<Original Article>

Anatomy of the diaphyseal nutrient foramen in the long bones of the pectoral limb of German Shepherds

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Abstract : This study investigated the anatomy of the nutrient foramen (NF) in German Shepherds by recording the number, site, position, and direction of penetration of the nutrient canal (NC) in the humerus, radius, and ulna of 50 individuals. The site index of the nutrient foramen (SI) was calculated as the ratio of the length to the NF site from the proximal end to the greatest length of the bone. The NF diameter was measured using different sized needles. Most humeri had only one NF on the caudal surface, particularly on the lateral supracondylar crest, or distal cranial surface. All radii had one NF, usually on the caudal surface, while most ulnae had one NF located on either the cranial or lateral surfaces. The SI and NF diameters were 58.0~59.5% and 0.73~0.78 mm in the humerus, 30.4~30.9% and 0.74~0.76 mm in the radius, and 29.3~29.8% and 0.67~0.68 mm in the ulna, respectively. With the exception of the relatively proximal NF of the radius, the direction of penetration followed Berard's rule. This study provides novel information on the location and diameter of the NF and direction of the NC in the long bones of the pectoral limb of German Shepherds.

Keywords : German Shepherd dog, humerus, nutrient foramen, radius, ulna

Introduction

During bone development, the primary ossification center that develops into the diaphysis of a long bone is formed after the nutrient artery penetrates the cartilage. The pathway for the nutrient artery is composed of the nutrient foramen (NF) and nutrient canal (NC) in the long bone diaphysis.

In long bones, such as the radius and ulna, the middle and distal parts of the diaphysis are the most common fracture sites in domestic dogs [14, 18, 27]. Bone repair after a fracture depends upon the blood supply [4, 16], with the nutrient artery playing an important role [23, 29]. Therefore, 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 [5, 12, 13, 26].

In general, the direction of the NC in long bones follows Bérard's rule: the NC is directed toward the elbow joint in the pectoral limb and away from the stifle joint in the hind limb [9, 19, 20]. However, in some mammals and birds, the direction of the NC does not follow this rule [9]. Since the dog is the most genetically diverse domesticated animal [28]

and the vascular distribution in the long bones of small breeds differs from that of large breeds [29], we postulated that the NF of different breeds would differ in number, site, direction, and diameter. Although the human NF and NC have been studied extensively [2, 11, 13, 17, 19-21, 24, 26], no studies other than one report [1] have examined the NF of purebred dogs, nor that of any other mammal, in detail. German Shepherds are large, purebred working dogs widely used for guarding, as well as military operations, in South Korea. Here we report basic data, including the number and location of the NF and the diameter and direction of the NC, in the humerus, radius, and ulna of German Shepherds.

Materials and Methods

Among the skeletons of 50 German Shepherds over 2 years of age that have been stored for veterinary anatomy courses, a total of 95 sets of long bones comprising the upper arm and forearm (47 left, 48 right), including the humerus, radius, and ulna, were included in this study. Bones were surveyed with the naked eye, and the number and location of the NF for each bone was recorded.

The NF was defined as a foramen or canal larger than 0.2

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mm in diameter. Thus, we excluded any tiny foramina on the surface of the bones. The diameter of each NF was estimated using needles of different diameters as reported in Ahn [1]: 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, and 1.2 mm. The NC diameter was defined as the diameter of the largest needle that could be inserted more than 1 cm into the NF. In addition, the penetration direction of the NC into the marrow cavity was noted, while the needle was inserted into the NF. To calculate the level of the NF, the site index of the nutrient foramen (SI) was defined as the ratio (%) of the length to the site of the NF from the proximal end of the bone to the greatest length of the bone. In the humerus, the greatest length was measured from the proximal end of the greater tubercle to the end of the condyle; in the radius, from the head of the radius to the tip of the styloid process; and in the ulna, from the tuber olecranon to the end of the styloid process. Vernier calipers (Mitutoyo Corporation, Japan) were used for the measurements.

Data on the greatest length of the bone and the location and diameter of the NF and NC were entered into a

Table 1. Length of the bone and number of nutrient foramina (NF) in the long bones of the pectoral limb of the German Shepherd

Type of bone, location, and number of bones		Length of bone (mm)	Number of NFs		
			1	2	Total
Humerus	Left (n = 47)	182.7 ± 11.9	44	3	50
	Right (n = 48)	183.3 ± 12.1	46	2	50
Radius	Left (n = 47)	186.8 ± 12.6	47		47
	Right (n = 48)	187.7 ± 12.3	48		48
Ulna	Left (n = 47)	222.3 ± 15.2	45	2	49
	Right (n = 48)	222.5 ± 15.4	45	3	51

Values are expressed as means ± SD.

