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GAZİANTEP UNİVERSİTY

INSTITUTE OF HEALTH SCIENCES

MORPHOLOGICAL AND TOPOGRAPHICAL ANATOMY OF NUTRIENT FORAMEN IN THE LOWER LIMB LONG BONES

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Gaziantep

December, 2017

T. C.
GAZİANTEP ÜNİVERSİTESİ
SAĞLIK BİLİMLERİ ENSTİTÜSÜ

ALT EKSTREMİTE UZUN KEMİKLERİNDE FORAMEN NUTRICIUM'LARIN MORFOLOJİK VE TOPOGRAFİK ANATOMİSİ

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Tez Savunma Tarihi: 27/12/2017

Prof. Dr. Mehmet TARAKÇIOĞLU
Sağlık Bilimleri Enstitüsü Müdürü

Bu tez çalışmasının bir "Yüksek Lisans" derecesi için uygun ve yeterli bir çalışma olduğunu onaylıyorum.

Prof. Dr. Piraye KERVANCIOĞLU
Anatomi Anabilim Dalı Başkanı

Bu tez tarafımca okunmuş, kapsamı ve niteliği açısından bir "Yüksek Lisans" tezi olarak kabul edilmiştir.

Prof. Dr. Piraye KERVANCIOĞLU
Tez Danışmanı

Bu tez tarafımca okunmuş, kapsamı ve niteliği açısından bir "Yüksek Lisans" tezi olarak kabul edilmiştir.

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DECLARATION

I declare that this thesis work is its own work, that there is no unethical behavior at all stages from the planning of the thesis until the writing, all the information in this thesis is obtained according to academic and ethical rules. The thesis work is almost entirely my own work; the collaborative contributions have been indicated clearly and acknowledged. Due references have been provided on all supporting literatures and resources. I declare that there is no violation of the patent and copyrights during the study and writing of this thesis.

December, 2017

Syeda Uzma ZAHRA

ACKNOWLEDGEMENT

I express my thanks and acknowledgement to many people who played an important role in the development of this thesis, especially my supervisor Prof. Dr. Piraye KERVANCIOĞLU and my colleague Dr. İlhan BAHŞİ, who provided a supportive learning environment for me during this study. Without these people, completing this thesis would not have been possible. I am also grateful to all the lecturers in the Department of Anatomy in particular, Prof. Dr. Erdem GÜMÜŞBURUN, Prof. Dr. Mustafa ORHAN, Ast. Prof. Dr. Ömer Faruk CİHAN for their support towards the successful completion of my education period.

I would also like to thank all my family and friends for their continued support and understanding most of all my parents and my husband. You have all been part of this thesis by default, yet you have contributed in many ways. Thank you for your patience, encouragement and love.

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ABBREVIATIONS

DNF	Distance from Nutrient Foramen
FI	Foraminal Index
NC	Nutrient Canal
NF	Nutrient Foramen
TL	Total Length

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ABSTRACT

MORPHOLOGICAL AND TOPOGRAPHICAL ANATOMY OF NUTRIENT FORAMEN IN THE LOWER LIMB LONG BONES

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December 2017, 57 pages

Nutrient foramina are important anatomical characteristics of long bones and help in determining the entry site of nutrient arteries and the weak areas that susceptible to fractures and hence study of the nutrient foramen is important in medical field. This study aimed to determine the number and positions of nutrient foramina of femur, tibia and fibula and to observe their sizes, direction and obliquity. Two hundred sixty five adult human bones of the lower limbs were observed. Nutrient foramina were identified with naked eyes and their direction, obliquity and size were determined by 20 and 24 gauge needles. Shapes were observed with naked eye and allotted to oval and round types. The location of the nutrient foramina were determined in relation to upper, middle and lower third segment of the bones and was validated by calculating foraminal index. Our study found 79% of specimens with a single nutrient foramen. More than 96% of the nutrient foramina were directed away from the knee. Eighty seven percent of the femoral nutrient foramina were located in the middle third, 72% of tibial nutrient foramina were located in the proximal third while 98% of the fibular nutrient foramina were located in the middle third of the specimens. Overall, no nutrient foramen was found to be present on the distal third of the bones studied. Our study findings are in accordance to the findings from several research studies. The assessment of pathological conditions associated with the findings of foramen nutricium in our study may help clinicians and surgeons in planning treatments for applications to be performed in this region. However, it is thought that literature will be a source for basic and clinical sciences by providing reference values.

Keywords: Femur, Fibula, Foraminal index, Nutrient foramen, Tibia

ÖZET

ALT EKSTREMİTE UZUN KEMİKLERİNDE FORAMEN NUTRICIUM'LARIN MORFOLOJİK VE TOPOGRAFİK ANATOMİSİ

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Aralık 2017, 57 sayfa

Foramen nutricium'lar uzun kemiklerin önemli anatomik özellikleridir. Arteria nutricia'ların giriş yerleri ile birlikte kırılmalara hassas olan zayıf alanların belirlenmesine yardımcı olması nedeniyle foramen nutricium çalışmaları tıbbı açıdan önemlidir. Bu çalışmada, femur, tibia ve fibula'daki foramen nutricium'ların sayılarının ve yerlerinin belirlenmesi, bunların boyutları yönleri ve obliliklerinin incelenmesi amaçlandı. İki yüz altmış beş yetişkin insan alt ekstremite kemiği incelendi. Foramen nutricium'ların yönleri, obliklikleri çıplak gözle incelendi ve büyüklükleri 20 gauge ve 24 gauge iğneler ile belirlendi. Şekilleri çıplak gözle gözlemlenerek; oval ve yuvarlak tip olarak ayrıldı. Foramen nutricium'ların yerleşimi, kemiklerin üst, orta ve alt üçte bir segmentinde olmasına göre belirlendi ve foraminal indeks hesaplanarak doğrulandı. Çalışmamızda örneklerin %79'unda tek bir foramen nutricium bulundu. Foramen nutricium'ların %96'sından fazlasının yönleri dizin ters yönüne doğru idi. Femoral foramen nutricium'ların %87'si orta 1/3 segmentte, tibial foramen nutricium'ların %72'si proksimal 1/3 segmentte ve fibular foraman nutricium'ların %98'i orta 1/3 segmentte yerleşmişti. Genel olarak, incelenen kemiklerin distal üçte birlik bölümünde foramen nutricium bulunmadığı tespit edildi. Çalışmamızın bulguları, literatürdeki birçok çalışmanın bulgularıyla uyumludur. Çalışmamızdaki bulgular foramen nutricium ile ilgili patolojik durumların değerlendirilmesi, bu bölgede yapılacak uygulamalar ile ilgili tedavilerin planlanması ile ilgili klinisyen ve cerrahlara yardımcı olabilecektir. Bununla birlikte literatüre referans değerler sağlayarak temel ve klinik bilimlere kaynak olacağı düşünülmektedir.

