

The Number and Determinants of Nutrient foramina among dry human femur bones from the East African population: A Cross-section study

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ABSTRACT

Background: Nutrient foramina form important landmarks on the femur and other bones as the portal of entry for nutrient arteries. Nutrient arteries are important sources of blood supply for growing bones; and their variations may be due to congenital or acquired causes. These variations are important in anatomical comparisons, orthopaedic surgical practice and forensic medicine.

Aims: This study aimed at establishing the number and determinants of the nutrient foramina among dry human femur bones from the East African population.

Materials and methods: This was a cross-section study of 333 dry femur bones from the East African population, at the Galloway osteological collection of Makerere University college of health sciences. The number of nutrient foramina on the shaft of each femur, the corresponding demographic, clinical and morphometric characteristics were documented. Data were entered in an Excel sheet and exported to STATA 14 for analysis. Univariate, bivariate and multivariable analyses were performed to obtain the summary statistics and the measures of association. At all levels of analysis, a p-value of less than 0.05 was considered statistically significant.

Results: Of the 333 femurs, 291 (87.4%) were from males; and 137(50.15%) were right femurs. The age ranged from 20 to 75 years with a mean age of 35 (SD± 12) years. Nutrient foramina ranged from one to four; mean of 1.4 (SD±0.5) and median of 1 (IQR: 1 to 2). Of the 333 femurs, 199 (59.8%) had one foramen, 129 (38.7%) had two foramina, four femurs had three foramina and one femur had four foramina. There was a statistically significant association between the number of nutrient foramina and the femur's: mid-shaft circumference (p=0.014; 95%CI: 0.003 to 0.028), nationality (p=0.016; 95%CI: -0.284 to -0.030) and sex (p=0.012; 96% CI: -0.405 to -0.050).

Conclusion: Nutrient foramina among femurs from the East African population range from one to four per femur, with predominantly one foramen. The key determinants of the number of foramina are: mean mid-shaft circumference, nationality and sex. These findings are significant in anatomical comparisons; forensic and orthopaedic practices.

KEY WORDS: Nutrient foramina, dry human femur, East African population, morphometric characteristics.

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INTRODUCTION

Nutrient foramina are openings that form the portal of entry for nutrient arteries into the medullary cavities of the shafts of long bones[1].

The number of nutrient foramina is a measure of the vascularity of long bones. Blood supply to the femur and other long bones is dependent on periosteal arteries and nutrient arteries-the main source of blood supply during early life [2]. Femoral nutrient arteries arise from the branches of the femoral arteries. Nutrient foramina and other morphometric characteristics of the human femur are important in Anatomical comparisons, orthopaedic surgery and forensic medicine. Identification of nutrient foramina is crucial for vascularized bone grafting, positioning of internal fixation, and microsurgical vascularized bone transplantation. These procedures require conservation of the circulation of the affected bone for quick healing of the graft in the recipient, and maintenance of osteogenic cells [3].

The variations in the femoral nutrient foramina is an indicator of the anatomical disparities of the femoral vasculature due to congenital or acquired anomalies. The congenital disparities may be due to a combination of persistent primitive arterial segments, abnormal fusions, and segmental vascular hypoplasia or aplasia [4].

Anatomical variations of the femoral artery include absent profunda femoris artery, persistent sciatic artery and duplication of superficial femoral artery; failure to recognize these variations can lead to limb ischemia, life threatening hemorrhage, delayed healing after surgical procedures, and other surgical complications [5].

Despite the wide spread of orthopaedic surgical practice and forensic practice in East Africa, limited focus has been directed on establishing the variation and determinants of lower limb vasculature. Therefore, this study aimed at establishing the number and determinants of the nutrient foramina among dry human femurs from the East African population for future use in regional

Anatomical comparisons; forensic and orthopaedic surgical practice.

METHODS

This was a cross-section study of 333 dry femur bones from the East African population. The bones were obtained from the Galloway osteological collection of Makerere University college of health sciences. The study was conducted after obtaining ethical approval from Makerere university School of Biomedical sciences research and Ethics committee (MaKSBS-REC). Only adult femurs were included in the study. Deformed femurs and femurs with incomplete demographic and clinical data were excluded. A magnifying glass was used to detect the foramina, and a hypodermic needle passed in each foramen to delineate its patency. The nutrient foramina were identified by the existence of a well-defined groove with a slightly elevated edge at the start of the foramen. The number of nutrient foramina on the shaft of each femur and the corresponding demographic, clinical and morphometric characteristics were documented. Each femur shaft (diaphysis) was divided into three equal parts: upper shaft, mid-shaft and lower shaft and the circumferences of each part taken. The femoral head, femoral neck and shaft circumferences were measured using a standard measuring tape graduated in millimeters. The physiological length- maximum vertical distance between upper end of the head of femur and the lowest point on femoral condyle of the femur, was measured using the osteometric-board and a standard measuring tape graduated in centimeters.

