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**Research Article**

# A study of diaphyseal nutrient foramina in human femur

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## ABSTRACT

**Background:** The external opening of the nutrient canal in a bone is the nutrient foramen (NF). It is clinically important to have an understanding of the location, number, direction and caliber of diaphyseal nutrient foramina in femur, especially in orthopedic surgical procedures. Here we study the diaphyseal nutrient foramina of femur in detail.
**Methods:** This study was conducted on 312, (154 right and 158 left), macerated specimens of adult human femur. All the important parameters were studied using osteometric board, vernier calipers and other precision measuring instruments.
**Results:** The mean number of nutrient foramina per femur bone was 1.64 and mean distance of NF from upper end of femur was 19.48 cms. The foraminal index obtained was 45.01%. The most common location of NF was on the medial lip of linea aspera (40.9%). 44.6% femur had only one NF, while 49.4% had two NF, 3.8% femur had three NFs and 2.24% femur had four NFs. 50.48% of NFs were of big size caliber, 26.6% were of medium size and 22.8% were of small caliber. So 77.1% NFs in femur were dominant foramina. In all the bones studied the direction of the nutrient foramina was always directed upwards.
**Conclusions:** The findings of this study on nutrient foramina adds to the information from studies in the past by other authors but the importance of this study lies in the large sample size and the detailed study of caliber of the nutrient foramen for the first time.

**Keywords:** Diaphyseal nutrient foramen, Femur, Nutrient artery, Foraminal index

## INTRODUCTION

The main blood supply to long bones is from nutrient arteries, especially during the active growing period in the embryo and fetus, and during the early phases of ossification. All arteries supplying the bone are 'nutrient' but the artery to the diaphysis has been known as 'nutrient artery' by most authorities. The original artery, which accompanies the initial invasion of the primitive cartilaginous rod by osteoclasts and osteoblasts, enlarges and persists as the nutrient artery. Bone is deposited round the vessel, thus forming a permanent track, which traverses the compact tissue thus forming a 'nutrient canal'. Nutrient foramen is the external opening of the nutrient canal in a bone. The principal nutrient foramen is commonly displaced nearer to one extremity of a long bone than the other and the canal is usually oblique with respect to the long axis of the bone. Berard was the first to point out that in the human long bones the nutrient canals were obliquely disposed, pointing towards the elbow in the upper limb and away from the knee in the lower limb.[1] The dissection room jingle "To the elbow I go; from the knee I flee" is originally in French, "Au coude je m'appuis, du genou je m'en fuis". This is called

the Berard's rule of canal direction.[1]

An understanding of the location, number, direction and caliber of diaphyseal nutrient foramina in long bones is very important clinically, especially in orthopedic surgical procedures such as joint replacement, fracture repair, bone grafting, vascularized bone microsurgery, peripheral vascular occlusive disease, longitudinal bone growth, non-unions, transplantation and resection techniques, intramedullary reaming and plating, as well as in medico legal cases. An accurate knowledge of the location of the nutrient foramina in long bones help prevent intraoperative injuries in orthopedic, as well as in plastic and reconstructive surgery. Preoperative planning of such procedures is vital for all such surgical interventions, together with an appropriate understanding of the extra osseous vascular supply for a successful outcome.[2]

Investigations on the vascular anatomy of long bones were in the past confined mostly to animals. A few authors have studied nutrient foramina in human long bones including the femur. Kizilkanat et al and Mysorekar have studied nutrient foramina of the six long bones in humans.[3,4] Other authors have studied different parameters of nutrient foramina of femur in limited number of bones. [2,5-10] In this study we examine in detail the diaphyseal nutrient foramina in 312 femur, of which 154 were of right and 158 were of left side femur, which is the largest sample size reported and we also study a new parameter - the caliber of the nutrient foramina.

