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ORIGINAL ARTICLE

Sexual Dimorphism of the Nutrient Foramen of the Fibula and Its Importance in Vascularised Bone Grafting: A Descriptive Cross-Sectional Study

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Abstract

Background Vascularised fibular bone grafting is widely used in many reconstructive surgeries to repair bony defects. It is very essential for the nutrient blood supply to be conserved in the vascular bone graft. Understanding the sexual differences of the fibular nutrient foramen can help operating surgeons make appropriate changes in their clinical methodologies according to the sex. The present study was done to evaluate the sexual dimorphism of fibular nutrient foramen and its clinical importance in the adult central Indian population.

Methods This descriptive cross-sectional study was done on 136 dry adult central Indian human fibula bones of known sex (male: 68 and female: 68). The presence of nutrient foramen, their numbers, relation with fibular surfaces, and distance from the styloid process were assessed and were then clinically correlated.

Results In males, single-nutrient foramen and double-nutrient foramina were seen in 92.65% and 7.35% of fibula, respectively. Whereas in females, single-nutrient foramen and double-nutrient foramina were seen in 95.59% and 4.41% of fibula, respectively. The position of the nutrient foramen and the fibular length showed significant sexual variation.

Conclusions This study concludes that among both sexes, the single fibular nutrient foramen in the middle third segment was the most prevalent. Compared to the female population, the male population demonstrated a broader location of the nutrient foramen.

Keywords Nutrient foramen · Fibula · Bone graft · Extensor hallucis longus · Peroneal artery

Introduction

Vascularised fibular bone grafting is the treatment of choice in many reconstructive surgeries to repair large bony defects [1–3]. It can fit to any of the long bones of the limbs due to the presence of the medullary cavity and similar diameter to the forearm bones [3, 4]. As compared to ilium and rib, the fibula has substantial strength due to a higher proportion of cortical bone and at least four times capacity of hypertrophy of its initial cross-sectional area. Due to these features, the fibula is an ideal bone for reconstructive bone grafting [4].

It is very essential that the nutrient blood supply is conserved in the vascular bone graft for the precursor bone cells to survive and hypertrophy [3–5]. Most bone grafting surgeons rely on preoperative color flow Doppler for the initial evaluation of fibula's vascularity followed by other imaging studies like invasive CT angiography and magnetic resonance angiography [6, 7]. Additionally, efforts are also being made to employ the patient's digital twin. However, the availability of these types of equipment in peripheral hospitals and higher costs are their limiting factors. Thus, in these regions, clinical examination and knowledge of fibular nutrient artery from literature remain the mainstay of locating the nutrient artery for bone grafting.

Measurements of fibula around the nutrient foramen have been used by forensic specialists for human identification,

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height interpretation, and gender discrimination [5, 8]. The position of the nutrient foramina of fibula is known to vary in humans. Usually, one or two nutrient arteries enter the middle third part of the shaft of fibula through these foramina. However, it has also been described in proximal one-fourth to one-third and middle two-quarters [9]. There are many osteological studies regarding morphology and morphometry of nutrient foramina in fibula [4, 5, 7, 10–14]. Most of the data present in these previous studies on nutrient foramen of fibula, evaluated only the laterality factor. Therefore, literature is scarce on the sexual differences of nutrient foramen of fibula. Understanding sexual differences can be a big help to the operating surgeon to make appropriate changes in his clinical methodologies according to the sex.

Thus, the present study was done to evaluate the sexual dimorphism of nutrient foramen of fibula and its clinical importance in an adult central Indian population.

Materials and Methods

This descriptive cross-sectional study was done on 136 dry adult central Indian human fibula bones of known sex [male: 68 (left: 34, right: 34), female: 68 (left: 34, right: 34)] with ages ranging from 30 to 80 years, obtained from the osteology museum of the anatomy department, Shyam Shah Medical College, Rewa, Madhya Pradesh. These bones were collected over a period from 1963 to 2022. Sexing of the fibula was documented through the museum catalogue. The study was conducted after seeking Institutional Ethics Committee Approval. The study was conducted according to the ethical principles of the Declaration of Helsinki of 1975, as revised in 2008. The sample size was calculated to be 67.4 using the formula [15]: $n = Z^2 \times P\ (1–P)/d^2$, where, n = sample size, Z = 1.96 for 95% confidence level, P = 0.954 (95.4%) expected prevalence taken from Murlimanju et al. [11] and d = 5% (precision). For the sampling, a systemic random sampling technique was used. At first, all the fibula exhibiting obscuring pathologies, such as bone deterioration and attrition, were omitted from the study. Now, the remaining fibula bones in the museum of a particular sex and side were arranged randomly in a line. Sexing of the fibula was documented through the museum catalogue. Starting at the fifth fibula bone, every third bone was then selected for the study. This was done for the fibula of each side of both sexes.

