A computed tomographic analysis of foramen magnum parameters for age determination in a sample of Egyptians

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KEYWORDS
Age Determination,
Foramen Magnum,
Skull Base,
Egyptian

ABSTRACT

Age determination is an essential step in the identification of human bony remains. Foramen magnum is a valuable landmark in the base of the skull and is of significant interest to forensic medicine, anthropology and anatomy. The aim of the study was the evaluating of the accuracy and reliability of foramen magnum parameters in age determination (among different age groups) using three-dimensional computed tomography. The present study is performed on 120 Egyptians from different age groups (from 1 year up to 65 years). The length of the foramen magnum (LFM) and the width of the foramen magnum (WFM) were measured on the 3D CT models. Then, foramen magnum index (FMI) and foramen magnum area (FMA) were calculated. The different age groups (1 – 9, 10 – 19, 20 – 29, 30 -39, 40 – 49,50 – 59 and 60+ years) show the mean LFM was 26.90, 35.75, 34.66, 34.42, 33.88, 33.27 and 32.50 mm respectively. Mean WFM was 20.90, 25.67, 29.47, 28.75, 28.47, 27.53 and 28.0 mm respectively. Mean FMI was 1.29, 1.39, 1.18, 1.20, 1.20, 1.21 and 1.16 mm respectively. Mean FMA was 444.2, 721.7, 804.3, 783.0, 759.3, 720.8 and 718.1 mm respectively. These values reveal that there is a significant difference between the four studied parameters and different age groups. This study elucidated that LFM decrease and WFM increase with aging. Subsequently, FMI tends to decrease with age. There was a weak positive correlation between age and LFM, WFM and FMA and there was a negative correlation between age and FMI.

Introduction

The determination of sex, age, race and stature of persons provides the basis for the identification of unknown individuals, which is crucial in forensic studies (Raikar et al., 2016).

Adult human skeletal remains can be used to determine age with a high degree of accuracy, if the entire skeleton is available for study. On the other hand, it is not always likely to discover an entirely intact skeleton (Priya, 2017).

Age in human skulls is typically determined by morphological characteristics, particularly the size and strength of specific structures that are distinctive to each population (Abdullah et al., 2022).

The skull is an appropriate skeletal structure to employ for determining the elements of identity (Pires et al., 2016). Several authors claim that the occipital bone can be used to estimate age (Smith et al., 2021).

On the other hand, from a quantitative perspective, age estimation indexes have been constructed using measurements of the foramen magnum (Yilma et al., 2021). Anthropology and forensic medicine are particularly interested in foramen magnum, which

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is a significant landmark at the skull base (Shanthi and Lokanadham, 2013).

Foramen magnum is presented within the occipital bone and joins the posterior cranial fossa with the vertebral canal. The occipital bone's squama, basilar portion, and two lateral parts, in that order, surround the foramen magnum on its anterior, posterior, and lateral sides (Ficke and Varacallo, 2022).

The posterior and anterior intraoccipital synchondroses, which ossify between the ages of 2-7 years old, serve as a link between those structures during the prenatal and postnatal phases. (Ominde and Igbigbi, 2022).

Many studies have been done to investigate whether traditional osteometric parameters may be obtained from the 3D reconstructions of the multi-slice computed tomography of the skull base for the aim of identification (Dalessandri et al., 2020).

The aim of the study was to determine the age (among different age groups) from the foramen magnum using three-dimensional computed tomography (3D CT).

Subjects and Methods

One-hundred and twenty Egyptians, from different age groups (from 1 up to 65 years), were selected randomly as referred to the Radiology Department of Alexandria Main University Hospital for radiological examination using a Multi-Slice Computerized Tomography (MSCT) of the skull.

The Ethics Committee of the Faculty of Medicine, Alexandria University provided approval of the study protocol. (IRB Number: 00012098, FWA Number: 00018699, Approval serial number: 0304840).

Patients with history of pathological lesions, surgery or trauma at the base of the skull that could preclude accurate measurements were excluded from the study.

An MSCT scan is obtained for each patient, and then a high quality 3D model of the cranium is performed. Various metric parameters related to foramen magnum are measured on the 3D models of the cranium of the studied persons (Figure 1).