The aim of this study was to determine the average number of diaphyseal nutrient foramina in femur and the average distance of the nutrient foramen from the upper end of femur. We shall calculate the 'foraminal index' for each nutrient foramen, and the range of foraminal index found in femur. The most common location of diaphyseal nutrient foramina in femur bone and the frequency of the location on the anatomical surfaces and borders of each of the femur will be determined and also the frequency of the location of nutrient foramina in fraction of total length; 'one sixths' part of femur will be determined. The direction of each diaphyseal nutrient foramina and the frequency of the cases not obeying the Berard's rule in femur will be studied.[1] We also aim to determine the caliber of the diaphyseal nutrient foramina and canal in categories of big, medium and small sizes, and the frequency of each category and finally if any variation occurred in these parameters in the femur of the right and left sides.

## METHODS

This study was conducted on 312 (154 right and 158 left), macerated specimens of adult human femur, available in bone store of government medical college, Surat, Gujarat. These were of Indian Gujarati race and of unknown sex. The instruments used for the study were an osteometric board, vernier calipers, hypodermic needles of size 20G and 24G, steel measuring scale, hand lens, divider, marking pen etc.

Each femur was numbered serially with a marking pen to help in identification. Their side (left or right) was determined. The diaphyseal nutrient foramina were observed in all the bones with a hand-lens and encircled with a marker pen. Various parameters were recorded for each of the femurs and the nutrient foramen and all values are recorded in centimeters. The following methodology was used to study the parameters.

### *1. The total length (TL)*

The total length (TL) of each femur was measured with the help of osteometric board and recorded closest to a millimeter. Determination of the total length of the individual bones was done by taking the measurement between the superior aspect of the head of the femur and the most distal aspect of the medial condyle. After measuring all the bones the 'range of total length' and the 'mean of total length' for femur was obtained.

### *2. Total number of nutrient foramina*

The diaphyseal nutrient foramina were observed in all the bones carefully with a hand-lens and the total number of foramina present on any surface or border was recorded. In bones where there was doubt as to the nature of a foramen, a fine wire was passed through it to confirm that it did enter the medullary cavity. Foramina at the ends of the bone were not taken into account.

### *3. The distance of the foramen or foramina from the upper end of the bone (DNF)*

The distance of the foramen or foramina from the upper end of the bone was measured by means of vernier sliding calipers and recorded as DNF. The range of distance of nutrient foramen from upper end and the mean of distance of nutrient foramen from upper end was obtained and recorded. The Foraminal Index (FI) for each nutrient foramen was obtained using the formula:

$$FI = \frac{DNF}{TL} \times 100$$

Where DNF was the distance from the proximal end of the femur to the nutrient foramina and TL was the total bone length. Thereafter the mean of foraminal index, least foraminal index and the highest foraminal index for femur was determined and recorded.

#### 4. *The location of nutrient foramen*

All the surfaces of the bones were scrutinized in a regular order. Foramina within 1 mm from any border were taken to be lying on that border. The descriptive term used for the surface and borders of the diaphysis of each femur was recorded according to the Grey's textbook of anatomy, for uniformity and standardization.[11] The location of the Nutrient foramina was also recorded in terms of the fraction of the bone it occupied from the upper end. For this the femur were divided into six fractions each in a similar way and denoted as I, II, III IV, V, and VI.

#### 5. *The directions of the nutrient foramina*

The directions of the obliquity of the nutrient foramina and their canals were noted. A long fine needle was passed through the nutrient foramen and canal, to ascertain the direction of the canal. It was recorded as 'up' or 'down' with respect to the proximal end of the femur being up.

#### 6. *Caliber of the foramen and canal*

Hypodermic needles of gauge 20 and gauge 24 were used to measure the caliber of the foramen and canal. If the size 20G passed through the nutrient foramen satisfactorily, it was classified as 'large' sized. If the needle of size 24G passed through the foramen and the size 20G did not pass through, the nutrient foramen was classified as 'middle' sized. Both large and middle-sized foramen was also categorized as being 'dominant'. If the needle of size 24G could not pass through the foramen it was classified as 'small' sized or 'secondary' nutrient foramen.

