J. Anat. (1967), **101**, 4, pp. 813–822
With 6 figures
Printed in Great Britain

Diaphysial nutrient foramina in human long bones

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The nutrient foramina in the long bones of human limbs are described as being directed towards the elbow and away from the knee. This is said to be due to one end of limb bones growing faster than the other. Variations in the direction of the nutrient foramina have been observed in many tetrapods and there is some similarity in the nutrient foraminal pattern in mammals and birds (Hughes, 1952). Knowledge of the position of nutrient foramina can be useful in certain surgical procedures.

The position and the direction of the nutrient foramina are known to vary in human long bones. The blood supply of the femur has been described in detail by Lexer, Kuliga & Turk (1904). Nutrient foramina of the femur and humerus have been investigated by Lütken (1950), Laing (1953, 1956) and Carroll (1963). Nutrient foramina on the radius and ulna have been studied by Shulman (1959). Hughes (1952) has formulated an interesting explanation for the normal and abnormal direction of the nutrient foramina and has stated that anomalous canals are frequent in the femur, but rarely occur in the radius and seldom in the other bones. None of the above workers has studied all the long bones together and it was thought worth while to reinvestigate the problem in all the long bones.

MATERIALS AND METHODS

In all, 1080 bones consisting of 180 each of femur, tibia, fibula, humerus, radius and ulna were studied. The material was divided into two series—(1) Known, and (2) Unknown.

Known series. This consisted of long bones of forty complete skeletons of Hindus of known age and sex macerated in this Department. Ten skeletons belonged to the age group of 10–15 years, whereas the rest varied from 16 to 78 years. Twenty-seven skeletons belonged to males and thirteen to females. Thus eighty bones each (forty right and forty left) of femur, tibia, fibula, humerus, radius and ulna were studied.

Unknown series. One hundred bones each (fifty right and fifty left) of femur, tibia, fibula, humerus, radius and ulna were studied. All the bones were above the age of 15 years: they were collected in this Department over the last 20 years and are preserved here.

The 'Known' series enabled observations on the frequency of symmetry and relations between age and occurrence of nutrient foramina. The diaphysial nutrient foramina were observed in all the bones with a hand-lens so that small foramina would not be missed. The length of each bone was measured with graduated calipers. The longest length of the bone was taken except in the tibia where the length was measured between the articular surface of the medial condyle and the tip of the medial malleolus. The distance of the foramen or foramina from the upper end of

the bone was measured by means of a divider read on a scale graduated in cm. In a few specimens of the age group 10–15 years, the length had to be taken without one of the epiphyses, but since there was no material change in the readings and indices this fact has been ignored. All the surfaces of the bones were scrutinized in a regular order. Foramina within 1 mm from any border were taken to be lying on that border. The directions of the foramina and their obliquity were noted. Where a bone had more than one foramen, the relative sizes of the foramina were recorded to determine which was the main foramen and which was accessory. In bones where there was doubt as to the nature of a foramen, a fine wire was passed through it to confirm that it did enter the medullary cavity. Foramina at the ends of the bone were ignored. Diaphysial foramina showed a distinct groove proximal to the foramen, and the margin of the foramen and the adjacent canal were slightly raised above the surface of the rest of the bone.

To describe the position of the foramina the femur and the humerus were divided into six parts. Where the foraminal index (Hughes, 1952) was up to 16·66, it was in the first sixth, when up to 33·33 in the second sixth, up to fifty in the third sixth and so on. The tibia, fibula, radius and ulna were divided into three parts each.

OBSERVATIONS

Number and position of foramina

These are given in tabular form for the six bones examined (Tables 1–8). Abbreviations used are explained in each table; R and L mean right and left, K and U refer to the known and unknown series.

(*a*) *Femora* (Tables 1 and 2).

Table 1. *Femora—analysis of foramina*

Known series; no foramina, 2R and 2L; with one, 14R and 16L; with two, 23R and 21L; with three, 1R and 1L.