The following outcome variables were defined in line with the objectives of the study:

Primary:

1. Identification of nutrient foramen in the fibula
2. Number of nutrient foramen in the fibula
3. Surface location of Nutrient foramina
4. Distance between nutrient foramen and the tip of styloid process of head of fibula.

Secondary:

1. Fibular length
2. Foraminal index
3. Segment location of nutrient foramina
4. Pearson correlation coefficient of different measurements
5. Intra-class correlation coefficient.

A 24-gauge hypodermic needle (0.56 mm in outer diameter) and a hand lens were used to identify the nutrient foramen. The opening with raised margins and the presence of a proximal groove were recognized as a nutrient foramen. The 24-gauge hypodermic needle was passed through the foramen to verify the patency of the nutrient foramen (Fig. 1). For fibula which had more than one nutrient foramen, the larger foramen was considered as dominant nutrient foramen and was used for all the observations and measurements in that bone. And, the smaller foramina were considered secondary nutrient foramen. To determine the larger diameter

Fig. 1 Fibula with **a** one nutrient foramen and **b** two nutrient foramen

foramen, the maximum transverse diameter at a plane perpendicular to the long axis of the nutrient foramen at the level of its surface opening was measured with the help of a digital vernier caliper (accuracy up to 0.01 mm). The topography of the dominant foramen in relation to specific borders or surfaces of the diaphysis was then noted. All the photography was done using Canon EOS 200D digital camera.

The following are the measurements of fibula in relation to nutrient foramen which were measured with the help of a measuring tape in centimeters (Fig. 2):

1. Total fibula length (FL): from the tip of styloid process of head of fibula to the tip of lateral malleolus.
2. Distance between nutrient foramen and the tip of styloid process of head of fibula (DTS).

To remove any inter-observer variability, the nutrient foramen was marked on each fibula by one person only, and all measurements were taken by the same person. Also, to eliminate intra-observer variability, all the measurements were calculated three times and the mean was taken. The location of nutrient foramina was then determined by calculating the foraminal index (FIP)[16] using the following formula: FIP = DTS/FL × 100.

The mean, standard deviation, and range of each measurement were calculated. Statistical analysis was done using an independent Student's t test for normally distributed continuous variables and a Chi-square test for nominal categorical data in Statistical Package for Social Sciences (SPSS) Windows version 23.0 to assess the relationship between the examined variables. All values have been expressed as mean ± standard deviation (SD) of the mean. A level of significance of $p < 0.05$ was used. Correlations of different measurements with total fibular bone length were tested using the Pearson correlation coefficient (r). Intra-rater reliability was analyzed using the intra-class correlation coefficient.

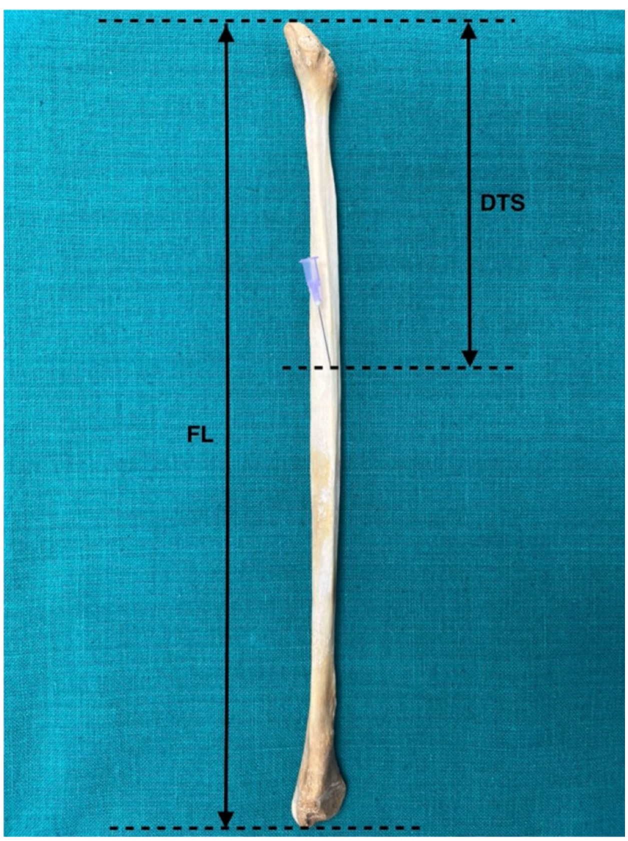

Fig. 2 Different measurements taken on fibula (*FL* total fibula length, *DTS* distance between nutrient foramen and the tip of styloid process of head of fibula)