The parameters (in mm) of the foramen magnum (FM) (Uthman et al., 2012) are as follows:

1. Length of foramen magnum (LFM): reported as the greatest anteroposterior dimension of the FM.
2. Width of foramen magnum (WFM): reported as the greatest width of the FM.
3. Foramen magnum index (FMI) (Sangvichien et al., 2007): calculated by dividing the length of the FM by its width.
4. Foramen magnum area (FMA) (Darwish et al., 2014): calculated using Radinsky`s formula: FMA (in mm2) = $0.25 \times L \times W \times 22/7$. (L = length of FM and W = width of FM).

Statistical analysis of the data:

Package version 20.0 of IBM SPSS software was used for data analysis (IBM Corp, Armonk, NY). The categorical data was presented as numbers and percentages. The normality of the data was verified using Shapiro-Wilk test. The quantitative data was expressed using mean and standard deviation, median, minimum and maximum. Pearson coefficient was used to correlate between normally distributed quantitative variables. ANOVA was implemented to compare different groups. Post Hoc test (Tukey) was used to compare two groups at 5 % level (Kirkpatrick and Feeney, 2013).

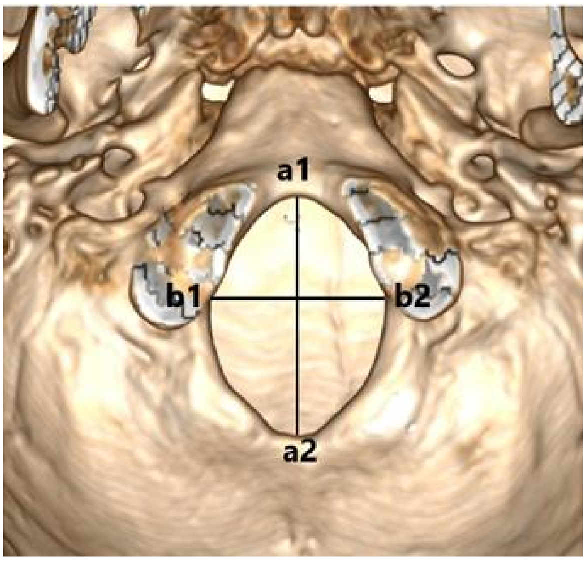

Fig. (1): Three-dimensional computed tomography of the base of the skull of 11 years old male showing measurements of the length and width of the foramen magnum. a1–a2 = the maximum length of the foramen magnum. b1–b2 = the maximum width of the foramen magnum.

Results:

The study was carried out on 120 individuals (65 males representing 54.2 %, and 55 females representing 45.8 %) of different age groups (1 – 9, 10 – 19, 20 – 29, 30 -39, 40 – 49, 50 – 59 and 60+ years) with a mean age of 31.56 ± 14.71 year (Table 1).

Table (1): Distribution of the studied patients according to their age and sex (n=120)

Age groups	Sex		Total (n = 120)
	Male (n = 65/54.2%)	Female (n = 55/45.8%)	
1 – 9	6 (9.2%)	4 (7.3%)	10 (8.3%)
10 – 19	5 (7.7%)	7 (12.7%)	12 (10.0%)
20 – 29	27 (41.5%)	11 (20.0%)	38 (31.7%)
30 -39	16 (24.6%)	8 (14.5%)	24 (20.0%)
40 – 49	8 (12.3%)	9 (16.4%)	17 (14.2%)
50 – 59	3 (4.6%)	12 (21.8%)	15 (12.5%)
60+	0 (0.0%)	4 (7.3%)	4 (3.3%)
Mean ± SD.	28.25 ± 11.62	35.47 ± 16.98	31.56 ± 14.71

n: Number, **SD:** Standard deviation

Table (2) shows that the mean length of foramen magnum in the different age groups (1 – 9, 10 – 19, 20 – 29, 30 -39, 40 – 49,50 – 59 and 60+ years) is 26.90, 35.75, 34.66, 34.42, 33.88, 33.27, 32.50 mm respectively. However, the mean length of foramen magnum after the age group of 10-19 years decreases with increasing age. There was a significant difference between length of foramen magnum and different age groups where $p<0.001$.