Unknown series; no foramina, 2L; with one, 29R and 22L; with two, 21R and 25L; with three, 1L.

	NF	I	II	III	IV	V	VI	LA	ML	LL	MML	LLL	LFI	HFI
R(K)	63	—	5	30	26	2	—	28	18	5	7	5	28·49	67·5
L(K)	61	—	8	30	22	1	—	28	16	4	10	3	·19·18	67·1
R(U)	71	—	2	38	31	—	—	38	17	2	11	3	29	65·8
L(U)	75	1	6	38	29	1	—	36	22	4	11	2	16·55	66·8

NF, total number of foramina. I, II, etc., represent the corresponding sixths of the bone; LA, linea aspera including its extensions above (part between the gluteal tuberosity and spiral line) and below (part between the supracondylar lines); ML, medial lip of linea aspera; LL, lateral lip of linea aspera; MML, medial to medial lip; LLL, lateral to lateral lip; LFI, lowest foraminal index and HFI, highest foraminal index.

In the miscellaneous group (Table 2) one R(K) had three foramina one each in the second, third and the fourth sixth; one L(K) had two foramina in the third sixth and one in the fourth; and 1L(U) had two foramina in the second sixth and one in the fourth.

Thus in the whole series, out of 180 femora, ninety-three (more than 51 %) had

more than one foramen. Of the total 270 foramina, 136 (just over 50 %) were in the third sixth, and 108 (40 %) in the fourth. Of the 270 foramina, 130 (48 %) were between the lips of the linea aspera, seventy-three (27 %) on the medial lip, and thirty-nine (14·5 %) medial to the medial lip, and the rest either on the lateral lip or lateral to it. In specimens having multiple foramina, sixty-nine (74 %) had one each in the third sixth and fourth sixth, ten (10·8 %) had one each in the second and fourth sixth.

Table 2. *Femora with multiple foramina*

	NF	I+III	II+II	II+III	II+IV	III+III	III+IV	III+V	MISC
R(K)	49	—	—	—	3	1	17	2	1
L(K)	45	—	1	1	4	—	15	—	1
R(U)	42	—	—	—	1	1	19	—	—
L(U)	53	1	1	—	2	2	18	1	1

Abbreviations used are the same as in Table 1. II+II means that one foramen was in the second sixth and the other also in the second sixth, III+V means that one foramen was in the third sixth and the other in the fifth sixth, and so on. MISC, miscellaneous.

(*b*) *Tibiae* (Table 3).

In the miscellaneous group, in 1R(K) the foramen was on the medial border above the soleal line; in 1L(K) it was just in front of the medial border on the subcutaneous medial surface above the soleal line; and in 2L(U) it was above the soleal line near the lateral side.

