1	6	3	4	3	0	20	54
B-f group (Adolescent Female)	0	4	7	6	1	4	1	3	26
B-m group (Adolescent Male)	7	7	4	9	2	9	4	2	44
C-f group (Adult Female)	2	9	4	6	1	9	3	0	34
C-m group (Adult Male)	5	18	22	9	6	11	3	3	77
Total	31	39	43	33	14	36	11	28	235
Percentage	13.2	16.6	18.3	14	5.95	15.3	4.6	11.9	-

Table no. 2 Percentage wise observation in each group

Groups	Circular	Oval	Egg Shaped	Rhomboid	Pentagonal	Hexagonal	Heptagona	Irregular
A group (Foetal)	31.4	1.85	11.1	5.5	7.4	5.5	0	37.3
B-f group (Adolescent Female)	0	15.3	26.9	23	3.8	15.3	3.8	11.5
B-m group (Adolescent Male)	15.9	15.9	9.1	20.4	4.5	20.4	9.1	4.5
C-f group (Adult Female)	5.88	26.4	11.7	17.6	2.9	26.4	8.8	0
C-m group (Adult Male)	6.4	23.3	28.5	11.6	7.79	14.28	3.89	3.89

Table no. 3 Shows group wise occurrences of overlapping of occipital condyles in each shape

Occipital condyles overlapping, shape wise → / Groups ↓	Circular	Oval	Egg Shaped	Rhomboid	Pentagonal	Hexagonal	Heptagonal	Irregular	Percentage
A group	0	0	0	0	0	0	0	0	0
B-f group	0	1	3	0	0	0	1	1	23.07
B-m group	3	2	2	0	0	0	0	0	15.9
C-f group	2	3	4	3	0	1	2	0	44.1
C-m group	1	6	8	2	1	1	1	2	28.5
Total	6	12	17	5	1	2	4	3	21.27

Table no. 4 Shows group wise appearance of anterior tubercle in each shape

Anterior tubercle occurrence, shape wise→ / Groups ↓	Circular	Oval	Egg Shaped	Rhomboid	Pentagonal	Hexagonal	Heptagonal	Irregular	Percentage
A group	0	0	0	0	0	0	0	0	0
B-f group	0	1	2	1	0	0	0	1	15.38
B-m group	0	2	1	2	0	0	1	0	13.63
C-f group	0	0	0	1	1	2	1	0	14.7
C-m group	0	5	0	1	1	1	0	1	11.6
Total	0	8	3	5	2	3	2	2	10.63

Part 1: shows the group wise occurrence of different shapes of the FM. It was observed that in overall 235 skulls studied, the number of skulls with egg shaped FM were more (18.3%), however their number was more(22), in adult male skulls (C-m group) where as the adult female (C-f group) had more number of oval and hexagonal shaped FM (9 each) than egg shape. (table no. 1).

The skulls with heptagonal shape FM were observed to be the lowest in number, with the maximum (four) number of heptagonal shaped FM observed in the adolescent male (9.1%) (B-m group) and only one heptagonal shaped FM was observed in adolescent female (B-f group), whereas no heptagonal shaped FM was observed in foetal skulls (A group). (table no. 1 and 2)

The irregular shape was observed more in the foetal (A group) FM. 20, (37.3%), and no irregular shape was observed in adult female (C-f). However, irregular shaped FM were observed in the adolescent female (B-f group) 3, (11.5%) and they were also observed in adult male (B-m group) (4.5%) and adolescent male (C-m group) (3.89%). (table no. 1 and 2)

In case of adolescent groups, it was observed that the adolescent female (B-f group) had more number of egg shaped FM,7 (26.9%) followed by the rhomboidal shape FM,6 (23%) and the adolescent male (B-m group) had more number of Rhomboidal and hexagonal shaped FM (20.4% each).