Table (2): Length of foramen magnum among different age groups in mm

Age groups	n	Min (mm)	Max (mm)	LFM Mean (mm)	SD.	Median	F	p
1 – 9	**10**	24.0	31.0	26.90	2.85	26.0	13.245*	<0.001*
10 – 19	**12**	30.0	41.0	35.75	3.57	34.50		
20 – 29	**38**	30.0	39.0	34.66	2.06	35.0		
30 -39	**24**	22.0	40.0	34.42	3.48	35.0		
40 – 49	**17**	31.0	36.0	33.88	1.87	34.0		
50 – 59	**15**	28.0	37.0	33.27	2.46	33.0		
60+	**4**	29.0	35.0	32.50	2.65	33.0		

Min: Minimum, Max: Maximum, n: Number, SD: Standard deviation, F: F for One way ANOVA test p: p value for comparing between the studied age group, *: Statistically significant at p ≤ 0.05, LFM: Length of the foramen magnum

Table (3) depicts that the mean width of foramen magnum in the different age groups (1 – 9, 10 – 19, 20 – 29, 30 -39, 40 – 49,50 – 59 and 60+ years) was 20.90, 25.67, 29.47, 28.75, 28.47, 27.53 and 28.0 mm respectively. The mean width of foramen magnum increases with increasing age among children, adolescents and early adulthood. There was a significant difference between the width of foramen magnum and the different age groups where p<0.001.

Table (3): Width of foramen magnum among different age groups in mm

Age groups	n	Min (mm)	Max (mm)	WFM Mean (mm)	SD.	Median	F	p
1 – 9	**10**	19.0	24.0	20.90	1.79	20.50	19.663*	<0.001*
10 – 19	**12**	24.0	28.0	25.67	1.30	26.0		
20 – 29	**38**	25.0	34.0	29.47	2.40	30.0		
30 – 39	**24**	16.0	33.0	28.75	3.10	29.0		
40 – 49	**17**	25.0	33.0	28.47	2.45	28.0		
50 – 59	**15**	25.0	32.0	27.53	1.81	27.0		
60+	**4**	26.0	30.0	28.0	2.31	28.0		

Min: Minimum, Max: Maximum, n: Number, SD: Standard deviation, F: F for One way ANOVA test, p: p value for comparing between the studied age group, *: Statistically significant at p ≤ 0.05, WFM: Width foramen magnum

Table (4) demonstrates that there is a significant difference between foramen magnum index and different age groups where p<0.001. The mean foramen magnum index in the different age groups (1 – 9, 10 – 19, 20 – 29, 30 - 39, 40 – 49, 50 – 59 and 60+ years) is 1.29, 1.39, 1.18, 1.20, 1.20, 1.21, 1.16 mm respectively. The age group of 10 – 19 years shows the highest mean foramen magnum index, while the age group of 60+ years shows the lowest mean foramen magnum index.

Table (4): Relation between foramen magnum index and different age groups

Age groups	n	Min (mm)	Max (mm)	FMI Mean (mm)	SD.	Median	F	p
1 – 9	**10**	1.14	1.45	1.29	0.10	1.28		
10 – 19	**12**	1.15	1.56	1.39	0.14	1.42		
20 – 29	**38**	.97	1.40	1.18	0.09	1.16		
30 – 39	**24**	.97	1.38	1.20	0.10	1.22	8.202*	<0.001*
40 – 49	**17**	1.03	1.44	1.20	0.10	1.20		
50 – 59	**15**	1.08	1.38	1.21	0.10	1.19		
60+	**4**	1.12	1.23	1.16	0.05	1.15		

Min: Minimum, Max: Maximum, n: Number, SD: Standard deviation, **F**: F for One way ANOVA test, p: p value for comparing between the studied age group, *: Statistically significant at $p \leq 0.05$, FMI: Foramen magnum index

Table (5) reveals that the mean foramen magnum area in the different age groups (1 – 9, 10 – 19, 20 – 29, 30 -39, 40 – 49, 50 – 59 and 60+ years) is 444.2, 721.7, 804.3, 783.0, 759.3, 720.8 and 718.1 mm respectively. The age group of 20 – 29 shows the highest mean foramen magnum area, while the age group of 1 – 9 shows the lowest mean foramen magnum area. There is a significant difference between foramen magnum area and different age groups where p<0.001.

