Anatomical Study on the Diaphyseal Nutrient Foramen of the Femur and Tibia of the German Shepherd Dog

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ABSTRACT. To provide anatomical data on the nutrient foramen (NF), the authors observed the number, site and its index (SI), position, diameter and penetrating direction of the nutrient canal (NC) in the femur and tibia of German shepherd dogs. The femur often had more than two NF on the caudal surface with 30.0 to 86.7% of SI. The proximal NF of the femur was regarded to be the major NF, because it was present in most dogs and had the largest diameter. The tibia always had only one NF with 23.2 to 38.3% of SI on the lateral border. Their direction of the NC followed Bérard’s rule with the exception of the proximal NF of the femur. These results describe the anatomical condition of the NF and NC in the dog.

KEY WORDS: femur, German shepherd dog, nutrient foramen, tibia.


Early in fetal development, the nutrient artery for bone formation first penetrates the cartilaginous tissue, after which the primary ossification center is formed. In long bones, such as the femur, the nutrient artery is important in bone repair after a fracture, as well as in the growth of the diaphysis [25]. The pathway for the nutrient artery comprises the nutrient foramen (NF) and nutrient canal (NC) on the diaphysis in long bones.

The femur and tibia are the most common fracture sites in domestic animals including the dog and most fractures involve the bone diaphysis [15, 30]. Anatomical characteristics of the NF, such as its site, size and penetration direction, are of consideration in orthopedic surgeries including bone grafting and fracture repair. These characteristics also contribute to the prognosis after a fracture, because they are essential to blood flow [6, 13, 14, 29].

In the dog, the NF of the femur is located caudally [8], whereas in ruminants it is cranial [31]. Hughes [10] observed that the direction of the NF of the femur in mammals and avians frequently differs from that of the human. Since the dog is the most genetically diverse domesticated animal [32], we postulated that the NF of different breeds would differ in site, direction and diameter. Although the human NF has been studied repeatedly [1, 12, 14, 17, 19, 21–23, 26, 28], no study has ever examined the NF of purebred dogs in any detail, nor that of any other mammal.

The German shepherd dog is a purebred working dog and is widely used for guarding as well as in military service areas in South Korea. We herein report basic data, including the number and location of the NF and the diameter and direction of the NC, in the femur and tibia of German shepherd dogs. This information will be helpful to both orthopedic surgeons and veterinary anatomists.

Among the skeletons of 50 German shepherd dogs more than 2 years of age, a total of 97 (47 left, 50 right) sets of femurs and tibias, the long bones that make up the thigh and crus, were surveyed (with the naked eye). For each sample, the number and location of the NF were recorded. Fibulas were omitted from investigation, because they were too slender to observe the NF or to appreciate the NF on the diaphysis.

Any foramina or canal larger than 0.25 mm in diameter was distinguished from the other tiny foramina on the bone surface as the NF. The diameters were estimated using needles with diameters of 0.25, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1 and 1.2 mm. If the needle was able to be inserted more than 1 cm, its diameter was recorded as the NC diameter. The penetration direction of the NC into the marrow cavity was also observed when the needle was inserted into the NF. To calculate the level of the NF, the site index (SI) was determined by the ratio (%) of the length from the proximal end up to the point of the NF to the greatest length (GL) of the bone. In the femur, the GL was measured from the proximal end of the greater trochanter to the end of the articular surface of the lateral epicondyle using a Vernier calliper (Mitutoyo, Tokyo, Japan) and, in the tibia, from the intercondylar eminence to the distal end of the medial malleolus.

Data on the location and diameter of the NF were entered into a Microsoft Excel spreadsheet; statistical analyses were then conducted using an analysis of variance (ANOVA) and Duncan tests with SAS version 9.1 for Windows 12.0.

The lengths of the left and right femurs were similar. No bones without an NF were found. All NF of the femur were
on the caudal surface, and 22 of 47 dogs (46.8%) had the same number of NF in the left and right femurs. A femur with only one NF was observed in 6.2% of cases (left, 2.1%; right, 10.0%), 60.8% showed two NF (left, 57.4%; right, 64.0%), 28.9% showed three NF (left, 31.9%; right, 26.0%) and 4.4% of left femurs showed four NF (Table 1). The mean number of NF in the femur was 2.3, from a total of 116 NF in the left and 108 in the right. In femurs with more than two NF, they mainly appeared in the proximal and distal third parts, although a small number of femurs had one in the middle third of the diaphysis (Fig. 1). Therefore, we used the SI to classify them into proximal, middle and distal NF or NC. To be considered proximal, the NF required an SI of <40%, which was observed in 95.9% of femurs (left 97.9%, right 94.0%), whereas a distal NF (SI of 70%) was seen in 88.7% (left 93.6%, right 84.0%) (Fig. 1). The middle third of the diaphysis contained an NF in 27.7% of left femurs and 24.0% of right.