## RESULTS

The total number of femur bones examined was 312, of which 154 were of right and 158 were of left side. The details summarized in Table 1-4 and Figure 1. Total no. of nutrient foramina studied was 511 and the mean of distance of NF from upper end was found to be 19.48 cms. The mean foraminal index was calculated as 45.01, the range being from 27.66 to 69.26. Out of 511 NFs 258 were of big size caliber, 136 of medium size and 117 were of small caliber. There were 139 bones with 1 NF, 154 bones with 2 NF, 12 femurs with 3 NFs and 7 with 4 NFs. All NFs were directed upwards. The most common location for the NF was on the medial lip of linea aspera. On dividing the femur into 1/6$^{th}$ fractions, the most common location of NF was on the 4$^{th}$ fraction from above followed closely by the 3$^{rd}$ fraction.

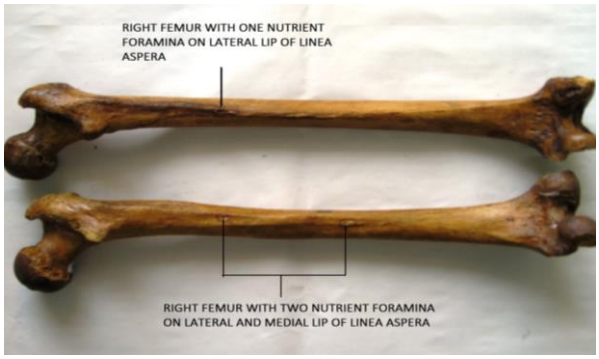


**Figure 1: Femur with nutrient foramina (NF).**

**Table 1: General observations about the nutrient foramen (NF).**

| Side | Total no. of bones examined | Total no. foramina | Range of total length (cms) | Mean of total length (cms) | Range of distance of NF from upper end | Mean of distance of NF from upper end | Mean of foraminal index | Least foraminal index | Highest foraminal index |
|---|---|---|---|---|---|---|---|---|---|
| Right | 154 | 257 | 37.3-46.5 | 42.91 | 12.8-29 | 19.36 | 45.09 | 30.13 | 65.76 |
| Left | 158 | 254 | 37.7-47.8 | 43.56 | 12-32 | 19.59 | 44.93 | 27.66 | 69.26 |
| Both | 312 | 511 | 37.3-47.8 | 43.23 | 12-32 | 19.48 | 45.01 | 27.66 | 69.26 |

**Table 2: Observations about the nutrient foramen (NF) regarding size, number and direction.**

| Side | NF of big size | NF of medium size | NF of small size | No. of bones : NF not seen | No. of bones with 1 NF | No. of bones with 2 NF | No. of bones with 3 or more NF | Direction of NF upwards | Direction of NF down wards |
|---|---|---|---|---|---|---|---|---|---|
| Right | 149 | 45 | 63 | 0 | 72 | 68 | 7 (3) & 7 (4) | 257 | 0 |
| Left | 109 | 91 | 54 | 0 | 67 | 86 | 5 (3) | 254 | 0 |
| both | 258 | 136 | 117 | 0 | 139 | 154 | 12 (3) & 7(4) | 511 | 0 |

**Table 3: Observations about the nutrient foramen (NF) regards to anatomical location.**

| Side | No. of NF located on AS | No. of NF located on LS | No. of NF located on MS | No. of NF located on PS | No. of NF located on LA-LL | No. of NF located on LA-ML |
|---|---|---|---|---|---|---|
| Right | 0 | 14 | 50 | 85 | 14 | 94 |
| Left | 0 | 10 | 35 | 46 | 48 | 115 |
| Both | 0 | 24 | 85 | 131 | 62 | 209 |

AS=Anterior surface; LS= Lateral surface; MS= Medial surface; LA= Linea aspera; LL= Lateral lip; ML= Medial lip.

**Table 4: Observations about the nutrient foramen (NF) regards to fractional location (fraction of total length; 'One Sixths' part of femur from upper end).**

| Side | Location of NF on I$^{st}$ (1/6$^{th}$) part | Location of NF on II$^{nd}$ (1/6$^{th}$) part | Location of NF on III$^{rd}$ (1/6$^{th}$) part | Location of NF on IV$^{th}$ (1/6$^{th}$) part | Location of NF on V$^{th}$ (1/6$^{th}$) part | Location of NF on VI$^{th}$ (1/6$^{th}$) part |
|---|---|---|---|---|---|---|
| Right | 0 | 57 | 103 | 97 | 0 | 0 |
| Left | 0 | 59 | 89 | 101 | 5 | 0 |
| Both | 0 | 116 | 192 | 198 | 5 | 0 |