Anahtar Kelimler: Femur, Fibula, Foraminal index, Foramen nutricium, Tibia

1. INTRODUCTION and AIM

Bone tissue is a highly vascular mineralized a type of dense connective tissue which has many essential functions in the human body. The blood supply of the bones differs according to the shape of the bone. There are four source of arterial blood supply of long bones: nutrient artery, metaphysial artery, epiphysial artery and periosteal artery (1-3).

Long bones are mainly supplied by the nutrient artery system which enters the bone from the nutrient foramen (NF) with their accompanying veins and it is particularly substantial during embryonic stages and growth period of bones. Absence of NF has been reported and well known, in this cases bones are entirely supplied by periosteal arteries (1-4). The knowledge of the arrangement of NF of long bones is critical to clinical applications and especially surgical procedures such as fracture repair, joint replacement therapy, and micro vascular bone transfer (5-6). The aim of this thesis is to study and observe the dried adult femur, tibia and fibula of human lower limbs for detecting the number and position of the NF in respect to the surfaces and the zones of these bones, to determine foraminal index of lower limb long bones and record the morphology, the size, the direction and the obliquity of the NF.

2. GENERAL INFORMATIN

2.1. Definition of Bones

Bones are the building blocks of human skeleton which forms the framework of human body, its structure and mechanisms. Bones are formed of living connective tissues and are calcified in structure. The skeletal system comprises of ligaments, cartilages and other connective tissues which stabilize the human skeleton and interconnect its components (1-4, 7).

2.2. Functions of Bones

Bones have several functions to play in human body. Followings are some important functions of human bones.

2.2.1. Support

Bones provide structural support to the body. All the bones individually or in groups provide a structure for attachment of soft tissues, muscles and protection of the organs (1-4).

2.2.2. Storage of minerals

Human bones serve as reservoir for storing minerals in the body. The main mineral stored in the bones is calcium. Human body has a total of 1 to 2 kilograms of calcium; of which 98 percent is deposited in the bones. The calcium salts found in the bones are responsible for maintaining normal calcium and phosphate ions concentration in the human body (1-4, 7).

2.2.3. Blood cells production

Medullary cavity of the human bones is filled by red marrow which is responsible for the production of different types of blood cells that include red blood cells, white blood cells and platelets (1-4).

2.2.4. Protection

Some human bones protect vital organs and soft tissues in the human body. For example, heart and lungs are protected by rib-cage, human brain is protected by the skull bones and spinal cord protected by the vertebral column (1-4).

2.2.5. Lever

Several skeletal bones also serve as levers and facilitates skeletal muscles in producing movements. These bones can alter the amount and direction of the force that the skeletal muscles generate. As a result, movements are produced that can help change the entire body posture or can produce delicate movement that help us accomplish simple tasks (1-4).

2.2.6. Detoxification

Bone tissues are very good absorbents of heavy metals and other foreign elements from blood thus helping in detoxification of human body. Bones then later can slowly release these heavy metals and contaminants for excretion (1-4).

2.3. Subdivisions of Skeleton

There are two subdivisions of skeleton; one is axial and the other appendicular skeleton. Axial skeleton consists of bones of skull, vertebral column, sternum and ribs. Appendicular skeleton consists of limbs and associated bones that connect the trunk at shoulder and pelvis (1-4).

2.4. Types of Bones

There are two types of bones; compact and spongy. Compact bones are dense bones that form the outer shell of all bones and surround the spongy bones. Compact bones contain blood vessels and NF. Spongy bones consist of spicules of bones that enclose marrow. Spongy bones do not contain blood vessels (1-4).

2.5. Classification of Bones

Bones are classified in different types by shape. Followings are the main types of human bones.

2.5.1. Long bones

Long bones are tubular bones of the body for example humerus and femur. Long bones are relatively longer and slender. They have a diaphysis, two metaphysis, two epiphyses and a medullary cavity (1- 3).

2.5.2. Short bones

Short bones are cuboidal bones for example ankle and wrist bones including carpels and tarsals. They are *'boxlike'* in appearance (1-2).

2.5.3. Flat bones

Flat bones consist of two compact bone plates separated by spongy bone. They are defined as flat bones, as '*spongy bone sandwich*'. Flat bones though strong are relatively light for example roof of skull, the sternum and the scapulae. Ribs are also categorized as flat bones (1, 2).

2.5.4. Irregular bones

Bones with various shapes are classified as irregular bones. These bones have complex shapes with short, flat, notched and rigid surfaces for example vertebrae and face bones (1, 2).

2.5.5. Sesamoid bones

Sesamoid bones are usually small, flat and round or oval in shape and they develop inside tendons and can be found near joints at the knee, hands and the feet. Patella is the example of sesamoid bones (1, 2).

2.5.6. Pneumatized bones

These are hollow and contain several air pockets such as the ethmoid bone (1, 2).

2.5.7. Sutural bones

Also known as *'Wormian Bones'*, are small, flat, oddly shaped bones found between the flat bones of skull in the suture line. These are classified as flat bones however, develop from a separate center of ossification (1, 2).

2.6. The Organization of Bones

2.6.1. The matrix of bone

Roughly one third of the bone matrix comprise of collagen fibers and other non-collagen proteins which contributes to the stretchiness of the bones. The remaining two third of the bone matrix is calcium phosphate with lesser amount of calcium carbonate. The calcium salts are strong and brittle while collagen fibers are weaker but relatively flexible. In bones, minerals are organized around the collagen fibers and hence results in a strong yet flexible combination that is very resistant of shattering (1, 2). Osteocytes and other cells of the bones account for 2% of the mass of the typical bones. Bone lacuna, a small cavity within the bone matrix which contains an osteocyte, and from which microscopic canaliculi radiate between the lacunae of ossified bone. The radiating processes of the osteocytes (called filopodia) project into these canals. These cytoplasmic processes are joined together by gap junctions. There are cytoplasmic extensions between the osteocytes and the blood vessels. Histologically the bone has four types of cells, including osteoprogenitor cells, osteoblasts, osteocytes and osteoclasts (1-4).

2.6.2. The periosteum and endosteum

The periosteum covers the outer surface of the bone. This surface isolates and protects the bone from surrounding tissues. The periosteum provides entrance for blood and nerve supply of the bone and takes par6t in the growth and repair of the bone. It also attaches the bone with the connective tissue network of the deep fascia. Interestingly, periosteum is not found on sesamoid bones or in areas where there is attachment for ligaments, tendons or joint capsule or where the articular cartilage covers the bone surfaces. There are two layers in periosteum, an outer fibrous layer and an inner cellular layer (1-4).

Inside the bone, the endosteum lines the medullary cavity. It plays an important role in the bone growth, repair and remodeling. The endosteum is one cell thick and is an incomplete layer (1-4).

2.7. Division of a Long Bone

Long bone is divided into three parts, diaphysis, epiphysis and metaphysis (1-3).