Results

All 136 fibula bones showed definite nutrient foramen which was confirmed by needle insertion. In males, single-nutrient foramen was seen in 63(92.65%) fibula and double-nutrient foramina (1 dominant and 1 secondary nutrient foramen) was seen in 5 (7.35%) fibula. Likewise in females, single-nutrient foramen was seen in 68 (95.59%) fibula and double-nutrient foramina were seen in 3 (4.41%) fibula.

The location of nutrient foramen with respect to the fibular surface is summarized in Table 1. On the posteromedial surface and medial crest, there was significant sexual dimorphism with regard to the prevalence of nutrient foramen. And, on the rest of the surfaces, it was insignificant (Table 1).

All the quantitative parameters (DTS, FL, and FIP) are summarized in Table 2. The fibular bone length showed significant sexual variation. In FIP, the p value was < 0.05,

Table 1 Sexual differences in location of nutrient foramen with respect to fibular surface

Location	Sex	Number of bones showing DF *n* (%)	*p* value
Posteromedial surface	Male	19 (27.94%)	**0.002**
	Female	5 (7.35%)	
Posterolateral surface	Male	37 (54.41%)	0.729
	Female	39 (57.35%)	
Medial crest	Male	11 (16.18%)	**0.017**
	Female	23 (33.82%)	
Medial surface	Male	0 (0%)	0.316
	Female	1 (1.47%)	
Lateral surface	Male	1 (1.47%)	0.316
	Female	0 (0)	

DF dominant nutrient foramen

Table 2 Sexual differences of various parameters related to fibular nutrient foramen

Parameters	Sex	Range (min.–max.) (cm)	Mean ± SD (cm)	*p* value
Distance from tip of styloid process (DTS)	Male	8–25.7	16.19 ± 4.21	0.612
	Female	12.4–19.5	15.90 ± 2.39	
Total fibula length	Male	35.2–40.2	37.39 ± 1.33	**0.000**
	Female	32–35.8	33.74 ± 1.39	
FIP Index (%)	Male	21–66.41	43.30 ± 11	**0.019**
	Female	38.27–57.94	47.08 ± 7.10	

FIP foraminal index, *SD* standard deviation

showing that there was significant variation in the position of the nutrient foramen with regard to sex. Out of all 68 foramina observed in fibula of males, 9 (13.24%) were present on the upper third of the fibula with FIP ≤ 33.33 and a total of 59 (86.76%) foramina were present on the middle third of fibula with FIP score between 33.33 and 66.66. All the nutrient foramina in fibula of females were located only on the middle segment of the bone. In both sexes, no foramina were found on the lower third of fibula (FIP > 66.66).

The correlation coefficients of DTS with regard to FL for males were 0.19 and 0.18 for females. The correlation coefficients of FIP and FL were 0.05 (males) and − 0.09 (females).

The intra-class correlation coefficient for total fibular length was 0.92 and 0.93 in males and females, respectively. Also, for DTS, it was 0.89 and 0.91 in males and females, respectively. All values were > 0.75, indicating that the measurements had good reliability.

Discussion

In the present study, the single fibular nutrient foramen was seen in greater than 90% of the cases irrespective of the sexes. The fibula is supplied by the branches of the peroneal artery [11, 17]. The fibular diaphyseal endosteal blood supply usually comes from a single-nutrient artery called the dominant pedicle [3]. Many osteological studies have also reported the presence of a single-nutrient foramen in most of the fibula [11, 18]. The studies of Kamath et al. [19] and Campos et al. [20] reported all the fibular bones to have a single-nutrient foramen. Our study also found that only a small fraction almost one-fourteenth males and one-twenty-second females' fibula bone had a secondary nutrient foramen (double-nutrient foramina). This comparatively small number of double-nutrient foramina corroborated with the previous study findings [4, 14, 18]. In contrast to our study, Rao et al. [21] reported double-nutrient foramen in 20% of males and 5% of females' fibula bones in the south Indian population. Some studies have also reported fibula with three or four nutrient foramen [5, 10] which was not seen in our study. This signifies that in both the sexes of the central adult Indian population, usually, there is only one dominant pedicle supplying the fibula. During harvesting, the peroneal artery should not be separated from the fibular bone. Also, the free vascularized fibular graft must include both the dominant pedicle and the section of bone containing the nutrient foramen through which this dominant pedicle is entering the bone. Therefore, making fibula an ideal candidate in both sexes for a large single free vascularized fibular graft with a single dominant pedicle which can be used to restore large bony defects.