## DISCUSSION

The principal nutrient vessels of a long bone are first indicated in late embryonic life (eighth week) by a localized vascular irruption into the midpoint of the cartilaginous primordium and at right angles to it. During embryonic development the initial nutrient artery lies at the central point and at right angles to the bone. The explanation of the displaced location of the foramen and the obliquity of the canal in an adult bone is usually said to hinge on the fact that longitudinal growth occurs only at the extremities of a long bone, in particular at the growth cartilages, and that growth at one end exceeds the other.

Gray's anatomy text book describes, The foramina for the nutrient arteries are situated close to the linea aspera.[11] They vary in number and position. One is usually at the upper end of the linea aspera, and a second, which is not always present, near its lower end. The foramina are directed upwards through the compact bone. The nutrient artery of the femur usually comes from the second perforating artery, which is one of the three perforating branches from the arteria profunda femoris. When two nutrient foramina exist, they usually come from the first and third perforating vessels". Textbook of anatomy by henry Hollinshead describes that "the body of the femur receives small blood vessels from the periosteal vessels, but its chief supply is from one or two nutrient arteries, which are usually derived from the upper perforating branches of the deep femoral artery, and enter the posterior surface of the femur close to the linea aspera".[12] Morris human anatomy describes that 'near the center of the linea aspera is the nutrient foramen conducting the nutrient artery into the nutrient canal directed towards the proximal end of the bone.[13] The blood supply of the shaft is derived from either the second or third perforating artery or from two nutrient vessels arising usually from the first and third perforating artery.

The present study is important because of the large number of bones studied. 312 femur bones have been used, 154 of the right side and 158 of the left side. Kizilkanat et al have used 100 femora, Mysorekar has used 180 femora, Laing have used 10 femora, Bridgeman et al used 109 femora and Motabagani has studied 130 femora.[3,4,6-8]

### *1. The total length (TL)*

The mean total length obtained is 43.23 cms. For the right side it is 42.9 and for the left side it is 43.6 cms. The mean total length for the femur in all previous studies is quite similar and the present study records it slightly higher (Table 5).

**Table 5: Comparison of the mean total length of the bone.**

| Author | Mean total length of the bone |
|---|---|
| Kizilkanat et al[3] | 42.58 cms |
| Nagel[2] | 40.1 cms |
| Kirschner et al[5] | 40.8 cms |
| Present Study | 43.23 cms |

### *2. Number of nutrient foramina*

In the present study the femur bone was found to have variable number of nutrient foramina, ranging from '1' to '4', on a single bone. On comparing the result of the present study with other authors who have done similar study before (Table 6), we find that Kizilkanat et al and Laing found no bones without a nutrient foramina similar

to the present finding, while Mysorekar, Bridgeman et al and Motabagani report femora having no nutrient foramina.[3,4,6-8] Although the majority of femora studied have been observed to have one or two nutrient foramina, there are reports of individual femora having as many as six or nine nutrient foramina and the maximum was 4 in the present study.[4,10] The observation of the present study that the majority (49.4%) of femora have 2 nutrient foramina is similar to Mysorekar, Nagel, Bridgeman and Brookes and Kirschner et al[5] as all reported the majority of femora to have two nutrient foramina.[2,4,5,7] A single nutrient foramen in majority was reported by Longia et al.[14] Three foramina were observed in a small number of femora in previous studies and also in this study.[2,4,5] The mean number of nutrient foramina per femur bone was calculated for the present study (Table 6). On comparing this with the other authors we have a similar value, of more than one, which again signifies the important clinical fact that femur commonly, has two nutrient foramina. When two nutrient foramina exist, the nutrient artery usually comes from the first and third perforating vessels.

The incidence of femur bones having variable number of nutrient foramina was analysed with respect to the sides (right or left), and the result compared with the other authors (Table 7). Both sides have similar number distribution of nutrient foramina, but 3 or more foramina are more frequent on the right femur, according to the present study.