2.7.1. Diaphysis

A long bone has one diaphysis or shaft with walls of compact bone. Diaphysis provides leverage and helps in movement and directing force (1-3).

2.7.2. Epiphysis

Epiphysis is the ends of a long bone and is filled with spongy bone. There are two epiphyses in a long bone, proximal and distal. Epiphysis is enlarged to strengthen the joint and provide an added surface area to the attachment of tendons and ligaments (1-3).

2.7.3. Metaphysis

Metaphysis separates the diaphysis and epiphysis at each end of the bone shaft. There are two metaphysis in a long bone (1-3).

2.8. Blood Supply of Long Bones

Bone is osseous tissue and is highly vascular. The blood supply of typical long bone is divided into four major sets of blood vessels that are nutrient, metaphyseal, epiphyseal and periosteal vessels (1-3).

2.8.1. The nutrient artery and vein

There is usually one nutrient artery and one vein that enters and leaves the diaphysis of long bone through a NF. The vessels penetrate the shaft to reach the medullary cavity through nutrient canal (NC). The nutrient artery further divides into ascending and descending branches, which approach the epiphysis (2, 5, 7). Nutrient artery is the main source of blood supply to the long bones and hence is extremely important in the growth of bones during infancy, childhood and all phases of ossification. Nutrient arteries are responsible for 70-80% of the blood supply of the bones and when this blood supply is restricted, it results in the ischemia of bones (6).

2.8.2. Metaphyseal vessels

These vessels are the branches of neighboring systemic vessels. They enter the long bones in the region of the metaphysis (1-2).

2.8.3. Epiphyseal vessels

The epiphyseal ends of long bones usually contain several smaller foramina. These foramina provide entry point for epiphyseal blood vessels. The epiphyseal artery mainly originates from the arteries that are supplying the joints (1, 3, 7).

2.8.4. Periosteal vessels

Periosteal vessels derivate mainly from the surrounding muscles and provide the blood to the outer one third to one half of cortex and undergo considerable intra-cortical anastomoses with ascending and descending divisions of nutrient artery (1-4, 7).

2.9. Nutrient Foramen

Nutrient foramen is an opening in the shaft of the long bones with a distinct margin. The NF provides entry to the blood vessels and leads to the NC to reach the marrow. The size and the shape of NF may vary. The direction and location of NF is of clinical significance. The nutrient artery obliquely enters the long bones and divides into ascending and descending branches after reaching the medullary cavity (1-4). In majority of instances the entry point and angulation remain constant and deviation is not common however, it is of paramount importance that deviations in the point of entry and angulation is understood for clinical safety (8). Literature suggests that the growing ends of the long bone grow twice as faster as the other end of the long bone

(9). Due to this faster growth in one direction (growing end), the obliqueness of NF and NC is directed towards the shaft and away from the growing end. This can be explained by the *'Berard's rule'* or growing end theory which suggests that the nutrient artery or NC is directed away from the growing end. This is because the NF is formed before the bone reaches its full length. Hence when the bone continues to grow, the NF's opening slowly and gradually stretches, its shape changes and the NC within the periosteum bends obliquely with the bone growth. Therefore, the nutrient vessels that passes through the NC move away from the growing end of the long bones. Some variations are observed in the obliquity of NFs of the lower limb bones only and those of upper limbs had not been observed for such variations (10, 11).

The location of NF is considered as point of initiation for longitudinal stress fractures commonly in tibia and less commonly femur, fibula and patella bones (12). Such fractures usually result in nutrient artery rupture and peripheral vascular disruption. Because of such fracture, the ruptured vessels and adjacent soft tissue vasculature start bleeding (13). For this reason, it is very important for orthopedic surgeons and emergency health workers to understand the location and number of NF in the long bones. Surgical procedures including joint replacement therapy, fracture repair, bone grafting, microsurgical procedures of vascularized bone as well as medicolegal cases require a good understanding of the location and number of NF (6). The nutrient arteries are very important in promoting fracture repairs and hence need to be preserved in free vascular bone grafting for enabling graft healing in the recipient (11, 14).

Apart from the importance of nutrient arteries in fracture healing, some other conditions of bones such as developmental abnormalities and hematogenic osteomyelitis are also dependent on the vascular system of bones (15). Study of long bone blood supply and the areas of bones supplied by nutrient artery had been important in development of new techniques in the field of transplantation and resection (16).

Given the significance of NF in clinical and morphological fields, it is of paramount importance that characteristics of NF are studies on ongoing basis to validate the findings from literature and to explore and discover new findings that can play a critical role in the field of medical science.

2.10. Long Bones of Lower Limbs

Long bones of human lower limbs include femur, tibia, fibula, metacarpals, metatarsals and phalanges. For this thesis, femur, tibia and fibula are described in detail.

2.10.1. Femur

Femur is the longest bone found in the human body. This bone has two ends, upper and lower and a shaft. The upper end has a head and a neck, and the upper part of the shaft has two projections called greater and lesser trochanters. The femur has three borders and three surfaces which are dominant in the middle third of the bone. Three surfaces include anterior, medial and lateral surface whereas, three borders include medial, lateral and posterior border. The posterior border harbors the linea aspera which is a prominent vertical ridge that has two distinct lips namely medial and lateral lips. The lower end of the bone consists of two large condyles- medial and lateral. The two condyles are joined together anterior while posteriorly, the two condyles project much beyond the plane of the shaft and are separated by intercondylar notch or fossa. Femur side is determined by the head which is always directed medially (1-4, 7).

2.10.2. Tibia

Tibia is the larger bone of human leg, situated medially. Its features consist of upper and lower ends and a shaft. Upper end is much larger than the lower end and the medial side of the lower end projects downwards beyond the rest of the bone. This projection is termed as medial malleolus. Anterior border of the shaft is most prominent and has a sharp crest. On the anterior border, there is a tibial tuberosity that can help in determining the anterior aspect of tibia. Tibia has three borders, anterior, medial and lateral or interosseous border. Three surfaces namely, lateral, medial and posterior surfaces are found on a tibia (1-4, 7).

2.10.3. Fibula

The fibula is the lateral and smaller bone of the leg and is very thin as compared to tibia. A fibula has an upper end, lower end and a shaft. The upper end or head is slightly expanded in all direction while the lower end, called lateral malleolus, is expanded antero-posteriorly and is flattened from side to side. The medial side of lower end bears a triangular articular facet anteriorly and a deep malleolar fossa posteriorly. The shaft of fibula has three borders, anterior, posterior and medial or interosseous and there are three surfaces of a fibula including medial, lateral and posterior surfaces (1-4, 7).

3. MATERIAL and METHOD

Ethics Committee Approval

As the research study was conducted using department of Anatomy owned human bones specimens, ethical committee review was not required. The research was performed according to the World Medical Association Declaration of Helsinki (1964).

Informed Consent

The study was conducted on human lower limbs long bones specimens found in the Gaziantep University, Department of Anatomy and hence no consent was required.