The SI of the proximal group ranged from 29.9 to 39.5%, which was taken from a total of 102 NF (52 left, 50 right) (Table 2). These NF were mainly located on the medial lip, lateral lip and rough surface (Table 3). The direction of the NC in the proximal group was oblique, and 84.3% were toward the stifle joint (left 80.8%, right 88.0%) (Table 2). The mean diameter of the proximal NC was the largest out of the three groups, while their diameter was variable (Table 2, Fig. 2). Compared with the middle and distal NC in the same femur, the proximal NC was larger with the exception of nine foramina (left only).

The 26 middle NF had an SI that ranged from 40.9 to 67.1%. These consisted of 14 left foramina in 13 dogs and 12 right foramina in 12 dogs (Table 2). The locations of the middle NF were similar to those of the proximal NF, but some middle NF were located on the outside of the rough surface and the area around the popliteal surface (Table 3). All middle foramina were directed away from the stifle joint, except for one in a left femur (Table 2). The mean diameter of the NC was smaller than the proximal one, but similar to those of the distal foramina (Table 2, Fig. 2).

A distal NF with an SI of 75.5–86.7% was seen in 44 and 42 femurs in the left and right, respectively, in which 6 and 4 femurs of the left and right had two distal foramina (Table 2). These were mainly located near the popliteals (Table 3) and often penetrated away from the stifle joint; however, some NCs were directed towards the joint, similar to the proximal NC. The mean diameter of the distal NC was similar to that of the middle NC, though somewhat variable (Table 2, Fig. 2).

Interestingly, the angle between the long axis of the bone and the direction of the NC tended to be more acute for the middle and distal NCs than for the proximal NC; however, we did not quantify this.

One left (female) and one right (male) femur had NF with the same SI, but a different direction of penetration. In addition, 35 of 46 left femurs and 36 of 45 right femurs had more than two foramina in the same bone, but they were orientated in different directions.

All tibias had only one NF that penetrated away from the stifle joint (Tables 1 and 2). Most of the NF in the tibia were located laterally, but a few were located caudally. Only one NF was located laterally (Table 3). The SI of the NF ranged from 23.2 to 38.3% in the left tibia and from 25.2 to 37.0% in the right; therefore, the NF of the tibia was located at the level of the proximal third (Tables 1 and 2, Fig. 1). Similar to the proximal NC of the femur, the diameter of the NC ranged from 0.4 to 1.2 mm. Nevertheless, the mean diameter was larger than that of the femur, especially in the right tibia (Table 2, Fig. 2).

The nutrient foramen and canal comprise a major pathway for the nutrient vessels of the diaphysis. Knowledge of these pathways is essential to conserve the main vessels during orthopaedic procedures, such as bone grafting and fracture repair [23]. In addition, healing after a fracture is dependent on the blood supply [4, 13, 14, 18]. Welch et al. [33] reported that the healing process is more dependent on the nutrient artery after a fracture occurring in the distal third of the long bone in small breed dogs, as well as on the intraosseous blood supply originating from the nutrient artery, branches of neighboring arteries and the metaphysial artery. The femur and tibia are the most common fracture sites of the long
They found that fractures occurred most frequently in the middle and distal third of the diaphysis in the femur and in the proximal and middle third in the tibia. Oblique and transverse are the most frequent fracture types in the femur and tibia of dogs. Ljunggren [20] conducted a study showing that small breed dogs are vulnerable to bone fractures and tibia-fibular fractures that were 10–15 mm from the proximal end occurred most frequently in Boston terriers. Notwithstanding the German shepherd, larger breed dogs have a lower frequency of fractures, and the tibia and fibula have a higher frequency of fractures than do the radius and ulna. Recently, Kumar et al. [15] also analyzed long bone fractures in dogs over the last 10 years based on variable factors. In normal dogs, fractures occurred in the radius and ulna, the femur and the tibia and fibula in 32, 31 and 26% of cases, respectively. These locations accounted for most of the fractures. In long bones, most fractures occurred in the distal and middle third of the diaphysis. In osteopenic bone, the most common fracture site was the femur, followed by the tibia and fibula. Therefore, the results of this study, particularly the observation that the NF is mainly located at the level of the proximal and distal third of the femur and the proximal third of the tibia, can aid treatments, including reconstructive and plastic surgery, after long bone fractures of the hind limb in dogs.