**Table 6: Comparison of number of nutrient foramina on femur.**

| Author | No. of bones studied | % of bones with '0' N.F. | % of bones with '1' N.F. | % of bones with '2' N.F. | % of bones with '>3' N.F. | Mean number of NF |
|---|---|---|---|---|---|---|
| Kizilkanat et al[3] | 100 | 0 | 75% | 25% | 0 | 1.24 |
| Mysorekar[4] | 180 | 3.3% | 45% | 50% | 1.6% | 1.5 |
| Laing[6] | 10 | 0 | 60% | 40% | 0 | 1.4 |
| Bridgeman et al[7] | 109 | 2.75% | 44.03% | 53.21% | 0 | 1.5 |
| Motabagani[8] | 130 | 3.07% | 48.46% | 48.46% | 0 | 1.45 |
| Present Study | 312 | 0 | 44.6% | 49.4% | 6.1% | 1.64 |

**Table 7: Comparison of % of femur bone on right and left sides with reference to number of number of nutrient foramina per femur bone.**

| Author | Total bones | '0' NF | | '1' NF | | '2' NF | |
|---|---|---|---|---|---|---|---|
| | | R | L | R | L | R | L |
| Mysorekar [4] | 180 | 1.1% | 2.2% | 23.8% | 21.1% | 0.5% | 1.1% |
| Motabagani[8] | 130 | 3.0% | 0 | 20.7% | 27.6% | 15.5% | 19.4% |
| Bridgeman[7] | 109 | 1.8% | 0.9% | 23.8% | 20.1% | 24.7% | 28.4% |
| Present | 312 | 0 | 0 | 23.1% | 21.5% | 21.8% | 27.5% |

**Table 8: Comparison of the foraminal indices.**

| Author | Lowest foraminal index | Highest foraminal index |
|---|---|---|
| Kizilkanat et al[3] | 27 | 63 |
| Mysorekar[4] | 16.55 | 67.55 |
| Forriol et al[9] | 25 | 58 |
| Sendermir et al[10] | 26.7 | 84.4 |
| Present Study | 27.66 | 69.26 |

**Table 9: Comparison of the foraminal indices of right and left sides of present study.**

| Foraminal index | Right | Left |
|---|---|---|
| Mean foraminal index | 45.09 | 44.93 |
| Highest foraminal index | 65.76 | 69.26 |
| Lowest foraminal index | 30.13 | 27.66 |

### *3. The foraminal index (FI)*

The foraminal index was obtained for the present study as 45.01%, the lowest being 27.66% and the highest being 69.26%. It is similar to the FI of other authors (Table 8), though the highest FI of Sendermir et al is significantly higher and the lowest FI of Mysorekar is quite low.[4,10] The FI of right and left sides were compared and a similar value is obtained for each side (Table 9).

### *4. Location of nutrient foramina*

*(i) On the anatomical surface and borders of the femur*

The nutrient foramina were located on variable anatomical parts (surface and borders) of the femur. This was studied and compared with the other authors in Table 10. The most common location is on the posterior surface, including the linea aspera.

No nutrient foramina was found on the anterior surface

by all authors, while Kizilkanat et al reported more frequency on the lateral surface and medial surface compared to Mysorekar and present study, which have similar findings on both lateral surface and medial surface.[3,4] The present study reports 78.9% nutrient foramina on the whole posterior surface (which includes linea aspera and its lips), similar to Mysorekar, but much more than Kizilkanat et al.[3,4]

*(ii) Location of nutrient foramina on the corresponding '1/6th' fraction from the upper end of the femur*

The location of the nutrient foramina on the femur with respect to the '1/6th' fraction of the total length of the bone from the upper end was documented in this study. On comparing my result with Mysorekar (Table 11), We find little higher incidence in IInd part, slightly lower incidence in IIIrd part and similar findings for other parts.[4] Kizilkanat et al, Mysorekar, Longia et al, Nagel, Kirschner et al report that the nutrient foramina are mostly located in the middle one-third of the diaphysis: however, Longia et al report that nearly half (43%) of the nutrient foramina lie in the upper one third.[2-5,14] According to present study the commonest location is on the 4th sixth part of femur.