Table (5): Relation between foramen magnum area and different age groups

Age groups	n	Min	Max	FMA Mean	SD.	Median	F	p
1 – 9	**10**	358.3	584.6	444.2	79.25	417.6		
10 – 19	**12**	612.9	869.8	721.7	88.14	704.0		
20 – 29	**38**	612.9	1015.1	804.3	96.56	825.0		
30 -39	**24**	276.6	919.3	783.0	127.2	812.4	18.279*	<0.001*
40 – 49	**17**	608.9	907.5	759.3	90.58	748.0		
50 – 59	**15**	572.0	930.3	720.8	83.98	721.3		
60+	**4**	592.4	825.0	718.1	113.0	727.6		

Min: Minimum, Max: Maximum, n: Number, FMA: Foramen magnum area, SD: Standard deviation, **F**: F for One way ANOVA test, p: p value for comparing between the studied age group, *: Statistically significant at $p \leq 0.05$.

There was a weak positive correlation and no statistically significant difference between age and length of foramen magnum (r=0.177, P=0.053). Also there was a weak positive correlation between age and width of foramen magnum but there was a statistically significant difference (r=0.321, P<0.001). There was a negative correlation but statistically significant difference between age and foramen magnum index (r=-0.241, P=0.008). Additionally, a weak positive correlation and statistically significant difference between age and foramen magnum area was found (r=0.263, P=0.004) (Figures 2 - 4).

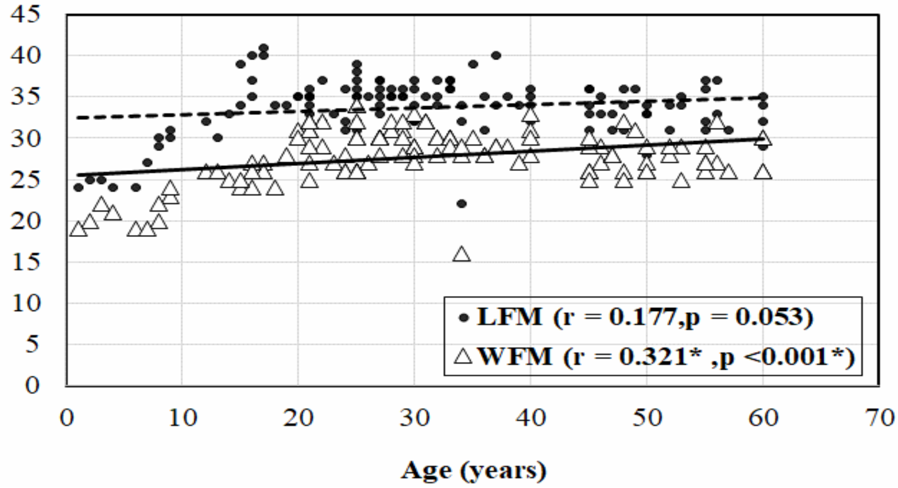

Fig. (2): Correlation between age and length and width of foramen magnum (n=120)

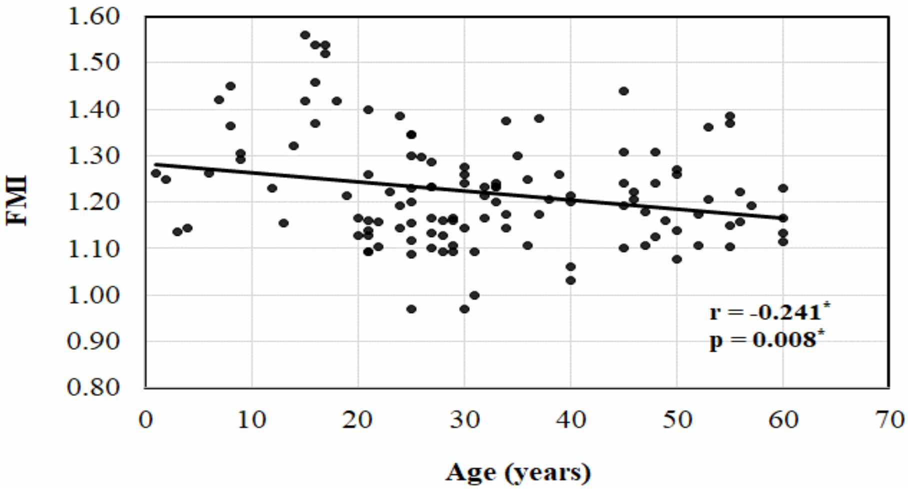

Fig. (3): Correlation between age and foramen magnum index (n=120)

