ORIGINAL PAPER

RJME
Romanian Journal of
Morphology & Embryology
http://www.rjme.ro/

Morphological and topographical anatomy of nutrient foramina in human upper limb long bones and their surgical importance

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Abstract

Objectives: To study the morphology and topography of nutrient foramina and to determine the foraminal index of the upper limb long bones. *Materials and Methods*: The study comprised 243 upper limb long bones, which included humeri, radii, and ulnae. The nutrient foramina were identified macroscopically in all the bones and an elastic rubber band was applied around these foramina. The bones were photographed with the digital camera and foramen index was calculated. Each bone was divided into five equal parts and was analyzed topographically. *Results*: From our observations, 93.8% of the humeri had single nutrient foramen. The double foramen was observed in 3.1% of the cases and the foramen was found absent in 3.1% of the humeri. In case of radius, 94.4% had single foramen, 1.4% had double foramen, and in 4.2% of the cases, it was absent. With respect to ulna, all the 75 bones had single foramen. The mean foraminal index was 57.6 for the humerus, 34.4 for both the ulna and radius. The majority (70%) of the foramina in humerus were located at the 3/5th part, 83.6% of the ulnae foramina at the 2/5th part and 87.7% of the radii foramina at the 2/5th part. *Conclusions*: The study has provided additional information on the morphology and topography of nutrient foramina in upper limb long bones. The knowledge about these foramina is useful in certain surgical procedures to preserve the circulation. As microvascular bone transfer is becoming more popular, a convention for the anatomical description of these foramina is important.

Keywords: foraminal index, long bones, morphology, nutrient artery, nutrient foramen, topography.

Introduction

The long bone is supplied by a nutrient artery, which enters the bone obliquely through the nutrient foramen, which is directed away, as a rule, from the growing end [1]. It is well known that they seek the elbow and flee from the knee [2]. This is because one end of limb bone grows faster than the other do. Henderson RG [3] reported that their position in mammalian bones are variable and may alter during the growth. The topographical knowledge of these foramina is useful in certain operative procedures to preserve the circulation [4–6]. It is important that the arterial supply be preserved in free vascularized bone grafts, so that the osteocytes and osteoblasts survive [7].

When a bone graft is taken, the vascularization of the remaining bones has to be considered. The vascularity of this area allows various options in grafting [8]. It was reported that the ideal bone graft for the free transfer should include endosteal and periosteal blood supply with good anastomosis [5]. The bony defect, which is left behind following traumatic injuries, tumor resection procedures, pseudoarthrosis all have been reconstructed by bone grafting procedures and the preferred modality is free vascularized bone graft [9]. The importance of preoperative angiography remains important to exclude the possible vascular anomalies in both recipient and donor bones for the microvascular bone transfers [10]. Though there are few reports available on the morphology of nutrient foramina of the lower limbs [6, 10, 11], the upper limb foramina were rarely studied. The aim of the present investigation was to study the topographic anatomy and morphology of the nutrient foramina in human adult upper limb long bones. The foraminal indexes for the upper limb long bones were also determined.

Materials and Methods

The study included 243 upper limb long bones which included 96 humeri (41 right side and 55 left side), 72 radii (41 right side and 31 left side) and 75 ulnae (31 right and 44 left). The bones (Figure 1) were obtained from the osteology section of our department.

The age and sex of the bones were not determined. There exists an agreement from the Manipal University Ethics Committee where the present study was performed. The bones, which had gross pathological deformities, were excluded from the study. All the bones were macroscopically observed for the number, location and direction of the nutrient foramina. A magnifying lens was used to observe the foramina.

The nutrient foramina (Figure 2) were identified by the presence of a well-marked groove leading to them and by a well-marked, often slightly raised, edge at the commencement of the canal. Only diaphysial nutrient foramina were observed in all the bones (Figure 2), a 24-gauge needle was passed through each foramen to confirm their patency.

Figure 1 – *Upper limb long bones (A – humeri; B – radii; C – ulnae): the rubber bands were tied at the foramina.*

Figure 2 – *The humerus (A), radius (B) and ulna (C) bones showing the nutrient foramina (arrow mark), which are directed towards the elbow joint.*

The number and topography of the foramina in relation to specific borders or surfaces of the diaphysis were analyzed. The foramina within 1 mm from any border were taken to be lying on that border. An elastic rubber band was applied around these foramina (Figure 1) and photographs were taken with the digital camera. The measurements of the bones were done over the photographs. The foramen index (F.I.) was calculated by applying the Hughes H [12] formula, dividing the distance of the foramen from the proximal end (D) by the total length of the bone (L) which was multiplied by hundred:

$$F.I. = \frac{D}{L} \times 100$$

The F.I. was determined for all the bones which give the location of the nutrient foramen, each bone was divided into five equal parts and was analyzed topographically. The data were collected on a standardized sheet and tabulated. Few of the bones were radiographed in order to look for the radiological appearance of the nutrient foramina. The films were taken using the diagnostic X-ray imaging system. The radiographic tubes were operated at approximately 60 kiloVolt peak (kVp) and 10 milliAmpere second (mAs) at a 100 cm source to image receptor distance (SID).