The material of the present study consisted of 265 cleaned and dried adult human bones of the lower limbs (Picture 3.1). They were divided into three groups namely femur (n:107), tibia (n:91) and fibula (n:67). They were obtained from the osteology collection held in the Department of Anatomy, Gaziantep University, Turkey.

Picture 3.1. Selected samples of long bones (fibula)

All selected bones were normal with no gross abnormality. The age and sex characteristics of the bones studied were unknown.

All bones were enumerated/indexed to use that information at a later stage for confirmation of information and to identify the bones (Picture 3.2).

Picture 3.2. Numbering of long bones (femur)

The NFs were observed in the bones with naked eye and identified by their elevated margins and by the presence of a distinct groove proximal to them (Picture 3.3). Only well-defined foramens on the diaphysis were accepted. Foramens at the ends of the bone were ignored.

Picture 3.3. Nutrient foramen and grove (arrow)

The following data were studied on the diaphyseal NF of each bone:

3.1. Number of Nutrient Foramen

Bones were examined for the number of NFs.

3.2.Position of Nutrient Foramen

Position of NF was observed by calculating foraminal index (FI) (sub-division) and by surface.

3.2.1. Calculation of the foraminal index

The positions of all NFs were determined by calculating the FI using the formula (6):

FI = (DNF/TL) x 100

DNF = the distance from the proximal end of the bone to the nutrient foramen. TL = total bone length.

3.2.2. Determination of the total length of bone

Determination of the total length of the individual bone was taken as follows (17):

Femur: the distance between the proximal aspect of the head of the femur and the most distal aspect of the medial condyle (Picture 3.4).

Picture 3.4. Determining total length of femur

Tibia: the distance between the proximal margin of the medial condyle and the tip of the medial malleolus (Picture 3.5).

Picture 3.5. Determining total length of tibia

Fibula: the distance between the apex of the head of the fibula and the tip of the lateral malleolus (Picture 3.6).

Picture 3.6. Determining total length of fibula

All measurements were taken using a measuring matrix chart with small squares and two metallic bars of which one was adjustable and other bar was fixed. Each side of a square was equal to 5 cm.

3.2.3. Location of nutrient foramen by subdivision

The position of the foramen was divided into three types according to FI as follow:

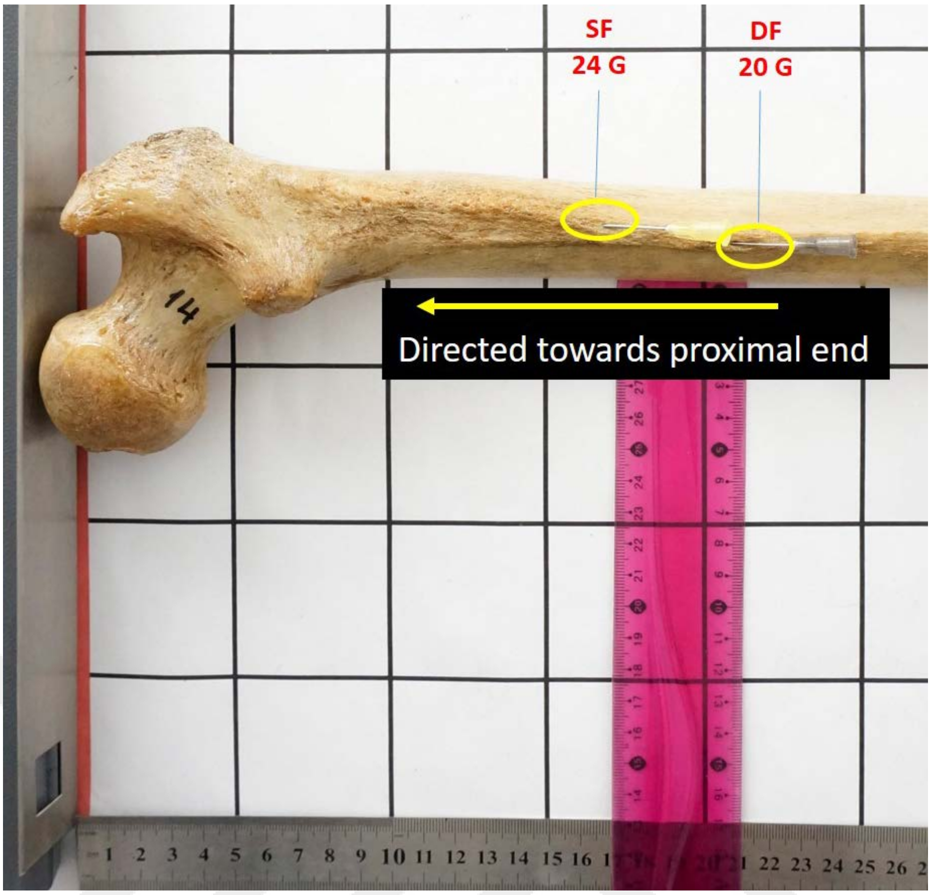
Type 1: FI up to 33.33, the foramen was in the proximal third of the bone.

Type 2: FI from 33.33 up to 66.66, the foramen was in the middle third of the bone.

Type 3: FI above 66.66, the foramen was in the distal third of the bone.

3.3. Size of Nutrient Foramen

Nutrient foramina smaller or equal to the size of 24 hypodermic needle (0.56 mm in outer diameter) were considered as being secondary NF while those smaller or equal to the size of 20 hypodermic needle (0.908 mm in outer diameter) were considered as being dominant NF (Pictures 3.7, and 3.8)



Picture 3.7. Size determination with hypodermic needle (femur) (DF: dominant nutrient foramen, SF: secondary nutrient foramen)

Picture 3.8. Determining size of nutrient foramen with hypodermic needle (tibia, fibula)

3.4. Obliquity of Nutrient Foramen

Hypodermic needle and naked eye confirmation was done to confirm the direction and obliquity of the foramen (Picture 3.10).

Picture 3.9. Direction of nutrient foramen

3.5. Determination of Various Parameters According To Side of Bone

Various parameters were compared on left and right-side bones to observe any prominent differences between left and right-side femur, tibia and fibula. Comparison between left and right bone was done on numbers of foramen, location of foramen, direction of foramen and size of NF.

3.6. Photographs

Photographs were taken by a cannon digital camera (12 mega pixels). Each photograph had a definition of 16x12 cm.

3.7. Statistical Analysis

The results were analyzed Statistical Package for the Social Sciences 22.0 packet software (IBM Corp.; Armonk, NY, ABD). $p<0.05$ was considered statistically significant. The range, mean and averages for various parameters were determined by left and right-side bones and by femur, tibia and fibula separately and comparison was done using student's t-test.