The present study found no absent nutrient foramen fibula bone in both sexes. Absent nutrient foramina in long bones is a well-known finding [4, 5, 11, 17, 18]. In such cases where the nutrient foramen is absent, the bone is supplied by periosteal arteries. Such fibula with absent nutrient foramen on preoperative angiography should not be chosen for a vascular bone grafting [5]. The presence of nutrient foramen is important for the vascularization of the graft, because the osteocyte's survival is primarily dependent on adequate nutrient blood flow. Thus, in both the sexes of the central adult Indian population, the fibula can be an ideal bone for vascular bone grafting as absent nutrient foramen was not seen in this population.

In our study, male and female showed an overall equal number of nutrient foramen on the posterior fibular surface. In the literature, variations were seen about the presence of nutrient foramen on the fibular surface. For instance, Zahra et al. [18] suggested that the majority of nutrient foramen is found on the posterior surface of the fibula. Sendemir and Cimen [22] found the presence of a majority of nutrient foramen on the medial surface of the fibula, whereas Mysorekar [17] suggested that the majority of nutrient foramen was found on the medial crest. However, in these studies, sexual variation of the fibular surface location of nutrient foramen was missing. It can be suggested from our study that sex has no effect on the location of nutrient foramen on the overall posterior fibular surface. The higher prevalence of nutrient foramen posteriorly may be due to the fact that the posterior surface of fibula provides attachment to more active, bulky, and stronger muscles, thus requiring maximum blood supply. And, the presence of nutrient foramen on the medial or lateral surface could probably result from the variable level of limb rotation during embryonic life [5, 13].

However, when the posterior surface is divided into three parts, i.e., posteromedial, posterolateral surface, and medial crest, sex showed some significant effects. Our study found that the majority of nutrient foramen was on the posterolateral surface (> 50%) irrespective of the sexes, whereas a considerable number was also found on the medial crest and posteromedial surface in both sexes. On the posteromedial surface of fibula, males showed a significant presence of nutrient foramen as compared to females. However, on the medial crest, females showed significant prevalence as compared to males. Rao et al. [21] reported nutrient foramen was commonly present on the medial crest of the fibula bone in either sex of the South Indian population. These may be due to the ethnic differences as our study was done in the central Indian population. This knowledge of sexual differences can help in finding the specific location of the nutrient foramen on the posterior surface when taking a vascularised fibular bone graft in different sexes. Commonly, a straight lateral incision is used to access the fibula, and a deep dissection between the lateral and posterior compartments of the leg is performed. The first portion of the fibula to be encountered during the dissection will be the posterolateral surface using this method. The nutrient artery present along this surface will be susceptible to harm during graft surgery, because the bulk of nutrient foramen from where the nutrient artery enters into the bone is located in the posterolateral surface. Therefore, when using this approach, surgeons must exercise extreme caution.

In the current study, males had a wider range of the distance between the nutrient foramen of the fibula and the tip of the styloid process of the fibula (DTS) than females. However, the statistical significance of their mean distance was negligible. In our study, males showed statistically significant higher average fibula length (37.39 ± 1.33 cm) as compared to females (33.74 ± 1.39 cm). A few illustrative studies of total fibular length include osteological studies by Ambekar et al. (from India) [8], Mazid et al. (from Pakistan) [12], Khatiwada et al. (from Nepal) [5], and Kizilkanat et al. (from Turkey)[10], who noted it to be 35.35 cm, 34.56 cm, 34.1 ± 1.9 cm and 34.02 cm respectively. In the study by Rao et al. [21], fibula length in males was 36.2 cm and in females was 33.8 cm, but this difference was statistically insignificant. The difference found in our study may be one of the causes of statistically significant sexual dimorphism in the location of fibular nutrient foramen calculated by the foraminal indices. Also, the total length of the fibula bone depends on the individual's height, which, in turn, is subjected to individual genetic makeup, hormones, activity levels, nutrition, medical conditions, and environmental factors [5].