Further in case of adult groups, it was observed that the adult female (C-f group) had more number of oval and hexagonal shaped FM (26.4% each), and the adult male (C-m group) had more number of egg shaped skulls (28.5%) followed by oval shaped skulls (23.3%) (table no. 1 and 2)

Part 2: (table no. 1 &3) In the second part of the observations, the occurrence of the overlapping of the occipital condyles were observed with respect to each shape. The overlapping of occipital condyles was noticed in 50 out of 235 skulls (21.27%). The overlapping was more frequently seen in the egg shaped FM (17 of 43 skulls of egg shaped FM) (39.5%) followed by oval shaped FM (12 of 39 skulls of oval shaped FM) (30.7%) and the least number of overlapping was observed in the pentagonal shaped FM (only 1 of 14 skulls of pentagonal shaped FM) (7.14%)

Even though the overlapping by occipital condyles in the FM was seen in all the shapes of FM in the adult male (C-m group) percentage wise, the maximum occurrence of overlapping of occipital condyles was observed in adult female (C-f group) (44.1%). The foetal FM (A- group) had no overlapping by occipital condyles. The adolescent male (B-m group) and females (B-f group) had less incidence of overlapping compared to the adult male (C-m group) and females (C-f group), whereas the males (B-m and C-m groups) had lower incidence of overlapping compared to the females (B-f and C-f groups).

Part 3: (Table 4). In the third part of observations, the occurrence of the anterior tubercle at the anterior end of the FM was observed. The incidence of appearance of the anterior tubercle was observed in 25 out of 235 skulls (10.63%). In the group wise observations, It was seen that percentage of appearance of anterior tubercle was more in adolescent female (B-f group) (15.38%) followed by the adult female (C-f group) (14.7%). Though the instances of the tubercle appeared more in the adolescent male (B-m group) than the adult male (C-m group), the appearance of the anterior tubercle in males (B-m and C-m group) was observed to be less than in females (B-f and C-f group).

Shape wise observations showed that the anterior tubercle occurred more frequently in the oval shaped FM (8 out of 39 skulls of oval shaped FM) (20.5%) followed by the rhomboid shaped FM (5 out of 33 skull of rhomboid shaped FM) (15.15%), while there were no instances of apperences of anterior tubercle in the circular shaped FM

Discussion:

Many researchers have studied the morphological shapes of FM because of the surgical importance of the FM and the advanced transcondylar approach techniques. Researchers have observed various shapes of the FM. However, the findings of researchers differ from each other.

Zaidi and Dayal (1988) [2] studied 200 skulls of Indian population. The FM Shapes noted by them were oval (64%), hexagonal (24.5%), pentagonal (7.5%), irregular (3.5%) and round (0.5%). The overall findings of this study are not similar to Zaidi and Dayal [2]. However, in percentage wise observations of each group (table no. 2), the hexagonal shape in C-f group, (adult female- 26.4%), the pentagonal shape in A group (foetus- 7.4%) and C-m group (adult male- 7.79%), irregular shape in C-m group (adult male- 3.89%) and circular in B-f group (adolescent female- 0%) is close to the finding of Zaidi and Dayal [2].

Murshed, et al. (2003) [3] observed different shapes of FM by studying the CT images of 57 males and 53 females between 18 to 80 years of age. They observed the following shapes in FM; Oval type 9 (8.1%), Egg type 7 (6.3%), Round type 24 (21.8%), Tetragonal type 14 (12.7%), Pentagonal type 15 (13.6%), Hexagonal type 19 (17.2%), Irregular type (A) 12 (10.9%), Irregular type (B) 10 (9.09%). Our study showed the frequency of egg

shaped FM to be highest (18.3%) which is more than the findings of Murshed et al [3]. However, the frequency of rhomboid shape (14%), hexagonal shape (15.3%) and irregular shape (11.9%) is to be close to the findings of Murshed et al [3].

Emel Avci et al (2010) [4] studied 10 formalin fixed cadaver heads and 30 dry skulls. In their study, the ovoid FM was demonstrated in 58% of the specimens, which is much more compared to the present study. They found asymmetrical FM in 10% of the specimens, which is near to findings of the present study (11.9%).

Chethan, et al (2011) [5]studied 53 dry skulls and determined various shapes in the FM as follows; round shape in 22.6% of cases, egg shape in 18.9%, tetragonal in 18.9%, oval in 15.1%, irregular in 15.1%, hexagonal in 5.6% and pentagonal in 3.8% of the cases. In the present study, the egg shaped FM is 18.3%, which is similar to the findings of Chethan et al [5] followed by the oval shaped FM (16.6%) and the pentagonal shaped FM (5.95%)

Radhakrishna et al. (2012), [6] observed 100 skulls (55 males and 45 females). They found the following shapes in the FM, Oval shaped FM in 22 male and 17 female skulls (total 39), Round shaped FM in 16 male and 12 female skulls (total 28), Tetragonal shaped FM in 10 male and 9 female skulls (total 19) and Pentagonal shaped FM in 8 male and 6 female skulls (total 14). In the present study, though the total number of oval shaped FM were observed to be 39 (similar to Radhakrishna et al [6]) the percentage of observed oval shaped FM is 16.6% (25 males, 13 females and 1 foetus). The pentagonal shaped FM was observed in 14 skulls in this study, which is again similar to the findings of Radhakrishna et al [6], however, the percentage of observation is 5.95% only.