Table 2. The site index (SI) of NF and the penetration direction and diameter of the nutrient canal (NC) in the long bones of the pectoral limb of the German Shepherd

Type of bone, location, and number of NFs		Penetration direction of NC (%)		SI of NF (%)	Diameter of NC (mm)
		Towards elbow joint	Away from elbow joint		
Humerus	Left (n = 50)	100.0		59.5 ± 4.4	0.73 ± 0.18
	Right (n = 50)	100.0		58.0 ± 9.6	0.78 ± 0.17
Radius	Left (n = 47)	10.6	89.4	30.4 ± 4.1	0.74 ± 0.18
	Right (n = 48)	14.6	85.4	30.9 ± 4.7	0.76 ± 0.23
Ulna	Left (n = 49)	100.0		29.8 ± 1.5	0.68 ± 0.19
	Right (n = 51)	98.0	2.0	29.3 ± 2.5	0.67 ± 0.18

Values are expressed as means ± SD.

Table 3. The position of NF on the surface of the bone

Type of bone, location, and number of NFs		Position								
		Cranial surface			Caudal surface		Lateral surface		Medial surface	
		HC	BG	CRS	LEC	CDS	LS	LB	MS	MB
Humerus	Left (n = 50)	4	1		43	1			1	
	Right (n = 50)	8	1		26	3			12	
Radius	Left (n = 47)					45		2		
	Right (n = 48)					47		1		
Ulna	Left (n = 49)			20			27		2	
	Right (n = 51)			26			23		1	1

HC: humeral crest, BG: brachial groove, CRS: cranial surface (excluding the former two structures on the cranial surface), LEC: lateral epicondylar crest, CDS: caudal surface (excluding the former two structures on the caudal surface), LS: lateral surface, LB: lateral border, MS: medial surface, MB: medial border.
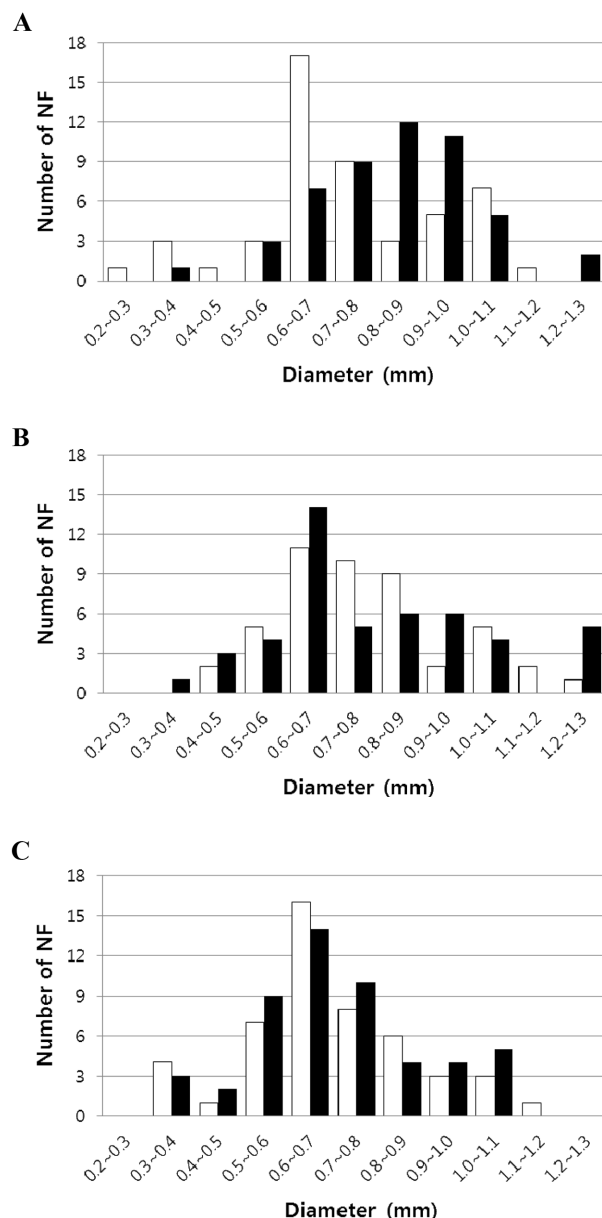
A