4. RESULTS

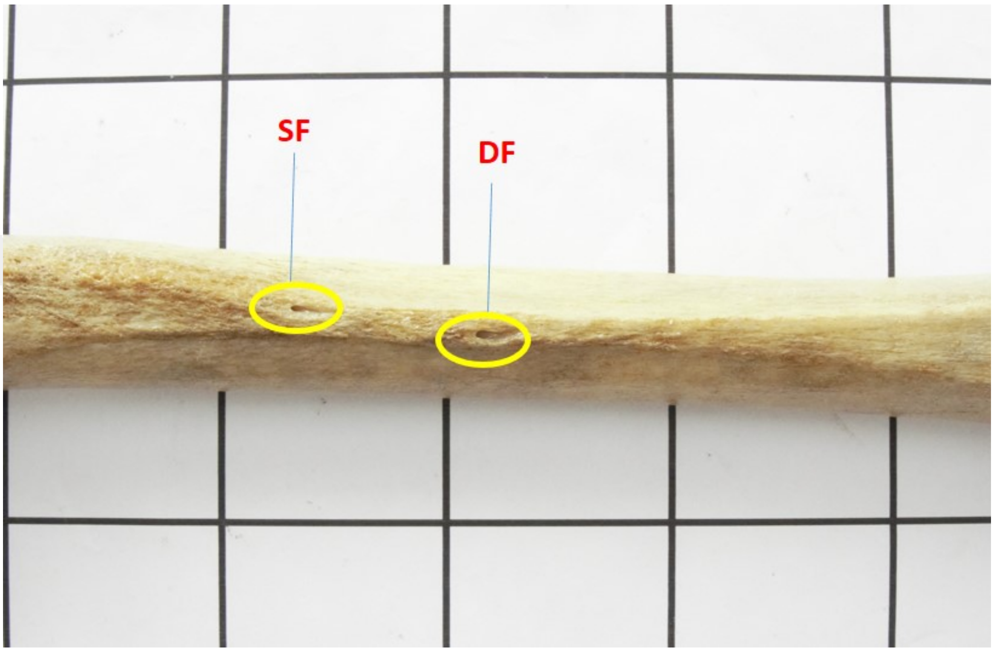
4.1. Number of Nutrient Foramen

In the whole series of 265 long bones of lower limb examined, 209 (78.8%) bone specimens had a single NF, 23 (8.7%) had double NFs, 32 (12.1%) had no NF and only 1 (0.4%) bone specimen had three NFs. In case of femur, mean number of NF was recorded 1.23 ± 0.7 (min: 0-max: 3), for tibia mean number of NF of 1.03 ± 0.23 (min: 0-max: 2) whereas for fibula a mean of 0.82 ± 0.46 (min: 0-max: 2) was recorded (Table 4.1).

Table 4.1. Number of NF observed

			Number of NF			
Long Bones		**Number of bones**	**0**	**1**	**2**	**3**
Femur	Left	54	9	32	13	0
	Right	53	8	37	7	1
	Total	**107**	**17**	**69**	**20**	**1**
Tibia	Left	51	1	49	1	0
	Right	40	0	39	1	0
	Total	**91**	**1**	**88**	**2**	**0**
Fibula	Left	23	8	15	0	0
	Right	44	6	37	1	0
	Total	**67**	**14**	**52**	**1**	**0**
Grand total (all bones)		***265***	***32***	***209***	***23***	***1***

Twenty (87%) out of 23 bones with double NFs were found on femur, whereas only 2 (8.65%) tibias had double NFs and only one (4.35%) fibula had double NFs (Picture 4.1). The only bone with three NFs was a femur. Out of total 32 bones with absent NF, 17 (53.13%) were femur, 14 (43.75%) were fibula whereas, only one tibia had no NF.



Picture 4.1. Double nutrient foramens on femur (DF: dominant nutrient foramen, SF: secondary nutrient foramen)

4.2. Direction/Obliquity of Nutrient Foramen

A total of 258 NFs were found in 265 long bones. Out of all NF, 112 (43%) were directed upwards, 143 (55%) were directed downwards and only 3 (1%) were directed horizontally.

The NFs in almost all femur examined, were directed upwards except three femur that were directed horizontally. In case of tibia, 91 (99% of total NFs found on tibias) were directed downwards with only one NF directed upwards and none was directed horizontally. In case of fibula, 52 (96% of total NFs found on fibula) were directed downwards while only 2 (4%) were directed upwards and none was directed horizontally (Picture 4.2).

Picture 4.2. Direction (arrows) of NF in lower limb long bones

Out of all upwards directed NFs found on observed long bones, 97% were present on femur while all the horizontally directed NFs were found on femur. Sixty four percent of the total downward directed NFs were found on tibia while the rest (36%) were found on fibula. No downwards facing NF was found on femur (Table 4.2).

Table 4.2. Direction of NF (numbers and percentage)

	Direction of NF (number)			
Long Bones	**Number of NF**	**Upwards (n/%)**	**Downwards (n/%)**	**Horizontal (n/%)**
Femur	112	109 (97%)	0 (0%)	3 (3%)
Tibia	92	1 (1%)	91 (99%)	0 (0%)
Fibula	54	2 (4%)	52 (96%)	0 (0%)
Total	258	112 (43%)	143 (55%)	3 (1%)

4.3. Total Bone Length

Average total bone length for femur was recorded at 43.32 cm ± 3.71 cm (min: 36 cm max: 54 cm), for tibia 35.90 cm ± 2.79 cm (min: 32 cm max: 42 cm) and for fibula 34.65 cm ± 2.31 cm (min: 30 cm max: 41 cm).

4.4. Distance of Nutrient Foramen from Upper End of Long Bone

Mean distance of NF from upper end of femur was recorded at 19.47 cm ± 5.06 cm (min: 11 cm max: 31 cm). Mean distance of NF from upper end of tibia was recorded at 11.66 cm ± 1.75 cm (min: 9 cm max: 23 cm) and from fibula upper end, NF was found at 16.32 cm ± 3.20 cm (min: 11 cm max: 24 cm).

4.5. Distance of Nutrient Foramen from Lower End of Long Bone

Mean distance of NF from lower end of femur was recorded at 23.84 cm ± 5.08 cm (min: 13 cm max: 37 cm). Mean distance of NF from lower end of tibia was recorded at 24.23 cm ± 2.28 cm (min: 18 cm max: 30 cm) and from fibula upper end, NF was found at 18.32 cm ± 2.69 cm (min: 11 cm max: 24 cm).

4.6. Location of Nutrient Foramen

Location of NF in all observed long bones was classified further into location by the segment and location by the surface of the long bones.

4.6.1. Location by segment

Out of all 258 NFs observed, 82 (32%) were present on the upper third of the long bones and 176 (68%) were present on the middle third of the long bones. None of the NFs was found on the lower third of the long bones during the process of examination.

Of all NFs found on femurs, majority (87%) were on the middle segment and those found of tibias, majority (72%) were on upper segment of the long bones. Fibula showed a reverse pattern as compared to tibia as 98% of the NFs found on fibulas were in the middle third (Table 4.3).