⊟ Results

In the present study, 93.8% of the humeri had a single nutrient foramen. The double foramen was observed in 3.1% of the cases and the foramen was found absent in 3.1% of the humeri. Fifty-eight humeri showed the foramina at the antero-medial surface (AMS), 32 at the medial surface (MS), three each at the anterior border and posterior surface. The morphological and topographical distribution of the foramina of humerus is represented in Table 1.

Table 1 – *Morphological and topographical distribution of the nutrient foramina in the humerus (n=96)*

No. of foramina	No. of humerus							
	Right side	Left side	Total	%	AB	MB	AMS	PS
0	1	2	3	3.1	–	–	–	–
1	39	51	90	93.8	2	31	54	3
2	1	2	3	3.1	1	1	4	–
Total	41	55	96	100	3	32	58	3

AB – anterior border; MB – medial border; AMS – anteromedial surface; PS – posterior surface.

In case of radius, 94.4% had single foramen, 1.4% had double foramen, and in 4.2% of the cases the foramen was absent. The foramen was present at the anterior surface (AS) in 52 radii, at the interosseous border (IB) in 10 bones, at the anterior border (AB) in four bones and at the posterior surface (PS) in four bones. The analyzes of the distribution of the radial nutrient foramen is shown in Table 2.

Table 2 – *Morphological and topographical distribution of the nutrient foramina in the radius (n=72)*

No. of foramina	No. of radius							
	Right side	Left side	Total	%	IB	AB	AS	PS
0	3	nil	3	4.2	–	–	–	–
1	37	31	68	94.4	9	4	51	4
2	1	nil	1	1.4	1	nil	1	nil
Total	41	31	72	100	10	4	52	4

IB – interosseous border; AB – anterior border; AS – anterior surface; PS – posterior surface.

With respect to ulna, all the 75 bones had single foramen. It was seen at the anterior surface in 65 cases, anterior border in eight cases and at the interosseous border in two cases. The distribution is represented in Table 3.

Table 3 – *Morphological and topographical distribution of the nutrient foramina in the ulna (n=75)*

Ulna	No.	IB	AB	AS
Right side	31	2	4	25
Left side	44	–	4	40
Total	75	2	8	65

IB – interosseous border; AB – anterior border; AS – anterior surface.

The mean foraminal index was 57.6 for the humerus, 34.4 for both the ulna and radius. The majority (70%) of the foramina in humerus were located at the 3/5th part, 83.6% of the ulnae foramina at the 2/5th part and 87.7% of the radii foramina at the 2/5th part. Table 4 analyzes the topography of the foramina along the length of the bones, i.e. in the 1/5th, 2/5th, 3/5th, 4/5th and 5/5th parts as seen from the foraminal index.

Table 4 – *Topographical distribution of the nutrient foramina based on the foraminal index of the upper limb long bones (n=243)*

Topography	Humerus	Ulna	Radius
1/5th part	nil	nil	nil
2/5th part	nil	83.6%	87.7%
3/5th part	70%	16.4%	12.3%
4/5th part	30%	nil	nil
5/5th part	nil	nil	nil
Mean F.I.	57.6	34.4	34.4

The radiographic appearance of the nutrient foramina of the humerus, radius and ulna (arrow marks) are shown in Figure 3.
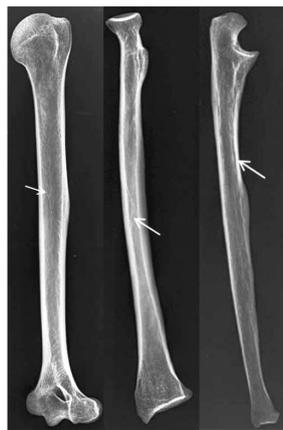

Figure 3 – *The radiographic film showing the upper limb long bones and their nutrient foramina (arrow mark).*

⌗ Discussion

The external opening of the nutrient canal, usually referred to as the nutrient foramen, has a particular position for each bone [13]. Longia GS *et al.* [14] observed that the position of nutrient foramina was on the flexor aspect in their human long bone specimens. It is generally agreed that the vessels which occupy the nutrient foramen are derived from those that took part in the initial invasion of the ossifying cartilage, so that the nutrient foramen was at the site of original centre of ossification [13]. Hughes H [12] observed that variant foramina are common in the femur, rare in the radius and very rare in other bones. Variations in the direction of nutrient foramina have been observed in many tetrapods and there is some similarity in the foraminal pattern in mammals and birds [12]. Schwalbe G [15] explained that growth at the two ends of a long bone before the appearance of the epiphyses is equal. Hence, the nutrient foramen before the birth should be directed horizontally. Many theories have been put forward to account for the direction of the foramina and also the anomalously directed ones. Among them, the 'periosteal slip' theory of Schwalbe [15] and the vascular theory of Hughes [12] are widely accepted in the literature. Longia GS *et al.* [14] stated that the vascular theory offers the best explanation of all reported anomalies as well as the normal fashioning of nutrient canals. Patake SM and Mysorekar VR [2] opined that the number of foramina does not seem to have any significant relation to the length of the bone. They described that the number of foramina may not have relation to the number of ossification centers, because