**Table 10: Comparison of the location of the nutrient foramina on surface and border.**

| Author | Total bones | Total NF | AS | LS | MS | PS | LA | |
|---|---|---|---|---|---|---|---|---|
| Mysorekar[4] | 180 | 270 | 0% | 4.8% | 14.4% | 80.6% | | |
| Kizilkanat[3] | 100 | 124 | 0% | 16.1% | 39.8% | 0.8% | 44.3% | |
| Present Study | 312 | 511 | 0% | 4.7% | 16.6% | 25.6% | 53% | |
| | | | | | | | LA-ML | LA-LL |
| | | | | | | | 40.9% | 12.1% |

AS=Anterior Surface; LS= Lateral Surface; MS= Medial Surface; LA= Linea Aspera; LL= Lateral Lip; ML= Medial Lip.

**Table 11: Comparison of the location of the nutrient foramina on corresponding 'sixths' fractions from the upper end of the femur.**

| Author | No. of Bones | Total NF | I | II | III | IV | V |
|---|---|---|---|---|---|---|---|
| Mysorekar[4] | 180 | 270 | 0.3% | 7.7% | 50.3% | 40% | 1.4% |
| Present Study | 312 | 511 | 0 | 22.7% | 37.6% | 38.7% | 0.9% |

### 5. *The direction of the nutrient foramina*

In all the bones studied the direction of the nutrient foramina was directed upwards, signifying that the lower end (near the knee joint) was the growing end. All the other authors have reported the same finding.

### 6. *Caliber of the foramen and canal*

The size or caliber of the nutrient foramina was determined and the result compared with Kizilkanat et al in Table 12 and the findings are similar.[3]

**Table 12: Comparison of the size of the nutrient foramina in terms of dominant and accessory.**

| Author | Total no. of NF | Dominant NF | Accessory NF |
|---|---|---|---|
| Kizilkanat et al[3] | 124 | 80.64% | 19.35 |
| Present Study | 511 | 77.1% | 22.9% |

The caliber of the NF was compared for the right and left sides (Table 13) and we find that the right femora have significantly more 'big' NF than the left side, yet similar number of dominant and accessory NFs. So there is no significant difference in the caliber on either side. The functional importance of the nutrient foramen depends upon the volume of blood that will flow and because a dominant nutrient artery will produce a foramen of bigger caliber, therefore the caliber of the foramen gives a clear indication about the blood flow through the nutrient artery.

**Table 13: Comparison of the size of the nutrient foramen of right and left sides in present study.**

| Size of nutrient foramen | Right | Left |
|---|---|---|
| Big | 149 | 109 |
| Medium | 45 | 91 |
| Dominant (big+med) | 194 | 200 |
| Small (accessory) | 63 | 54 |

It is emphasized that an understanding of the location, number, direction and caliber of nutrient foramina in long bones is very important clinically, especially in orthopedic surgical procedures such as fracture repair, bone grafting, vascularized bone microsurgery, peripheral vascular occlusive disease, longitudinal bone growth, non-unions, joint replacement therapy, and resection techniques, intramedullary reaming and plating, as well as in medico legal cases. An accurate knowledge of the location of the nutrient foramina in long bones should

help prevent intraoperative injuries in orthopedic, as well as in plastic and reconstructive surgery. Surgeons should avoid a limited area of the cortex of the long bones containing the nutrient foramen, particularly during open reduction, an improvement in the management of fractures and their healing problem might be attained.

## CONCLUSION

The mean total length of femur obtained was 43.23 cms. Femur was found to have variable number of nutrient foramina, ranging from '1' to '4', on a single bone. 1.64 was mean number of nutrient foramina per femur bone. The foraminal index was obtained for the present study as 45.01%, the lowest being 27.66% and the highest being 69.26%. The most common location was on the posterior surface, on the medial lip of the linea aspera, while 78.9% nutrient foramina were found on the whole posterior surface. According to present study the commonest location of NF was on the $4^{th}$ -$1/6^{th}$ sixth part of femur. The total no. of NF studied was 511, dominant NF was 77.1% and accessory NF was 22.9%. Nutrient foramina in femur have been studied in the past by other authors but the importance of this study lies in the large sample size and the detailed study of caliber of the foramen for the first time.

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