B

C
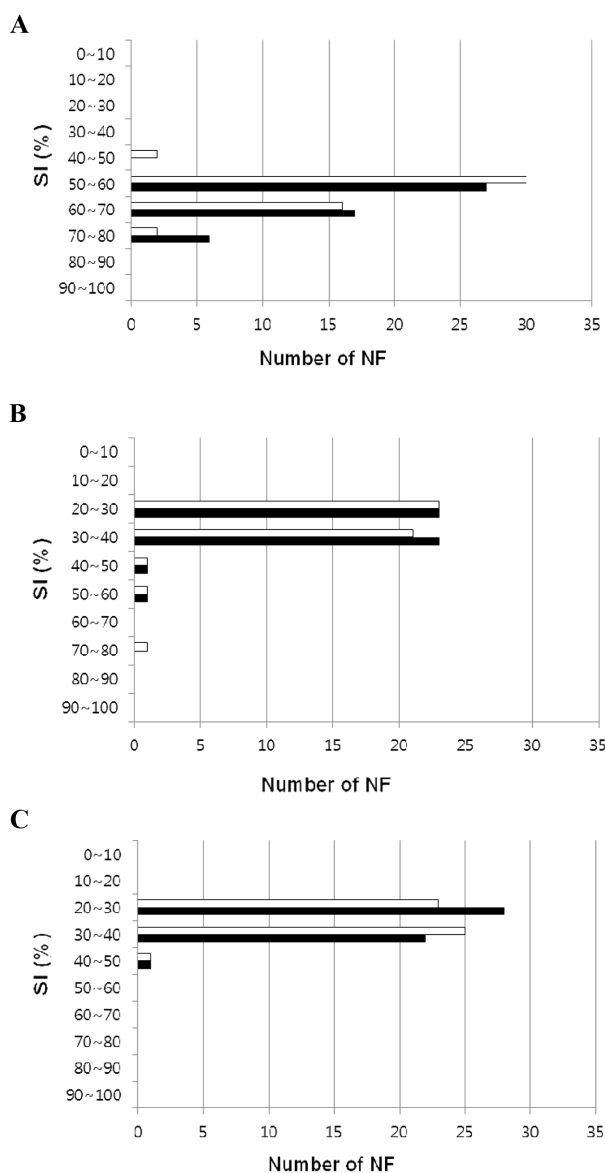
Fig. 1. The SI of NF and its frequency in the humerus (A), radius (B), and ulna (C). White bar; left humerus, radius, and ulna, black bar; right humerus, radius, and ulna.

A

B

C

Fig. 2. Diameter of NF and its frequency in the humerus (A), radius (B), and ulna (C). White bar; left humerus, radius, and ulna, black bar; right humerus, radius, and ulna.

Microsoft Excel spreadsheet. Statistical analyses included the Student's *t* test, analysis of variance (ANOVA), and Duncan's test, all of which were performed using SAS for Windows 12.0 (ver. 9.1; SAS Institute, USA).

Results

All radii had only a single NF, and the majority of humeri and ulnae (94.7% in both) also had one NF. Five humeri and five ulnae had two NFs (Table 1); the diameter of the proximal NF was larger than that of the distal NF in the humerus but not in the ulna. No bones had more than three NFs. Six

dogs differed in the number of NFs in the left and right bones: one male and two females had more NFs in the left humerus, and two males and one female had more NFs in the right ulna.

The mean diameter and SI for each type of bone are summarized in Table 2, and the ranges are depicted in Figs. 1 and 2. The NF diameter did not differ significantly between the left and right bones, and most were in the range of 0.6~0.7 mm, with the exception of the right humerus.

The NF of the humerus was usually located on the lateral epicondylar crest of the caudal surface (73.0%), followed by the cranial surface (14%) and the medial surface (13.0%)

Table 4. The position of NF and the SI of the humerus

Classification	Position of NF		
	Cranial surface	Caudal surface	Medial surface
SI (%)*	69.5 ± 3.2^a	57.9 ± 3.3^b	57.9 ± 4.6^b

*Values are expressed as means ± SD. The different letters indicate significant differences among the positional groups ($p < 0.01$).