Data were entered in an Excel sheet and exported to STATA 14 for analysis. Univariate, bivariate and multivariable analyses were performed to obtain the summary statistics, the measures of association and the strength of association. At bivariate analysis, simple linear regression was performed to establish the association between the number of nutrient foramina and: mean femur head circumference, mean femur neck circumference, mean femur upper shaft circumference, mean femur mid-shaft circumference and mean lower shaft circumference. The independent

t-test was performed to establish if there was a difference in the mean number of nutrient foramina among the different categories of: femur side, sex, nationality and the presence of the third trochanter. Linear regression was performed to determine the association between the number of nutrient foramina and the femur: head circumference, neck circumference, upper shaft circumference, mid-shaft circumference and lower shaft circumference. Factors that had a p-value of up to 0.2 at bivariable analysis were fit in the multiple linear regression model. At all levels of analysis, a p-value of less than 0.05 was considered statistically significant.

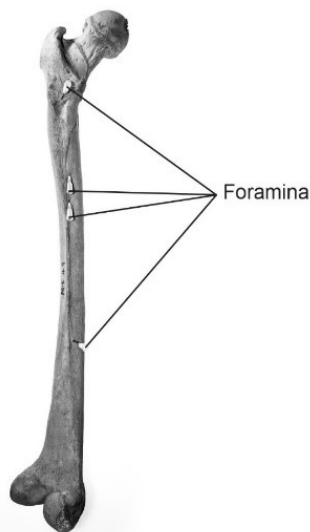


Fig. 1: Femur with four nutrient foramina.

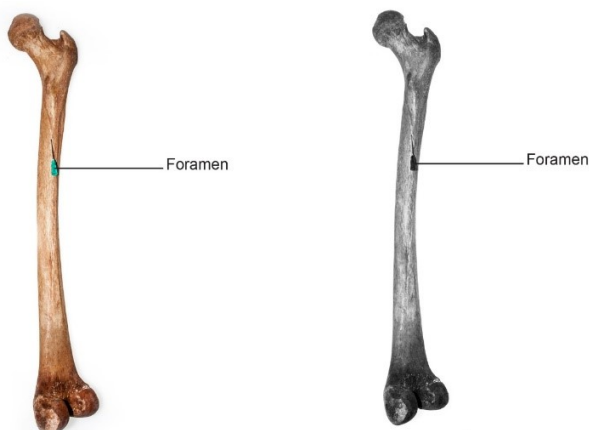


Fig. 2: Femur with one nutrient foramen.

RESULTS AND DISCUSSION

Baseline Characteristics: Of the 333 femur bones analyzed, 291 (87.4%) were from males with a male to female ratio of 7: 1. The femurs were of persons aged 20 years to 75 years with a mean age of 35years (SD± 12). One hundred and sixty-seven (50.15%) femurs were right

femurs while 166 (49.85%) were left femurs. The femur bones had: mean head circumference of 134.9mm (SD± 8.9); mean neck circumference of 91.7mm (SD ±7.4); mean Upper shaft circumference of 84.5mm (SD ±6.2); Mean mid-shaft circumference of 81.1mm (SD ±6.8); Mean lower shaft circumference of 104.7mm (SD ±9.9); and the mean physiological length of 46.6cm (SD± 3.0). The prevalence of the third trochanter was 7.2% (24 out of 333 femurs); the prevalence of the third trochanter among right femurs was 9.0% (15 out of 167 right femur bones) and among the left femur bones, the prevalence was 5.4% (9 out of 166 left femurs).

Nutrient Foramina: The number of nutrient foramina ranged from one to four (Figures 1 and 2), with a mean of 1.4 (SD±0.5) and median of 1 (IQR: 1 to 2). Of the 333 femurs, 199 (59.8%) had one foramen, 129 (38.7%) had two foramina, four femurs had three foramina and one femur had four foramina. On average, the number of foramina were more among femurs from: left side, females, non-Ugandan, and femurs with third trochanters (Table 1)

Determinants of the number of Nutrient foramina: At bivariate analysis, there was a statistically significant association between the number of nutrient foramina and the femur mid-shaft circumference ($p=0.006$; 95% CI: 0.003 to 0.020). For every unit increase in the mid shaft circumference, there was a 1.2% increase in the number of nutrient artery foramina. Other femur parameters did not show statistical significance (Table 2). There was no statistically significant difference in the mean number of nutrient foramina between: the left and right femur; female and male femur; Non-Ugandan and Ugandan femur; femur with third trochanter and femur without the third trochanter (Table 3).