Loyal et al. (2013) [7] studied 202 dry skulls in adult kenyan population. In their study, they found the shape of the FM was oval, circular and polygonal in 13%, 24% and 63% of the cases respectively. They also concluded FM does not show sexual dimorphism in shape among Africans. In the present study, the percentage of oval shaped FM is more and that of the circular shaped FM, which is less than the finding of Loyal et al [7]. The polygonal shape was subcategorised in the present study.

Aragão, et. al. (2014) [8] studied the Morphological types of foramen magnum in 110 dry crania of known sex (66 males and 44 females) ranging from 11 to 91 years in their observations they found the following shapes in the FM; Pear shape FM in total 41 skulls (37.3%) [20 males, (18.2%) and 21 females (19.1%)], Rounded shape FM in 17 skulls (15.5%) [11 males (10%) and 6 females 5.5%)], Tetragonal shape FM in 12 skulls 10.9% [10 males (9.1%) and 2 females (1.8%)], Biconvex shape FM in 12 skulls 10.9% [10 males (9.1%) and 2 females (1.8%)], Hexagonal shape FM in 10 skulls (9.1%) [3 in males (2.7%) and 7 in females (6.4%)], Oval shape FM in 6 skulls (5.5%) [3 in males (2.7%) and 3 in females (2.7%)], Pentagonal shape FM in 3 skulls (2.7%) [all 3 in males], Heptagonal shape FM in 2 skulls 1.8% [1 in male (0.9%) and 1 in female (0.9%)], Irregular shape FM in 7 skulls (6.4%) [5 in males (4.5%) and 2 in female (1.8%)].In the present study, the egg shaped (pear shaped) FM are observed to be 43 in number which is close to Aragao et al[8], however the percentage of egg shaped FM in this study is less (18.3%). The percentage of round shaped FM in this study is 13.2%, but the number of skulls is more (31) which includes 17 foetal skulls, and only 2 female skulls (table no.1). The percentage of other shapes found in this study is higher than the findings of Aragao et al [8]

Emel Avci, et al (2010) [4] observed that the Occipital Condyle protruded into the FM in 57% of the skulls examined, and according to them, such protrusion may indicate more extensive bone removal during surgery. In their study of 50 dry skulls Muthukumar et al. (2005) [9] observed that the occipital condyle protruded in the FM in 20% of skulls studied. Chethan et al (2011) [5] also observed the protrusion of occipital condyles in the FM. In their study of 53 dry skulls, it was observed that in 20.7% of skulls, the occipital condyle protruded into the FM. They further stated that this type of morphology could lead to compression of structures passing through the FM. In this study, it was observed that overall, the occipital condyles protruded in the FM in 21.27% of the skulls. This result is closer to the findings by Chethan et al [5] and Muthukumar et al [9]. However, it is to be noted that this study also included foetal skulls and none of the foetal skulls showed the overlapping of FM by occipital condyles. Previous researches do not report of any study of overlapping of foetal FM by occipital condyles. Considering only the adult skulls in this study, the percentage of overlapping of FM by occipital condyles would be 27.6%, which is higher than the findings by Chethan et al [5] and Muthukumar et al [9]. This may be because the total numbers of skulls studied in this study were more and the skulls included female skulls of adolescent and adult age, which showed more percentage of overlapping of FM by occipital condyles than the male skulls of adolescent or adult age (see table no.3).

Vazquez et al (1996) [10] studied the Tubercle at the FM and in their study of 382 skulls found the appearance of the Tubercle in 1.3% cases. They came to think that, due to its structure, this tubercle is an ossification of the ligamentum apicis dentis because it is not radiographically homogeneous. Lakhtakia et al. (1991) [11] studied 422

adult Indian skulls of either sex and found the anterior tubercle in 64 skulls (15%). Vazquez et al.[10] state that this must be an epigenetic variation with a marked racial component. This statement holds true in case of this study as 10.63% of the skulls observed in this study showed this tubercle as opposed to 1.3% observed by Vazquez et al [10]. Foetal skulls were also included in this study, which did not show the anterior tubercle, taking in consideration only the adult skulls; the percentage would be 13.8%, which is close to the finding by Lakhtakia et al [11].