Table 5. The penetration direction of NF and the SI of the radius

Classification		Penetration direction of NF	
	Side of radius	Towards elbow joint	Away from elbow joint
SI (%)*	Left	40.7 ± 5.2 (n = 5)†	29.6 ± 2.5 (n = 42)
	Right	37.5 ± 8.8 (n = 7)†	29.8 ± 2.2 (n = 43)
	Total	38.8 ± 7.4 (n = 15)†	29.7 ± 2.4 (n = 83)

*Values are expressed as means ± SD; †$p < 0.01$, significant differences within each line.

(Table 3). In eighteen dogs, the location of the NF differed between the left and right humeri. Interestingly, the NFs on the cranial surface were located more distally than those on the caudal and medial surfaces, although the sample size for the caudal NFs was small (n = 14) (Table 4). In all humeri, the direction of NC penetration was towards the elbow joint (Table 2).

The NF of the radius was usually located on the caudal surface, where it was medial to the crest for the attachment of the interosseus ligament, near the lateral border (Table 3). In six dogs, the location of the NF differed between the left and right radii. The NC was directed away from the elbow joint in all but 13 cases (Table 2). Interestingly, the NFs in which the NC was directed towards the elbow joint had SIs over 35% (range 35.1~55.0%), but the NFs in which the NC was directed away from the elbow joint seldom had SIs over 35% (Table 5).

In the ulna, the NF was almost always present on the cranial or lateral surface; however, these areas are quite close to each other. The NF of the ulna was usually located in the area proximal to the interosseus border and distal to the medial or lateral coronoid processes (Table 3). The NC of the ulna was directed towards the elbow joint in all but one case (Table 2).

Discussion

The nutrient foramen and nutrient canal are major pathways for the nutrient vessels of the diaphysis. Knowledge of these pathways is essential for preservation of the main vessels during orthopedic procedures, such as bone grafting and fracture repair [21]. In addition, healing after a fracture is dependent on the blood supply [4, 12, 13]. Welch et al. [29] reported that the healing process is dependent primarily on the nutrient artery after a fracture, followed by the intraosseous

blood supply originating from the nutrient artery, the branches of neighboring arteries, and the metaphysial artery. The radius and ulna are the most common fracture sites in the long bones of dogs [14, 18]. Singh et al. [27] observed that the humerus accounts for 13.2% of fractures, a smaller proportion than those of the femur, tibia, radius, or ulna. Smaller breeds of dogs are more vulnerable to bone fractures than are larger breeds [14, 18], but larger breeds, such as German Shepherds and Dobermans, still account for over 25% of fracture cases [14]. Kumar et al. [14] and Singh et al. [27] found that fractures occur most frequently in the middle and distal thirds of the diaphysis of the long bones. Oblique/ spiral and transverse fractures are the most common types of fractures in the long bones of dogs. Ljunggren [18] observed that comminuted fractures primarily occur in the middle diaphysis in the long bones of smaller breeds of dog.

Evans and De Lahunta [7] noted that the NF of the humerus was perforated below the middle third on the lateral supracondylar crest, while the NF of the radius and ulna occurred at the junction of the proximal and middle thirds of the bone. The results of our study are consistent with their report. In addition, our results indicate that the NF of the humerus can also occur on the cranial or medial surface, especially in bones on the right side of the body. Interestingly, we found that NFs located near the elbow joint were more likely to occur on the cranial surface than on the caudal or medial surfaces, although our sample size was relatively small. Nonetheless, these findings could have implications for the treatment of fractures in the long bones of dogs.

Many studies have investigated the anatomy of the NF in the long bones of humans [2, 11, 13, 17, 19-21, 24, 26]; however, this subject has hitherto attracted scant attention in domestic animals. Hughes [9] studied the NF of the long bones of various birds and mammals, but the sample size for each breed was quite small. Payton [22] reported the position, development, and direction of the NF in pigs, while Daniel et al. [5] assessed the relationship between the NF and disease in the sesamoid bones of greyhounds. Ahn [1] and Evans and De Lahunta [7] have described in detail the direction and location of the NF and the direction of perforation of the vessels in the long bones of the hind limb of dogs. To our knowledge, our study is the first to include a detailed description of the NF in the forelimb skeleton in a large purebred dog, including the diameter and change of direction of the NC in the radius. In our study, the humerus, radius, and ulna of German Shepherds generally each had one NF with a diameter ranging from 0.5~1.0 mm. No long bones had more than three NFs on the diaphysis. The direction of perforation of the NC in this study followed Bérard's rule, in which the NC was directed toward the elbow joint in the long bone of the pectoral limb; however, in the radius, the NC was directed away from the elbow joint. Since some variation in the direction of the NC is known to occur in the radius and femur of mammals [1, 9], and since the nutrient artery for the radius extends distally in dogs [7], this result is not surpris-

ing. It is, however, very interesting that when the diaphyseal NF of the radius had an SI over 35%, canalization occurred toward the elbow joint into the marrow cavity.