Table 4.3. Location of nutrient foramen by segment (numbers and percentage)

Long Bones	Number of NF	Upper 1/3 (n/%)	Middle 1/3 (n/%)	Lower 1/3 (n/%)
Femur	112	15 (13%)	97 (87%)	0 (0%)
Tibia	92	66 (72%)	26 (28%)	0 (0%)
Fibula	54	1 (2%)	53 (98%)	0 (0%)
Total	258	82 (32%)	176 (68%)	0 (0%)

Location of NF by segment was also validated by calculating FI. According to the FI, 82 (32%) of all NFs were Type 1 while 176 (68%) Type 2. This is in line with the findings from the location by distance (Table 4.4).

Table 4.4. Location of NF by FI

Number of Long Bones	Type 1	Type 2	Type 3
Number	82	176	0
Percentage **(%)**	32%	68%	0%

4.6.2. Location by surface of the long bone

The analysis of surfaces of long bones of lower limbs revealed that 100% of NFs present on tibia were found on the posterior surface. Nineteen out 54 (35%) NFs found on fibula were located on medial crest while remaining 35 (65%) were found on posterior surface of the fibula. In case of femur, the analysis reveals that while all 112 NFs were found on posterior surface, there was slight variation in location with relation to the lateral and medial lips of linea aspera. Tree out of 112 (2.68%) NFs on femur were found lateral to the lateral lip, 18 out 112 (16.07%) NFs were found medial to the medial lip whereas 39 our 112 (34.82%) were found between the lateral and medial lips of linea aspera. 13 out of 112 (11.61%) femoral NFs were found on the lateral lip whereas 39 out of 112 (34.82%) were found on the medial lip of linea aspera.

4.7. Size of the Nutrient Foramen

Results from our study suggest that majority (67%) of the NFs found in long bone specimen of our study were secondary NFs. In femur specimen, around 63% of the NFs were secondary and allowed 24-gauge hypodermic needle while rest of them was dominant NFs and allowed 20-gauge needle. In tibia, majority (71%) of the f NFs were dominant while almost quarter of total (29%) were secondary NFs. In case of fibula, 100% of the NFs were secondary and only allowed 24-gauge hypodermic needle (Table 4.5).

Table 4.5. Size of NF by number and percentage

Long Bones	Number of NF	20 Gauge (n/%)	24 Gauge (n/%)
Femur	112	42 (38%)	70 (63%)
Tibia	92	27 (71%)	65 (29%)
Fibula	54	0 (0%)	54 (100%)
Total	258	86 (33%)	172 (67%)

4.8. Shape of Nutrient Foramen

According to the observation 98% of NFs observed on all long bones of lower limbs were oval owing to their obliquity and signifying the growth direction. Only 2% of NFs on femurs were found to be round and did not show any evidence of obliquity per se.

4.9. Comparison of Nutrient Foramen Characteristics In Relation To the Left and Right Side:

In our study, a total 265 long bones of lower limbs were studied of which 128 (48%) were of the left limb while 137 (52%) were of the right limb.

Out of total 265 bone specimens 128 (48%) were of the left side while 137 (52%) were of the right side. Fifty-four (50.5%) femur specimens were of left side while 53 (49.5%) were of right side.

Of the 112 NFs found on femur specimens, 58 (51.8%) were found on left side while 54 (48.2%) were on right side. Mean number of NF for left side femur was recorded at 1.25 ± 0.68 whereas for right side femur, mean number of NF was 1.29 ± 0.72. No significant difference was found in numbers of NF between left and right side femur ($p = 0.627$). Of the 109 upward facing NFs found on femur, 57 (52.3%) were found on left side while 52 (47.7%) were found on right side. Out of total foramen found on femur, 70 (63%) were secondary NF of which 37 (52.85%) were found on left side whereas 33 (47.15%) of secondary NF were found on right side. Mean FI of left side femur was recorded 45.29 ± 11.46 and right side femur mean FI was 44.57 ± 10.25 (Table 4.6).

Table 4.6. Comparison of NF characteristics in relation to the left and right side for femur

	Side	Number	Mean±St. Deviation (mm)	p-value
Distance from upper ends	Left	58	19.60±5.15	0.802
	Right	54	19.36±5.01	
Distance from lower ends	Left	58	23.72±5.40	0.783
	Right	54	23.98±4.75	
Position by foraminal index	Left	58	45.29±11.46	0.729
	Right	54	44.58±10.25	
Total bone length	Left	58	43.32±3.63	0.994
	Right	54	43.32±3.84	

Fifty-one out of 91 tibias (56%) were of left side while 40 (44%) were of right side. Of 92 NFs found on tibias, 51 (55.4%) were on the left side, while 41 (44.6%) were on the right side. Mean number of NF for left side tibias was recorded at 1.01 ± 0.24, whereas for right side tibias, mean number of NF was recoded at 1.04 ± 0.21. No significant difference was found in number of NF on left and right side tibias (p=0.543). Out of total NF found on tibias, 65 (71%) were secondary NF of which 34 (52.3%) were found on left side and 31 (47.7%) were found on right side. Average FI for NFs found on left side tibias was recorded at 32.05 ± 4.6 whereas FI for NF found on right side tibias was 32.39 ± 2.21 (Table 4.7).

Table 4.7. Comparison of NF characteristics in relation to the left and right side for tibias

	Side	Number	Mean±St. Deviation (mm)	p-value
Distance from upper ends	Left	51	11.77±2.13	0.478
	Right	41	11.51±1.10	
Distance from lower ends	Left	51	24.39±2.52	0.460
	Right	41	24.03±1.93	
Position by foraminal index	Left	51	32.50±4.60	0.884
	Right	41	32.39±2.21	
Total bone length	Left	51	36.17±2.96	0.285
	Right	41	35.54±2.53	

Twenty tree out of 67 (34.3%) fibula specimens were of the left side while 44 (65.7%) were of the right side. Of 54 NFs found on fibula specimens, 27.7% NF were found on left side while 72.3% of NFs were found on right side. Mean number of NF on left side fibula was recorded at 0.65 ± 0.48 whereas mean number of NF on right side fibula was 0.91 ± 0.41 (Table 4.8).

Table 4.8. Comparison of NF characteristics in relation to the left and right side for fibula

	Side	Number	Mean±St. Deviation (mm)	p-value
Distance from upper ends	Left	15	16.97±3.43	0.365
	Right	39	16.07±3.11	
Distance from lower ends	Left	15	17.20±2.85	0.056
	Right	39	18.75±2.53	
Position by foraminal index	Left	15	49.51±8.36	0.142
	Right	39	46.02±7.46	
Total bone length	Left	15	34.16±2.31	0.347
	Right	39	34.83±2.31	

Our study findings suggest that a significant difference was not found between left and right side femurs, tibias and fibulas in terms of total size of bones, size of NF, distance of NF from upper and lower ends and location of NF by FI (Table 4.6, 4.7 and 4.8). This study found that there is a significant difference between number of NF found on left and right side fibula (p=0.025).