According to Sperber and Guttmann (2001) [12], the squamous portion of the occipital bone ossifies above the superior nuchal line from a pair of intramembranous occification centres in the eight week post conception and forms a pair of infranuchal endochondral ossification centres in the 10th week. These infranuchal segments fuse and a median wedge of cartilage usually develops posterior to foramen magnum. The single median basicranial, endochondral ossification centre, appearing at the 11th week forms the basioccipital bone anterior to foramen magnum and anterior one third of occipital condyles. A pair of endochondral ossificantion centres appearing at the 12th week forms the exoccipital bones, lateral to foramen magnum, including the posterior two thirds of the occipital condyles. These anterior and posterior parts of the occipital condyles surround the hypoglossal nerves forming the hypoglossal canals. Postnatally, by 2nd to 3rd year the squamous portion of occipital bone starts fusing with the exoccipital portion including the anterior one third and posterior two thirds of the occipital condyles, and by the 3rd to 4th year, the anterior synchondrosis between exoccipital portion and the basioccipital portion start disappering. By 7th year of age a single occipital bone is formed around the FM. Although, nor the overlapping of occipital condyles on the FM neither the anterior tubercle of the FM was observed in the foetal skulls. The overlapping of occipital condyles on the FM and the anterior tubercle of the FM was observed only in the some adolescent and some adult skulls (table no. 3 and 4), however, it was not known by this study that, why the occipital condyles overlap the FM in some skulls. This may be due to overgrowth of the bone due to many possible reasons. In addition, it is not clear from this study as to why does a tubercle appear at the anterior border of the FM. Predictably, this could be due to ossification of the apical ligament of dens of axis vertebra.

Conclusion:

Part 1:

1. The frequency of appearance of egg shaped FM is most (18.3%) and it appears most frequently in the adult males (28.5%) and adolescent females (26.9%).
2. The oval shaped FM follows next (16.6%), and is more frequently seen in adult group (male: 23.3% and female: 26.4%), than the adolescent (male: 15.9% and female: 15.3%) or foetal group (1.85%).
3. Next is the hexagonal shape (15.3%) which is more frequent in the adult female group (26.4%), followed by adolescent male group (20.4%).
4. The rhomboid shape follows (14%) and is more frequent in adolescent male (20.4%) and adolescent female (23%) than the adult male (11.6%) and adult female (17.6%) and foetal group (5.5%).
5. The circular shape is next (13.2%), however it is more frequently seen in foetal skulls (31.4%) and is absent or seldom seen in adolescent females.
6. The irregular shape (11.9%), which is seen next to the circular shape, is more frequent in the foetal FM (37.3%), and absent or seldom seen in adult females.
7. The less frequently seen shapes of FM are the pentagonal (5.95%), followed by the heptagonal shape (4.6%) which is absent in foetal FM.

Part 2:

1. The occipital condyles overlap the FM in 21.27% cases in the present study.
2. The most frequently overlapped shape of the FM is the egg shaped FM (17 of 43 egg shaped FM i.e. 39.5%). followed by the oval, circular, rhomboid, heptagonal, irregular, hexagonal and pentagonal shaped in the descending order. (table no. 3)
3. Sex wise, the overlapping of occipital condyles on FM is more frequent in female skulls (adolescent: 23.07% and adult: 44.1%) than in male skulls (adolescent 15.9% and adult 28.5%). (table no. 3)
4. Age wise, the overlapping of occipital condyles on FM is more frequent in adult skulls (male 28.5% and female 44.1%) than in adolescent skulls (males: 15.9% and females: 23.07%). (table no. 3)
5. The occipital condyles do not overlap the FM of foetal age group.

Part 3:

1. The anterior tubercle rarely appears in the FM and its frequency varies in different races.
2. The anterior tubercle is most frequently seen in oval shaped FM (8 of 39 oval shaped FM i.e. 20.5%) and more in males (adolescent and adult) than in females, followed by Rhomboid shaped FM. (table no. 4)

3. Sex wise, the anterior tubercle appears more frequently in females (adolescent 15.38% and adult 14.7%) than in males (adolescent 13.63% and adult 11.6%).
4. Age wise, the anterior tubercle is seen more in adolescent males (13.63%) and females (15.38%) than in adult males (11.6%) and females (14.7%) respectively
5. The egg shaped, hexagonal, heptagonal and irregular shaped FM, also show the anterior tubercle.
6. The circular shaped FM does not show the anterior tubercle in any age group.