Several hypotheses have been suggested to explain the etiology of the direction of the NC. Humphrey [10] and Schwalbe [25] suggested that epiphyseal growth rates that exceed interstitial growth by the periosteum result in the obliquity of the NF, which assumes a right angle at the primary ossification center. This hypothesis was supported by an experiment in rat tibias, in which the NFs moved distally as the bone developed, while the SI remained constant [8]. Some of the results of the current study support this hypothesis. For example, the NCs in the humerus and fibula were directed opposite of the proximal epiphysis of the humerus and distal fibula, respectively, where growth is relatively faster than in the other epiphysis and where delayed union with the diaphysis occurs [7, 30]. However, this hypothesis does not explain the general case for the radius, in which an NC directed toward the distal epiphysis grew faster and united later than did that of the proximal epiphysis, while the level of the NF was near to proximal. Furthermore, the more distal NF of the radius was directed toward the proximal epiphysis. Indeed, this hypothesis has largely been discredited, since neither the SI nor the location of the NF is affected by different epiphysial growth rates or age [22, 26], and different directions and angles of the NC can exist with the same SI in a bone [19, 20]. Another hypothesis suggested by Lacroix [15] is that the traction force acting on the periosteum can be modified by asymmetrical muscular development to cause a reverse in the direction of entry of the nutrient artery into the diaphysis. However, this hypothesis has not been examined, as there has been no follow-up research. A third vascular hypothesis by Digby [6] suggests that the change in the direction of the nutrient artery at its origin might determine the obliquity of the NC. This hypothesis was strongly supported by Shulman [26], 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 formation 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 [9]. Initially, the 'collateral radial artery' in dogs runs distally caudal to the brachial muscle, medial to the accessory head of the triceps brachii muscle, and craniodistally after the 'nutrient artery for the humerus' branches off; it then anastomoses with the superficial brachial artery at the flexor surface proximal to the humeral condyle. Subsequently, the nutrient arteries of the radius and ulna branch from the caudal interosseus artery, which runs along the space between the two bones; the nutrient arteries then extend distally and proximally, respectively [7]. Therefore, the vascular hypothesis is even more consistent with our results. However, it still fails to explain the different directions and angles of the NC in bones with the same SI, in other words, abnormal direction [19, 20]. It

seems plausible that the changes in the direction of a nutrient artery at its origin may determine the NC direction [13]. Although the first two hypotheses cannot account completely for our results, they cannot be entirely rejected since the NC is formed in bone that grows based on the epiphyseal plate and periosteum [3]. Therefore, to fully explain the direction of the NC, all relevant factors in individual bones should be considered.

Given the above information on the nutrient vessels for the three long bones of the pectoral limb, we can explain why the NF appeared on the caudal surface of the radius, on the cranial surface of the ulna, and on the caudal, medial and cranial surfaces of the humerus but not on its lateral surface.

In summary, this study found that German Shepherds had one NF on three surfaces of the humerus, with the NF on the cranial surface located more distally than those on the others. The radius had one NF on the caudal surface, and the ulna had one NF on the cranial surface just below the elbow joint. The penetration direction of the NC followed Bérard's rule, with the exception of the relatively proximal NF of the radius.