At multivariable analysis, there was a statistically significant association between the number of nutrient foramina and the: sex, nationality and mid-shaft circumference of the femurs. The nutrient foramina were 22.7% lower among femurs from males compared to females, adjusting for nationality, age, femur neck circumference, femur upper shaft circumference, and mid-shaft circumference. The nutrient foramina were 15.7% lower among femurs from Ugandans

Table 1: Distribution of Nutrient foramina by Demographic and Clinical Characteristics.

Variable	Mean number of nutrient foramina (SD)	Median number of nutrient foramina (IQR)	One foramen (%)	Two foramina (%)	Three foramina (%)	Four foramina (%)
Femur side (N=333)						
Right (n=167)	1.4 (0.5)	1 (1 to 2)	108 (64.67)	57 (34.13)	2 (1.20)	0 (0.00)
Left (n=166)	1.5 (0.5)	1 (1 to 2)	91 (54.82)	72 (43.37)	2 (1.20)	1 (0.60)
Sex (N=333)						
Male (n=291)	1.4 (0.5)	1 (1 to 2)	180 (61.86)	106 (36.43)	4 (1.37)	1 (0.34)
Female (n=42)	1.5 (0.5)	2 (1 to 2)	19 (45.24)	23 (54.76)	0 (0.00)	0 (0.00)
Nationality (N=333)						
Non-Ugandan (n=200)	1.5 (0.6)	1 (1 to 2)	113 (56.50)	82 (41.00)	4 (2.00)	1 (0.50)
Ugandan (n=133)	1.4 (0.5)	1 (1 to 2)	86 (64.66)	47 (35.34)	0 (0.00)	0 (0.00)
Presence of third trochanter						
Yes (n=24)	1.4 (0.7)	1 (1 to 2)	17 (70.83)	6 (25.00)	1 (4.17)	0 (0.00)
No (n=309)	1.4 (0.5)	1 (1 to 2)	182 (58.90)	123 (39.81)	4 (1.29)	0 (0.00)

Table 2: Results of simple linear regression determinants of the number of nutrient foramina.

Independent Variable	Regression Coefficient	t-statistic	p-value	95% CI
Age	-0.0032	-1.31	0.19	-0.008 to 0.001
Femur Head circumference	0.0003	0.1	0.921	-0.006 to 0.007
Femur Neck circumference	0.006	1.46	0.146	-0.002 to 0.014
Femur Upper shaft circumference	0.008	1.62	0.106	-0.002 to 0.017
Femur Mid-shaft circumference	0.012	2.75	0.006	0.003 to 0.020
Femur Lower-shaft circumference	0.0004	0.12	0.904	-0.005 to 0.006
Femur Physiological length	-0.007	-0.73	0.465	-0.027 to 0.012

Table 3: Independent t-test results of the mean number of foramina difference by Femur side, Sex and Nationality.

Variable	Mean number of foramina (SD)	Mean difference	t (df)	p-value	95% CI
Femur side					
Left femur	1.45(0.56)				
Right femur	1.37 (0.51)	0.11	1.89 (331)	0.059	-0.004 to 0.225
Sex					
Female	1.55 (0.50)				
Male	1.40 (0.54)	0.15	1.65 (331)	0.1	-0.027 to 0.319
Nationality					
Non-Ugandan	1.47 (0.57)				
Ugandan	1.35 (0.47)	0.11	1.87 (331)	0.062	-0.006 to 0.229
Presence of Third trochanter					
Yes	1.38 (0.71)				
No	1.42 (0.52)	-0.05	-0.43 (331)	0.667	-0.272 to 0.174

Table 4: Results of Multivariable analysis of the determinants of the number of nutrient foramina.