This knowledge of the FM, occipital condyles and the anterior tubercle shall be useful for Surgeons, Neurosurgeons and Radiologists for various skull base surgeries, neurosurgeries that include the transcondylar approaches. It will also be very useful for the Clinical Anatomists, Forensic Experts and Anthropologists.

Conflicts of interest: None

Bibliography:

1. Susan Standring, Neil R Borley, Patricia Collins, Alan R Corssman, Michael A Gatzoulis, Jeremiah C. Healy, David Johnson, Vishy, Mahadeved, Richard LM Newell, Caroline B., Wigley. Gray's Anatomy, The Anatomical Basis of Clinical Practice, 40th Edition (15th Anniversary Edition) Churchill Livingstone 2008. International Edition ISBN 978-0-8089-2371-8.

2. Zaidi S.H., Dayal S.S., Variations in the shape of foramen magnum in Indian skulls. Anat Anz. 1988;167(4):338-40.

3. Khalil Awadh Murshed, Aynur Emine Çiçekcibaşi, Işik Tuncer: Morphometric Evaluation of the Foramen Magnum andVariations in its Shape: A Study on Computerized Tomographic Images of Normal Adults. Turk J Med Sci 33 (2003) 301-306.

4. Emel Avci , Ahmet Dagtekin, A. Hakan Ozturk, Engin Kara, Nail Can Ozturk, Kutluay Uluc, Erinc Akture, Mustafa K. Baskaya. Anatomical variations of the Foramen Magnum, Occipital Condyle and Jugular Tubercle. Turkish Neurosurgery (2011), Vol: 21, No: 2, 181-190

5. P. Chethan, K.G. Prakash, B.V. Murlımanju, K.U. Prashanth, Latha V. Prabhu, Vasudha V. Saralaya, Ashwin Krıshnamurthy, M.S. Somesh, C. Ganesh Kumar. Morphological Analysis and Morphometry of the Foramen Magnum: An Anatomical Investigation. Turkish Neurosurgery (2012), Vol: 22, No: 4, 416-419.

6. Radhakrishna S.K., Shivarama C.H., Ramakrishna A., Bhagya B.; Morphometric Analysis Of Foramen Magnum For Sex Determination In South Indian Population; Nitte University Journal of Health Science NUJHS March (2012), Vol. 2, No.1, ISSN 2249-7110.

7. Loyal P, Ongeti K, Pulei A, Mandela P, Ogeng'o J.: Gender Related Patterns In The Shape And Dimensions Of The Foramen Magnum In An Adult Kenyan Population; Anatomy Journal of Africa. (2013), 2 (2): 138 – 141

8. José Aderval Aragão, Raisa de Oliveira Pereira, Rebeca Zelice da Cruz de Moraes and Francisco Prado Reis: Morphological Types of Foramen Magnum. Annual Research & Review in Biology 4(9): 1372-1378, 2014.

9. Muthukumar N, Swaminathan R, Venkatesh G, Bhanumathy SP: A morphometric analysis of the foramen magnum region as it relates to the transcondylar approach. Acta Neurochir (Wien)147:889-895, 2005

10. Juan Francisco Pastor Vazquez, J. A. Gil Verona, J. A. Moro Balbas, M. Gracia Porrero and E. Barbosa Ayucar: Tubercle at Foramen Magnum. Skull Base Surgery, July 1996, Volume 6, Number 3.

11. P. K. Lakhtakia, I.C. Premsagar, K. K. Bisaria, and S. D. Bisaria: A Tubercle at the Anterior Margin of the Foramen Magnum. J. Anat. (1991), 177, pp. 209-210.

12. Craniofacial Development (Book for Windows & Macintosh) By Geoffrey H. Sperber, Geoffrey D. Guttmann, Steven M. Sperber 2001 ISBN 1-55009-127-1

13. F. Burdan, J. Szumiło, J. Walocha, L. Klepacz, B. Madej, W. Dworzański, R. Klepacz, A. Dworzańska, E. Czekajska-Chehab, A. Drop; Morphology of the foramen magnum in young Eastern European adults, Folia Morphol., (2012), Vol. 71, No. 4.