Anatomical studies on the NF of long bones have mainly involved humans [1, 12, 14, 18, 19, 21–23, 26, 28]; this subject has hitherto received scant attention in animals.
number of NF differs in the human femur. Several researchers have reported that the femur frequently has one NF [1, 14, 26]. However, other studies have mainly identified two NF [12, 17, 19, 21–23]. In humans, the maximum numbers of NF have been reported as five [12], six [22] and nine [28]. It is difficult to find studies that report accurate numbers of NF in animal femurs. In dogs, the largest NF is simply described as being located caudally at the approximate junction of the proximal and middle third of the bone [8]. To the best of our knowledge, our study is the first to include a detailed description of this anatomical feature in the dog, including its diameter and the direction of the NC. In this study, the German shepherd dog generally had two more NF in the femur and some specimens had up to four. In the human femur, the NF is located on the medial lip or rough surface, and the SI is on the middle and/or proximal third of the diaphysis [14, 17, 19, 21–23, 26]. Hughes [10] studied the NF of long bones in various mammals and avians and although he observed relatively few specimens, he found that two peaks were formed on the femur SI graph of every mammal, except for humans. Our findings of a high incidence of NF in the proximal and distal third coincide with his findings on the SI in the femur. Nonetheless, in our study, there was a larger distribution range than in the human femur, which does not have a SI of more than 70%. The diameter of the NC of the human femur has been measured in only a few papers [19, 21]. In cases that had more than two NF, the diameter of the NC of the proximal part was larger than that of the distal parts [19]. In this study, the German shepherd dog had two NF that were classified as the major NF (in the proximal part) and the minor NF, due to their diameter and appearance. The proximal NF had a larger diameter than the middle and distal NF.

Only one NF was found in the tibias examined in this study, which tended to be similar to the human tibia, although several exceptions have been noted [1, 14, 19, 21–23, 26]. Because there is no reference on the diameter of the NC in the dog tibia, the results of this study provide novel data. In the present study, the SI of the proximal part was one-fourth to one-third, and the NF was located on the lateral border, which differs from Evans’ report describing a caudal location [8].

According to Bérard’s rule regarding the stipulation of the relationship between the direction of the NF and the bone, the NC is directed toward the elbow joint in the pectoral limb and away from the stifle joint in the hind limb [3]. In the present study, we found that this rule is applicable to the tibia. However, the direction of the NC of the femur does not follow the rule. This phenomenon is also observed especially in cases in which the femur has two NF; the proximal one is directed toward the stifle joint, while the other is oriented differently [12, 19, 21, 22].

There are several theories on the etiology of the NC direction. Humphry [11] and Schwalbe [27] suggested that epiphyseal growth rates greater than the interstitial growth by the periosteum result in obliquity of the NF, which assumes a right angle at the primary ossification center. This hypothesis is supported by an experiment in rat tibias, in
which the NFs moved as the bone developed [9]. This is plausible because in this study, the NCs in the middle and distal femur and in the proximal tibia were directed opposite of the distal epiphyseal of the femur and the proximal tibia, where growth is more rapid than in the proximal epiphysis and delayed union with the diaphysis occurs [2, 8]. However, this does not explain the different directions and angles of the NC with the same SI in a bone. According to this, foramina in the center of the body or in the site thought to be the ossification center would be less oblique than those at the metaphysis; however, more inclined NCs were observed in the present study. This theory was further discredited, since neither the SI nor the location of the NF is affected by different epiphysial growth rates or age [24, 29]. Another theory suggested by Lacroix [16] is that the traction force acting on the periosteum could be modified by asymmetrical muscular development to cause a reverse of the direction of entry of the nutrient artery into the diaphysis. However, this theory has not gained attention, as there has been no follow-up research. A third vascular theory by Digby [7] suggested that the change in the direction of the nutrient artery at its origin might decide the obliquity of the NC. This was strongly supported by Shulman [29] who argued that the development of the nutrient artery, rather than osseous development, is primarily responsible for formation of the NC, because the direction of a blood vessel determines the form of its surrounding tissue. The direction of the NC would thus appear to be determined by the forces exerted by the growing bone and by the growing blood vessels within the limb [10]. Because the medial circumflex femoral artery and the caudal tibial artery, which are the main nutrient arteries of femur and tibia, respectively, in the dog, branched above the proximal end of the bones [5, 8, 10], the proximal NF of femur and tibia, directed distally, of dog in this study are regarded for these vessels. Thus, the vascular theory is even more persuasive. However, it still fails to explain the different directions and angles of the NC in bones with the same SI [21]. It seems plausible that other nutrient vessels determine the NC direction [14]. Although the first two theories cannot be perfectly accounted for, they cannot be discarded since the NC is formed in bone that grows due to the epiphysial plate and periosteum [2]. Therefore, to explain the direction of the NC, all factors that are responsible in individual bones should be considered proportionately.

The arterial branches from the lateral circumflex femoral artery, the proximal caudal femoral artery, the middle caudal femoral artery or the distal caudal femoral artery could also be distributed into the femur as the main nutrient vessel or another nutrient artery in the dog [5]. Considering this and the location and direction, the middle and distal NF on the femur might be postulated for another artery from them.

In conclusion, the femur of the German shepherd dog has two NF on its caudal surface over a broad range of SI. The tibia has only one NF on the lateral border over a small range of SI. The penetration direction of the NF in the femur and tibia follow Bérard’s rule, except for the proximal NF of the femur. ACKNOWLEDGMENT. This paper was supported by research funds from Chonbuk National University in 2010.

REFERENCES