the femur, which is having one primary centre, usually has two foramina and clavicle, with two primary centers, has generally a single foramen. It was suggested that the direction of nutrient foramina is determined by growing end of the bone. The growing end is supposed to grow at least twice as fast as the other end [4].

The well-known factors, which may affect nutrient foramen position, are the growth rates at the two ends of the shaft and bone remodeling [3]. Lacroix P [16] suggested that the pull of muscle attachments on periosteum explained certain anomalous nutrient foramina directions. Nutrient arteries, which are the main blood supply to long bones, are particularly vital during the active growth period and at the early phases of ossification [17]. These nutrient arteries pass through the nutrient foramina, the position of nutrient foramina in mammalian bones are variable and may alter during the growth [3]. In humerus, the nutrient artery usually arises either from the brachial artery or from the profunda brachii artery as one or more branches or from the muscular branches of these arteries. The double foramina in humerus would suggest that one of them would be the main foramen and the other accessory one and hence the nutrient artery can arise either from the brachial or profunda brachii artery [4]. Menck J *et al.* [8] reported that the inner part of humerus is usually supplied by just one nutrient artery entering the nutrient foramen just below its middle part. In radius the artery arises from the anterior or posterior interosseous artery, this explains the foramina on its posterior surface. The ulna gets its nutrient artery from the ulnar artery or any of its muscular branches. In both radius and ulna, the main branch of the nutrient artery has an ascending course. The anterior interosseous artery, as the main artery of periosteal and endosteal supply of human ulna and radius, is important in transplantation and reconstruction, especially with a view to reduce the rate of pseudarthrosis [18]. The nutrient arteries of the ulna and radius enter the bones in the second proximal quarter of diaphysis, at the radius from anterior to medial, at the ulna from anterior to antero-lateral [19].

The available reports on the upper limb bone nutrient foramina include the study on nutrient foramina of the metacarpals and metatarsals by Singh I [20, 21], Patake SM and Mysorekar VR [2], on the radius and ulna by Shulman SS [22]. Mysorekar VR and Nandedkar AN [1] studied the nutrient foramina in the phalanges. Forriol Campos F *et al.* [23] studied the nutrient foramina of both upper and lower limbs. According to Mysorekar VR [4], humerus usually has two nutrient foramina and they occur just below the middle part of the bone or in the radial groove or frequently in both these locations. However, we observed the double nutrient foramina of the humerus in only 3.1% of the cases. The radius and ulna usually have a single nutrient foramen [4]. In the present study, all the ulnae had single nutrient foramina, but we observed the double nutrient foramina of the radius in 1.4% of the cases. The radius has its foramen invariably above the middle part, whereas in the ulna, the foramen will be in the middle third. In both radius and ulna, the foramen most frequently occurs on the anterior surface nearer to anterior or interosseous border

[4]. In the present study, 86.7% of the ulna and 72.2% of the radius had the foramen at the anterior surface. The absence of nutrient foramina in the long bones is well known [4, 24]. In the present study, 3.1% of the humeri and 4.2% of the radii showed the absence of the nutrient foramina. It was reported that in case the nutrient foramen is absent, the bone is likely to be supplied by periosteal arteries [2].

According to the study from Kizilkanat E *et al.* [17], the foramina were located on the diaphysis 15–69% of the overall length of the humerus, 22–46% for the radius and 27–54% for the ulna. In contrast, Forriol Campos F *et al.* [23] reported that the diaphysial nutrient foramina in the humerus are located at between 50 and 65% of the total length and in the radius and ulna at between 25 and 50%. In the present study, we observed that the nutrient foramina were present between 43–66% of the length of the humerus, 26–46% of the length of radius and 25–58% of the length of ulna. These findings were similar to the reports of Kizilkanat E *et al.* [17] and Forriol Campos F *et al.* [23].

Nagel A [25] described the risks for intraoperative injury to the nutrient artery during its exposure. He has also offered some suggestions for placing the internal fixation devices with minimal injury to it. It was described that the knowledge about these foramina is useful in the surgical procedures to preserve the circulation. The findings are important for the clinicians who are involved in bone graft surgical procedures and are enlightening to the clinical anatomists and morphologists.

⊟ Conclusions

The present study has provided additional information on the foraminal index, morphology and topography of the nutrient foramina in upper limb long bones. The anatomical data of this subject is enlightening to the clinician as the microvascular bone transfer is becoming more popular.

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