References

1. **Ahn D.** Anatomical study on the diaphyseal nutrient foramen of the femur and tibia of the German shepherd dog. J Vet Med Sci 2013, **75**, 803-808.
2. **Ajmani ML.** A study of diaphysial nutrient foramen in human long bones. Anat Anz 1982, **151**, 305-314.
3. **Andersen AC, Floyd M.** Growth and development of the femur in the Beagle. Am J Vet Res 1963, **24**, 348-351.
4. **Coolbaugh CC.** Effects of reduced blood supply on bone. Am J Physiol 1952, **169**, 26-33.
5. **Daniel A, Read RA, Cake MA.** Vascular foramina of the metacarpophalangeal sesamoid bones of Greyhounds and their relationship to sesamoid disease. Am J Vet Res 2008, **69**, 716-721.
6. **Digby KH.** The measurement of diaphysial growth in proximal and distal directions. J Anat Physiol 1916, **50**, 187-188.
7. **Evans HE, de Lahunta A.** Miller's Anatomy of the Dog. 4th ed. pp. 129-136, 466-473, Saunders, St. Louis, 2013.
8. **Henderson RG.** The position of the nutrient foramen in the growing tibia and femur of the rat. J Anat 1978, **125**, 593-599.
9. **Hughes H.** The factors determining the direction of the canal for the nutrient artery in the long bones of mammals and birds. Acta Anat (Basel) 1952, **15**, 261-280.
10. **Humphry GM.** Observations on the growth of the long bones and of stumps. Med Chir Trans 1861, **44**, 117-134.
11. **Kawahara G, Matsuda M, Kitai T, Sugiyama K, Aihara A.** Anatomical observations on the foramen nutricium of the long bone (tubal bone) of the Japanese (further study)- its location number and direction in the bone. Kaibogaku Zasshi 1967, **42**, 132-145.
12. **Kirschner MH, Menck J, Hennerbichler A, Gaber O, Hofmann GO.** Importance of arterial blood supply to the femur and tibia for transplantation of vascularized femoral

diaphyses and knee joints. World J Surg 1998, **22**, 845-852.

13. **Kizilkanat E, Boyan N, Ozsahin ET, Soames R, Oguz O.** Location, number and clinical significance of nutrient foramina in human long bones. Ann Anat 2007, **189**, 87-95.

14. **Kumar K, Mogha IV, Aithal HP, Kinjavdekar P, Amarpal, Singh GR, Pawde AM, Kushwaha RB.** Occurrence and pattern of long bone fractures in growing dogs with normal and osteopenic bones. J Vet Med A Physiol Pathol Clin Med 2007, **54**, 484-490.

15. **Lacroix P.** The organization of bones. 1st ed. pp. 1-235, J. & A. Churchill, London, 1951.

16. **Laing PG.** The arterial supply of the adult humerus. J Bone Joint Surg Am 1956, **38**, 1105-1116.

17. **Lee HY, Kim HS, Suh JS, Chung IH.** A metric study of the femoral, tibial and fibular nutrient foramens in Korean adults. Korean J Phys Anthropol 1994, **7**, 125-136.

18. **Ljunggren G.** Fractures in the dog. A study of breed, sex, and age distribution. Clin Orthop Relat Res 1971, **81**, 158-164.

19. **Longia GS, Ajmani ML, Saxena SK, Thomas RJ.** Study of diaphyseal nutrient foramina in human long bones. Acta Anat (Basel) 1980, **107**, 399-406.

20. **Mysorekar VR.** Diaphysial nutrient foramina in human long bones. J Anat 1967, **101**, 813-822.

21. **Nagel A.** The clinical significance of the nutrient artery. Orthop Rev 1993, **22**, 557-561.

22. **Payton CG.** The position of the nutrient foramen and direction of the nutrient canal in the long bones of the Madder-fed pig. J Anat 1934, **68**, 500-510.

23. **Rhinelander FW.** Tibial blood supply in relation to fracture healing. Clin Orthop Relat Res 1974, **105**, 34-81.

24. **Sakul BU, Güzel MB, Islam C.** The location and the number of nutrient foramina on the shafts of the lower limb bones. Kaibogaku Zasshi 1994, **69**, 410-411.

25. **Schwalbe G.** Ueber die Ernährungskanale der Knochen und das Knochenwachstum. Zeitschr Anat Entwgesch 1876, **1**, 307-352.

26. **Shulman SS.** Observations on the nutrient foramina of the human radius and ulna. Anat Rec 1959, **134**, 685-697.

27. **Singh AP, Mirakhur KK, Nigam JM.** A study on the incidence and anatomical locations of fractures in canine, caprine, bovine, equine and camel. Indian J Vet Surg 1983, **4**, 61-66.

28. **Wade CM.** Inbreeding and genetic diversity in dogs: results from DNA analysis. Vet J 2011, **189**, 183-188.

29. **Welch JA, Boudrieau RJ, DeJardin LM, Spodnick GJ.** The intraosseous blood supply of the canine radius: implications for healing of distal fractures in small dogs. Vet Surg 1997, **26**, 57-61.

30. **Yonamine H, Ogi N, Ishikawa T, Ichiki H.** Radiographic studies on skeletal growth of the pectoral limb of the beagle. Nihon Juigaku Zasshi 1980, **42**, 417-425.