The higher prevalence of nutrient foramen in the middle third part of the fibula in both males and females found in our study concludes that the middle third segment is the most common location for finding nutrient foramen in fibula irrespective of the sexes. And the least common location was the lower third segment of the fibula in both sexes where no nutrient foramen was found. This is in agreement with previous studies done on the fibula of unknown sexes inferring high vasculature in the middle third of the fibula bone [4, 5, 7, 10, 18]. The osteological study by Rao et al., also showed the most common position of nutrient foramen was in the middle segment in either sexes [21]. In contrast to our study findings, some studies have also reported the presence of nutrient foramen in the lower one-third (ranging from 2.2% to 0.7%) also [4, 17]. In our study, in males, some nutrient foramen (13.24%) was found in the proximal one-third segment also, which also indicated a wider range of locations of a nutrient foramen as compared to females. To be more specific, in females, nearly all the nutrient foramen is located in the middle 3/5th part, and in males, it is located in the proximal 2/5th and 3/5th part. Our study also shows that these differences in the location of nutrient foramen with respect to the fibular length in both sexes are significant as indicated by their FIP indexes (Table 2). The nutrient foramen in the fibula of different sexes can be better located during graft operations with the aid of the above exact knowledge and differences. Also, the length of the incision in harvesting a fibular vascularized graft would be less thus decreasing the complication of compartment syndrome when the precise site of the nutrient foramen is known [23].

Maximally, a vascularized fibular graft that can be obtained from fibula is 6 cm away from the proximal end and 4 cm from the distal end of fibula [3]. This is to reduce the risk of peroneal nerve damage proximally and ankle joint instability distally [23]. Various authors have reported motor weakness mainly extensor hallucis longus ranging from 10 to 55% of the cases after fibular resection for grafting due to injury to the deep peroneal nerve [24, 25]. In a cadaveric study, Shingade et al. [26] studied the branching pattern of the deep peroneal nerve and found that most of the branches to the muscles of anterior compartment of leg are given out in its proximal third. The tibialis anterior and extensor digitorum longus muscle was supplied by two or three branches from the deep peroneal nerve. However, only a single branch was found supplying extensor hallucis longus muscle from it. Many authors have also studied the course of motor nerve branch to the extensor hallucis longus muscle and they also suggested that dissection of fibula in the upper one-third carries a risk of injury to the nerve branch innervating the extensor hallucis longus muscle [25, 27, 28]. According to our study, the nutrient foramen in males was also found in the proximal third, which may result in more dissection in this area during fibular graft surgeries to locate the nutrient artery, increasing the risk of injury to the branches of the deep peroneal nerve. This may ultimately lead to a higher risk of extensor hallucis longus muscle weakness in males as compared to females.

The distal quarter of the fibula is essential to maintain a stable ankle mortise [26]. Fibular resection may cause loss of weight-bearing function of the fibula which may lead to ankle joint instability in approximately 10% of cases [24]. This may be due to the mobile distal fibular remnant left after resection which may be unable to counter the pressure from the talus during weight-bearing. Therefore, many surgeons have recommended preserving the distal 6–8 cm of the fibula to provide lateral stability to the ankle joint [24, 25]. In our study, we found that the distal one-third of the fibula in both sexes does not have a nutrient foramen, which decreases its potential for use as a fibular vascular graft. This section of the leg will likely be left intact during resection, which minimizes the chance of ankle joint instability for individuals of the central Indian population.

Limitation

Some of the nutrient foramina may have been missed due to erosion or mishandling. The variations and relations of the nutrient artery and safe zones of dissections cannot be ascertained from the osteological materials. Therefore, further correlation with the actual dissection-based study is necessary.

Conclusion

The present study concludes that the single fibular nutrient foramen on the posterolateral surface in the middle third segment was the most common type seen among both sexes in the central adult Indian population. Also, the male population exhibited a wider range of nutrient foramen sites. With this detailed knowledge, the nutrient foramen in the fibula of both sexes can be better located during graft procedures, resulting in shorter incisions and fewer complications.

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Data Availability All data generated or analyzed during this study are included in this published article.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval The study was approved by the institutional ethical committee (No. IEC 241, 13/7/2021).

Informed Consent For this type of study, informed consent is not required.

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