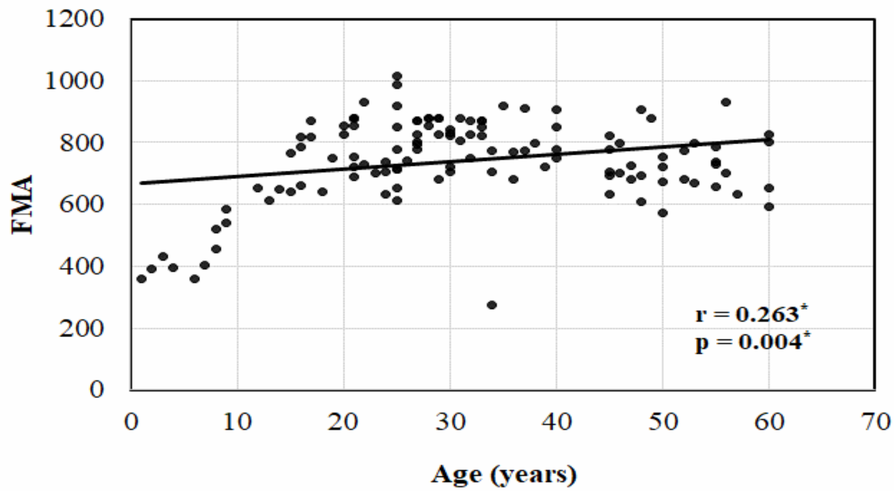

Fig. (4): Correlation between age and foramen magnum area (n=120)

Discussion:

Numerous authors have been interested in studying the morphometric parameters of foramen magnum in relation to age. They conclude that identifying the dimensions of foramen magnum is important for forensic experts when determining the age of an individual (Shaikh and Kulkarni, 2015). So the present work aimed at evaluating the accuracy and reliability of foramen magnum parameters in the determination of different age groups among Egyptians using three-dimensional computed tomography.

This study has been carried out on 120 individuals (65 males and 55 females) of seven age groups (1 – 9, 10 – 19, 20 – 29, 30 - 39, 40 – 49, 50 – 59 and 60+ years) to cover the different periods of an individual's development.

The present study revealed a significant difference between the length of foramen magnum and different age groups, and it shows that the mean length of foramen magnum after the age group of 10-19 years decreases with increasing age. This can be attributed to the ossification of the occipital bone with increasing age (Sanchez and Graham, 2017). This coincides with the study done by Wilk et al. (2022). Furthermore, the study conducted by Samara et al. (2017) showed a weak negative linear relation between the age of individuals and the length of foramen magnum.

In the current work, the mean width of foramen magnum increases with increasing age among children, adolescents and early adulthood, proving the rapid growth of foramen magnum in this period. There is a significant difference between the width of foramen magnum and different age groups. This agrees with the study done by Moodley et al. (2019) on the South African Black population. The mean width of foramen magnum among the adult group in this work is nearly similar to that presented in the study of Patel and Mehta (2014) on the adult Indian population.

In the present research, there is a significant difference between foramen magnum indices with different age groups. The age group of 10 – 19 years shows the highest mean foramen magnum index, while the age group of 60+ years shows the lowest mean foramen magnum index. This may be attributed to the rapid growth of bones at the young age. The foramen magnum index among the adult ages in this study is similar to the findings present in the study done by Samara et al. (2017).

In the current study, there was a significant difference between foramen magnum area and different age groups. The age group 20 – 29 years shows the highest mean foramen magnum area while the age group of 1 – 9 years shows the lowest mean foramen magnum area. The value of foramen magnum area obtained from calculation using a formula containing length and width of the foramen magnum which showed a high value at the age group 20 – 29 years and low value at the age group of 1 – 9 years. So, the mean foramen magnum area was highest at the age group 20 – 29 years and lowest at the age group of 1 – 9 years.

By studying the different age groups, it was noticed that foramen magnum area increases with age until adulthood. This nearly agrees with Moodley et al., 2019 who used computer tomography scans to examine foramen magnum morphology and morphometry in South African Black people. In contrast to the present research, Meral et al. (2020) reported larger foramen magnum area among Turkish adults.

In the present work, there is a weak positive correlation and no statistically significant difference between age and length of foramen magnum and a weak positive correlation and a statistically significant difference between age and width of foramen magnum. Additionally, there was a negative correlation but statistically significant difference between age and foramen magnum index and a weak positive correlation and statistically significant difference between age and foramen magnum area.