5. DISCUSSION

5.1. Number of Nutrient Foramen

Our study findings reveal that single NF are more likely (78.8%) to be observed on all long bones of lower limbs as compared to double and triple NFs. In our study, 107 femurs were studied for numbers of NF and it was observed that majority (64.5%) of femur had only one NF each while 20 (18.7%) femurs had double foramen and only 1 femur bone had three foramen. 17 femurs (16%) had no NF present. Several authors had similar findings and reported presence of a single foramen in most of the bones they studied (11, 18-22). On the contrary, other studies have reported observing double NFs in majority of femurs studied (9, 10, 14, 23, 24). In line with our study findings, a very small number of femurs had been observed for the presence of three NFs (11, 12, 14, 23). Some studies have found more than three NFs in femur (14) and as high as nine NFs (25).

Majority of studied tibias in our study were observed to have only a single foramen (96.7%). Only a small fraction (2.2%) had double NFs while one tibia had no NF. Literature suggests similar findings observed by various studies with almost 90% of the tibias found with single foramen and presence of double nutrient were observed in smaller fraction of tibias studied (9, 10, 14, 23, 25)

Of the 67 fibulas studied, 77.6% of bones presented a single NF, while 20.9% of fibulas had no NF and only a small fraction (1.5%) had double NFs. Similar findings had been observed by studied reporting majority of fibula with a single foramen (10, 11, 23, 25, 26). Some studies also reported fibula with no NF hence confirming the findings of our study (10, 14, 21, 25, 27). One study from our bibliography also reports three NFs on fibula (26).

5.2. Direction/Obliquity of Nutrient Foramen

Our study suggests that 97% of the NFs found on femur were directed upwards and away from the growing end. This finding confirms away from the knee and towards the elbow' theory. Our study also found 3% horizontally directed NF and none of the NF in femur were observed to have direction towards the distal end. This is in line with findings from previous studies and literature however; findings exist to suggest a small fraction (less than 1%) of NFs on femurs directed towards the knee (11, 18, 28).

Our study also found that 99% of NFs present on tibias were directed away from the knee while only 1% NF were directed towards the knee. These findings are confirmed by previous reports where a significantly large number of NFs on tibias directed away from the knee (10, 29). Similar to our study, a small fraction of NFs were observed in a study to be directed towards the knee (11).

In case of fibula, findings similar to tibia were observed where 96% of the 54 observed NFs were directed away from the knee while only 4% were directed towards the knee. Literature confirms the finding of our study and reported similar variation in direction of NF found on fibulas (10, 11).

5.3.Location of Nutrient Foramen

Our study suggests that 87% of the NFs found on femur were located in the middle 3rd of the bone, the rest were on the upper/proximal third, with no NF found on the distal third of the femur observed. These findings are in accordance with the findings from several other studies (10, 14, 22, 23)

In terms of NF presence on surface of observed femurs, our findings suggest that 69% of the NF were found either on or lateral to medial lip of linea aspera that is found on the posterior surface of the femur bone. Sixteen percentage of NF were medial to the medial lip and remaining 15% were distributed on the lateral lip or towards its lateral side. Our study results are confirmed by various previous studies that suggest most of NF were concentrated along the linea aspera (11, 14, 16, 19, 25, 30)

In our study, 72% of the NFs found on tibias were in the proximal third of the bone while 28% were found in the middle third. No NF was found on the lower third of the tibias. All NFs found on tibias were on the posterior surface of the bones. Other studies have found similar observations and reported majority of NFs on proximal third and posterior surface of the tibia (9-11, 14, 31). Contrary to our findings, one of the studies done in 2007 suggests that most of the NFs were located in the middle third of the tibias (21).

Fracture healing depends greatly on the vasculature of the bones and hence areas of the bones with good vasculature heal more rapidly as compared to those with poor blood supply. In case of tibia, fractures of distal end/third of the bone usually show a delayed union due to absence of NF and poor blood supply (32).

Findings from our study suggest that 98% of the NF found on fibula were situated in the middle third of the bone while only 2% of the NF were found on the upper third. This is in accordance with the findings from previous studies suggesting high vasculature in the middle third of the fibula (9, 10, 14, 23, 25, 26, 33). Our study found that majority (65%) of the NF were on the posterior surface while a sizeable number (35%) were found on the medial crest. In literature, variations were found in relation to the presence of NF on surface of fibula. For instance, a study done in 1991 by Sendemir and Cimen (25) confers presence of majority NFs on medial surface of the fibula while another study by Mysorekar done in 1967 suggests that majority of NFs are found on the medial crest (10). In our literature review, majority of the studies however, concur to our study findings and suggest that majority of NFs were found on the posterior surface of fibula (9, 21, 23, 26).

It is of paramount importance for surgeons to understand the location of NF especially in instances of bone grafting where fibula is used. As our study and literature confirms that majority of studied bones suggest that the middle third is highly vascularized in case of fibula, this section will be ideal for use in bone grafting operations where implants with endosteal and peripheral vascularization are required (26). It is also interesting finding from our study and literature to note that majority of NF were found on the posterior surface of the long bones of the lower limbs which provides attachment to more bulky flexor muscles.

5.4. Size and Shape of Nutrient Foramen

Our study findings suggest that almost two third of the total NF of the long bones were secondary and only one third were dominant. In case of femoral NF, almost two third (63%) of the NFs were secondary NFs. Similarly, observation of tibia showed that more than half of the NFs were secondary NFs and in case of fibula, all NFs were secondary NFs.

Literature suggests that almost two third of the NFs were secondary NFs (11, 34). Others have reported that majority of NFs observed were dominant NFs (21) while a study also suggested that all femurs were observed to have dominant NF (25). Our study did not conclude such findings and femurs with one or double NF was observed to have both dominant and secondary NFs and a mix pattern was observed.

5.5. Comparison of Nutrient Foramen Characteristics In Relation To the Left And Right Side

In our study, no significant differences in characteristics of NF found on right and left femur were recorded. Our study found only marginal differences in characteristics of NF found on right and left tibia that are not significant. This study found that there is a significant difference between number of NF found on left and right fibula ($p=0.025$).

5.6. Clinical Significance

Understanding of location and number of NF and nutrient arteries in the long bones is of utmost importance in the field of orthopedic surgery and orthopedic procedures including femoral diaphysis transplants, fibular grafting, fracture repair, joint replacement therapy and microsurgical procedures involving vascularized bones (21).

5.6.1. Femoral fractures

The femoral diaphysis is provided by the nutrient arteries arising from profunda femoris artery that can be used in the transplant surgery of femoral diaphysis. The healing of fractures, as of all wounds, is dependent upon blood supply and hence considering highly vascularized bone graft will be critical in the outcomes of such transplant surgeries. To attain such better outcomes, the position and number of the NF need to be understood by the surgeons (35).