Variable	Regression Coefficient	t-statistic	P-value	95% CI
Femur side	-0.1069	-1.87	0.063	-0.220 to 0.006
Sex	-0.2274	-2.52	0.012	-0.405 to -0.050
Nationality	-0.157	-2.43	0.016	-0.284 to -0.030
Age	-0.0009	-0.34	0.737	-0.006 to 0.004
Femur Neck circumference	0.0023	0.44	0.66	-0.008 to 0.013
Femur Upper shaft circumference	-0.0033	-0.46	0.648	-0.017 to 0.011
Femur Mid-shaft circumference	0.015	2.47	0.014	0.003 to 0.028

compared to non-Ugandans, adjusting for femur side, sex, age, femur neck circumference, femur upper shaft circumference, and mid-shaft circumference. For every unit increase in the mid-shaft circumference, there was a 1.5% increase in the number of nutrient foramina, adjusting for femur side, sex, nationality, age, femur neck circumference and femur upper shaft circumference (Table 4).

DISCUSSION

Nutrient foramina allow the passage of nutrient arteries that are the main blood supply to long bones, and vital during the active growth period and at the early phases of ossification. The number and position of nutrient foramina in human bones are variable and may alter during growth.

The number of Nutrient foramina: In this study, the number of nutrient foramina ranged from one to four. Majority (59.8%) had one foramen and only one femur had four foramina. The one foramen predominance is similar to previous studies among the Asian population, where of the 80 femurs with one to two foramina, 93.8% had one foramen [6]; 62% of the 100 femur bones with one to three foramina had a single nutrient foramen [7]; and 64.5% of the 107 femurs with zero to three foramina had one nutrient foramen [8].

However, other studies in Asia noted a predominance of double nutrient foramina of 50% among 60 femur bones [9], and 60% among 300 femur bones [10]. The differences in the range of foramina could be due to the differences in the genetic makeup, nutrition, and age differences of the samples studied. Generally, of all the lower limb bones, the femur has been observed to have more nutrient foramina [8, 11]; this may partly explain why the femur is the longest of all lower limb bones.

Determinants of nutrient foramina: The mean number of nutrient foramina was 1.4 (SD±0.5). This is consistent with the findings among the Asian population [12]. On average, the number of foramina were more among femurs from: left side, females, non-Ugandan, and femurs with third trochanters (Table 1). Sex and nationality were significantly associated

with number of nutrient foramina (Table 4). This observation could be due to the vascular variations due to differences in hormones, genetics and nutrition across different sex and nations.

The mean mid-shaft circumference of 81.1mm (SD ±6.8) was the smallest compared to the mean upper shaft circumference of 84.5mm (SD ±6.2) and mean lower shaft circumference of 104.7mm (SD 9.9). However, only the mean mid-shaft circumference was significantly associated with the number of nutrient foramina ($p=0.014$; 95%CI: 0.003 to 0.028). This could explain the differential growth rates among the different femur parts. Although this study did not assess the topography of the nutrient foramina, previous studies consistently report the predominance of nutrient foramina in the mid-shaft of the femur [8, 12, 13]. Consequently, the mean mid-shaft circumference would be expected to be the greatest in this study. The observed discrepancy may be due to the interplay of different factors in femur growth and development that affect the femur vascularity [5].

In this study, the mean length of the femur was 46.6cm (SD ±3.0); this is higher compared to reports of studies in South Africa, Asia and Europe that report mean lengths ranging from 40cm to 44.96cm [9, 13, 14]. Although this study did not show a statistically significant association between the number of nutrient foramina and the mean length of the femur (Table 2), there is a possibility that increased nutrient foramina with nutrient arteries lead to increased femur length holding other factors constant.

The magnitude of the t-statistics (Table 4) suggest that among the determinant of nutrient foramina that achieved statistical significance, the mean mid-shaft circumference had the biggest influence ($t=2.47$), followed by Nationality ($t=-2.43$) and sex had the least influence ($t=-2.52$). Therefore, the number of nutrient foramina may be used to predict the mid-shaft circumference, the nationality and sex of human remains.

CONCLUSION

Results of this study suggest that nutrient foramina among femur bones from the East African population range from one to four per

femur; and the majority of the femur bones have one foramen. On average, the number of foramina are more among femurs from: left side, females, non-Ugandan, and femurs with third trochanters. The key determinants of the number of foramina are: mean mid-shaft circumference, nationality and sex. These findings should be considered in Anatomical comparisons across regions, forensic and orthopaedic practices.

ABBREVIATIONS

IQR: Interquartile range

SD: Standard deviation

MaKSBS-REC: Makerere university School of Biomedical sciences research and Ethics committee

Competing interests: The authors declare no competing interests

Authors' contributions: All authors contributed equally in conceptualizing the study, funding, data collection and analysis, manuscript writing and quality control.

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