The use of wide sample size and the variety in the examined age may be responsible for age induced change in the foramen magnum morphometry. This correlation may have been affected by underlying dietary and sociodemographic factors. For instance, good nutrition and an increase in stature may have resulted in a regional intergenerational increase in the foramen magnum dimensions (Samara et al., 2017).

Samara et al. (2017) study found a weak negative linear correlation between age and both foramen magnum anteroposterior and transverse diameters. Other researches have showed either no correlation or a positive correlation between age and foramen magnum dimensions (Manoel et al., 2009).

In most foramen magnum researches, results are yielded from the measurements taken mainly in adults, whereas researches on children are rare. Therefore, the current work fulfills a research gap; because it is the first study to show the relation between different age groups (children, adults and the elderly) and different measurements of foramen magnum measured on the 3D models of the cranium.

Conclusion:

The current study reveals that the mean LFM decreases with increasing age, whereas the mean WFM increases with increasing age. Subsequently FMI tends to decrease with age. Regarding mean FMA, the age group of 20 – 29 shows the highest value, while the age group of 1 – 9 shows the lowest value. There is a weak positive correlation between age and length of foramen magnum, width of foramen magnum and foramen magnum area and there is a negative correlation between age and foramen magnum index.

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Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose.

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تحليل قياسات الثقبة العظمى باستخدام الاشعة المقطعية لتحديد العمر في عينة من المصريين

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يعد تحديد العمر خطوة أساسية من بقايا العظام البشرية. الثقبة العظمى هي علامة بارزة قيّمة في قاعدة الجمجمة ولها أهمية كبيرة في الطب الشرعي والأنثروبولوجيا وعلم التشريح. لذلك كان الهدف من الدراسة هو تقييم دقة وموثوقية قياسات الثقبة العظمى في تحديد العمر (بين الفئات العمرية المختلفة) باستخدام التصوير المقطعي ثلاثي الأبعاد. و قد أجريت الدراسة الحالية على ١٢٠ مصريًا من مختلف الفئات العمرية (من ١ إلى ٦٥ سنة). تم قياس طول وعرض الثقبة العظمى على نماذج التصوير المقطعي ثلاثي الأبعاد. ثم بعد ذلك تم حساب مؤشر الثقبة العظمى ومساحة الثقبة العظمى. هذا و قد اظهرت الفئات العمرية المختلفة (١-٩ ، ١٠-١٩ ، ٢٠-٢٩ ، ٣٠-٣٩ ، ٤٠-٤٩ ، ٥٠-٥٩ ، ٦٠+ سنة) أن متوسط طول الثقبة العظمى كان ٢٦,٩٠ ، ٣٥,٧٥ ، ٣٤,٦٦ ، ٣٤,٤٢ ، ٣٣,٨٨ ، ٣٣,٢٧ و ٣٢,٥٠ ملم على التوالي. و كان متوسط عرض الثقبة العظمى ٢٠,٩٠ و ٢٥,٦٧ و ٢٩,٤٧ و ٢٨,٧٥ و ٢٨,٤٧ و ٢٧,٥٣ و ٢٨,٠ ملم على التوالي. بينما كان متوسط مؤشر الثقبة العظمى ١,٢٩ و ١,٣٩ و ١,١٨ و ١,٢٠ و ١,٢٠ و ١,٢١ و ١,١٦ ملم على التوالي. و كان متوسط مساحة الثقبة العظمى ٤٤٤,٢ و ٧٢١,٧ و ٨٠٤,٣ و ٧٨٣,٠ و ٧٥٩,٣ و ٧٢٠,٨ و ٧١٨,١ ملم على التوالي. و تظهر هذه القيم أن هناك فرقا معنويا بين المعايير الأربعة المدروسة في الفئات العمرية المختلفة. و تخلص هذه الدراسة الى أن طول الثقبة العظمى ينخفض بينما يزداد عرض الثقبة العظمى مع تقدم العمر. ،في حين يميل مؤشر الثقبة العظمى إلى الانخفاض مع تقدم العمر. كان هناك ارتباط إيجابي ضعيف بين العمر و طول ،عرض و مساحة الثقبة العظمى وكان هناك ارتباط سلبي بين العمر و مؤشر الثقبة العظمى