There is a rich blood supply to the head and neck of the femur. Most commonly neck fractures of femur are intra-capsular and in such cases the head of femur get necrosed for which hemiarthroplasty or total hip joint replacement may be required. In such orthopedic procedures, the surgeons should know the position of NF in the femur and its blood supply (1, 36).

Another common fracture is the intertrochanteric fracture in which the line of fracture runs from greater trochanter to the lesser trochanter of femur and does not involve the femoral neck, preserving the blood supply of femoral neck. In this case, there is no ischemia of femoral head. These types of fractures are treated by orthopedic surgeons by using femoral plate and a pin to align the neck of the femur and taking care of not damaging the small arteries supplying the head neck and shaft of the femur. In this case they should know the no and position and location of NF according to surface and segments. These fractures heal well because of good supply of blood which helps in early mobilization. Whereas in femoral shaft fractures there is involvement of other soft tissues damage like muscles compartments and other structures (1).

The fracture of the shaft in children called greenstick sometimes heal naturally by the formation of blood clot between the fracture margins into which the new vessels grows to form matrix. It is accompanied by other collagen producing cells and calcium hydroxyapatite is produced by osteoblast which helps in the formation of bone matrix at the site of fracture. On the other hand if natural healing does not occur, other treatment involves fracture line reduction. It may require internal or external fixation with screws and metal rods. In such surgeries surgeons need to know about the location of NF located on the shafts of the bone (1).

5.6.2. Tibial and fibular fractures

Literature suggests that tibias are highly susceptible to longitudinal stress fractures whereas such fractures are also experienced in the femurs and fibulas less commonly. The reason being that the long bones are generally weak and susceptible to fracture at the location of NF. As a result, such longitudinal stress fractures generally initiate from the position of NF on these long bones, thus understanding of the location and position of NF is critical in making correct clinical diagnosis in instances of such fractures (12). In addition, manipulation of fractures of the long bones particularly open reduction requires surgeon to give careful attention to the site of NF and avoiding a limited area of the long bone cortex that contains NF may result in an improved outcome of such procedures (12).

The most common site of fracture in tibia is the junction of lower and middle third of its shaft because this is the narrowest part of the tibia. Because of the shin which is subcutaneous the most common fracture is open fracture also called compound fracture, in which not only perforation of skin is involved but there is damage to blood vessels supplying the bone. Another type of tibia fracture is diagonal fracture. Fracture of the tibia through the NC damage the nutrient artery which leads to poor healing and sometimes union of the fragments of the bone fails (7). Treatment may be done by fracture repair surgery for which surgeons should pay attention to the location of NF.

In case of fibular fractures the most common fracture site is just proximal to the lateral malleolus which most frequently associated to the dislocation of ankle joint and rupture of the associated ligaments. It occurs in persons who slips with the foot inverted in position. Fracture repair surgery can help the patient in treating the fractured bone for which surgeons should be aware of nutrient arteries and their entry points located on the bone (7).

Fractures which involve the epiphyseal plates of tibia and fibula in children are responsible for failure of growth because of damaging the ossification centers and also responsible for poor blood supply by damaging the epiphyseal arteries entering the bone.

5.6.3. Bone marrow transplants and grafts

Bone marrow transplant is done in patients with aplastic anemia, leukemia, lymphoma, multiple myeloma, thalassemia and sickle cell anemia. In this case, bone marrow replaces the damaged stem cells with the healthy cells which are responsible for the formation of white blood cells, red blood cells and platelets .Donor stem cells can be collected in two ways, that is bone marrow harvest in which bone marrow is taken from bone with the help of bone marrow needle or leukapheresis in which blood is taken from the person through intravenous line and stem cells from the blood is then separated in a machine from the blood to be later given to the patient (37). Whereas in autologous bone marrow grafting for the treatment of osteonecrosis the bone marrow is taken from the iliac crest and grafted to the femoral head using a small trocar (38) so while conducting these procedures of bone marrow harvest doctor should know the site of NF and foramen to avoid any damage.

5.6.4. Bone grafts

The bone that is commonly used for grafting is fibula. Because, if a segment is removed from its shaft the normal activities of that person will not get effected as for example walking, running and jumping. This process is done in patients having congenital bone defects to secure the proper structure and function of the skeleton. It is also performed in patients who have had a trauma or the removal of some malignant tumor to repair the broken bones that have lost the bone mass and also to repair the injured bone that has not healed. The periosteum and the nutrient artery is normally taken with the piece of bone that is going to be grafted so that it can remain alive and grow well at the site where it is transplanted. In this way it can help restoring the blood supply of the bone to which it is attached. There is always a risk of injuring the vessels or nerves near the bone grafting area (7).

In procedures such as periosteal stripping, a technique used to correct deformity in bones by cutting the periosteum and peeling it away to enable proper growth of the bones, and in internal fixation techniques, there are highly likely chances of damaging the nutrient arteries. Nagel A. (35) describes the risks for intraoperative injury to the nutrient artery in such procedures and provides suggestion that for preservation of circulation in such surgeries, knowledge of NF is important.

5.6.5. Intraosseous infusions

According to Snell R. this technique is applied to infants when there is failure to get access to intravenous line. So, intraosseous infusions of fluid or blood can be given through the tibia by piercing bone marrow needle to the tibia. While performing this procedure doctor should take care for not injuring the vessels and epiphyseal plates to avoid any growth disorder and impaired blood supply to bone later in life (36).

It is evident from literature that there are several instances, medical and surgical procedures in which preservation of the vascular integrity of long bones is of paramount importance and hence the knowledge of position and number of NF and arteries is of great value to the orthopedic surgeons and emergency department personnel.

Our study had tried to bring together findings from different research studies and have used those findings to validate the outcomes of the present research. It can now be said with great confidence that our study not only present observations that are consistent with literature but have also identified the deviations that are founds in the literature and their importance in the field of medical science. Our research will not only be useful for practicing clinicians but for upcoming medical professionals and new graduates to understand the importance of NF present in the long bones.

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7. RESUME

Born in 1986 in a small town of Pakistan, I was raised by my parents in the city of Peshawar. I completed my medicine degree in 2010 from Fatima Jinnah Medical College in Lahore, Pakistan. After completing my medicine degree, I went to Khyber Teaching Hospital Peshawar and completed a one year internship in General Medicine, Gynecology and Obstetrics. After getting married in 2011, I moved to Liberia with my husband and worked in Liberia as volunteers with Ministry of Health. In 2014, I returned back to Pakistan and joined post-graduate training programme in Pediatrics in North West General Hospital, Peshawar however, I had to move to Turkey with my husband in 2014 due to which my studies were interrupted. My passion for further studies brought me to Gaziantep University where I enrolled in Masters programme in the Anatomy Department. I am a proud mother of two sweet daughters Fizza and Zahra and a proud wife of a Public Health Professional who have provided me his support throughout my masters' studies.