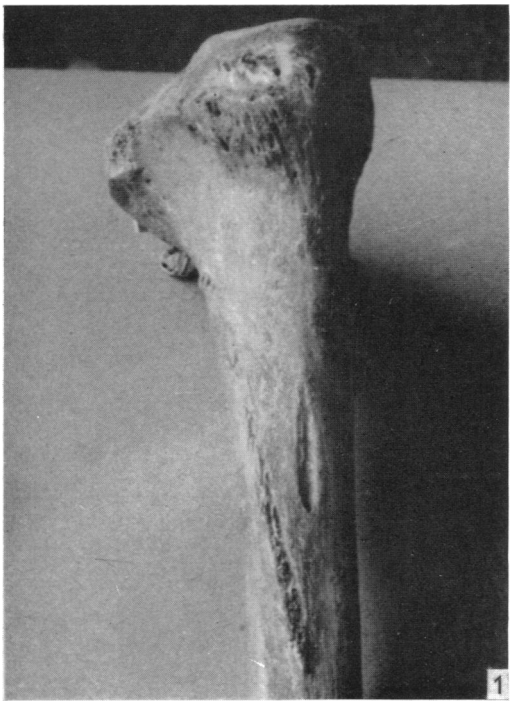
Table 3. *Tibiae—analysis of foramina*

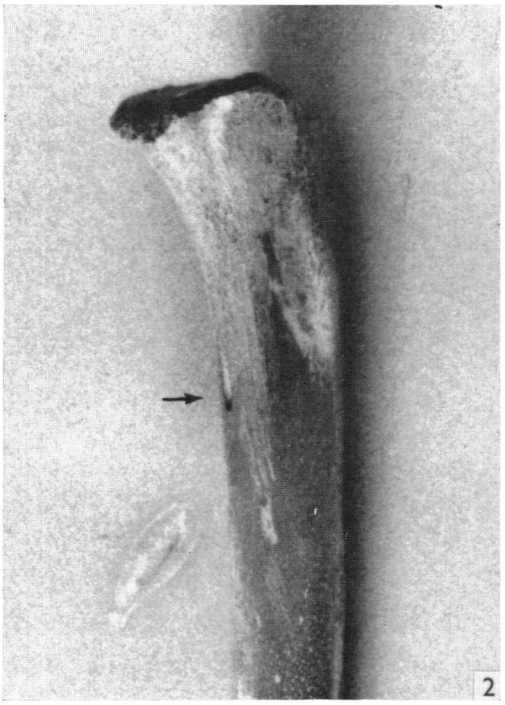
All had one foramen in each bone except in the known series 1R and 1L had two foramina, one in the upper and one in the middle third.

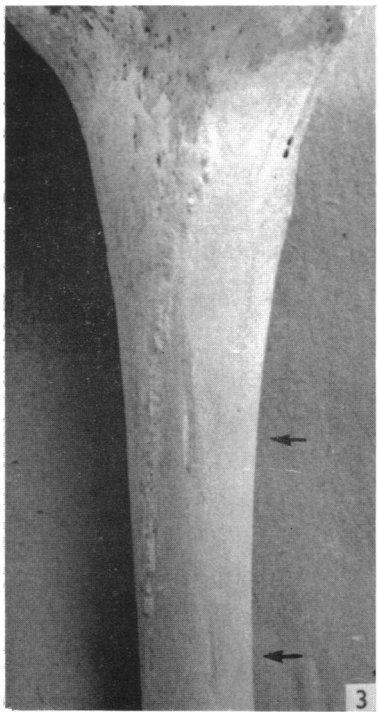
	NF	I	U–M	II	III	LV	VL	IB	MV	MISC.	LFI	HFI
R(K)	41	30	2	9	—	32	5	2	1	1	25·13	38·89
L(K)	41	34	—	7	—	34	2	3	1	1	24·61	44·63
R(U)	50	36	—	14	—	35	10	1	4	—	27·2	38
L(U)	50	41	—	9	—	34	3	3	8	2	23·5	40·3

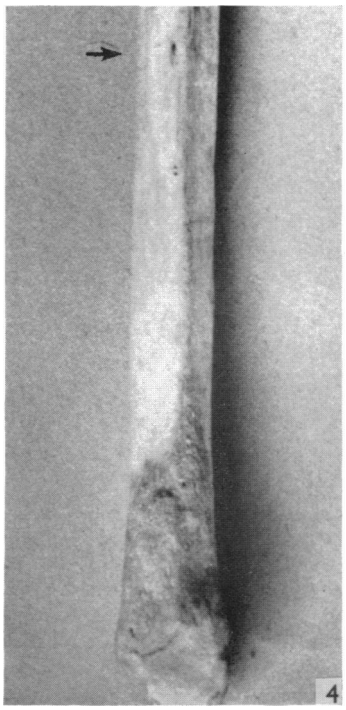
NF, total number of foramina; I, II, III, corresponding thirds of the bone; U–M, junction of upper and middle third; LV, lateral to vertical line (the line supposed to divide the posterior surface below the soleal line); VL, on vertical line; IB, interosseous border; MV, medial to vertical line even reaching as far as medial border but below the soleal line; MISC, miscellaneous; LFI, lowest foraminal index; and HFI, highest foraminal index.

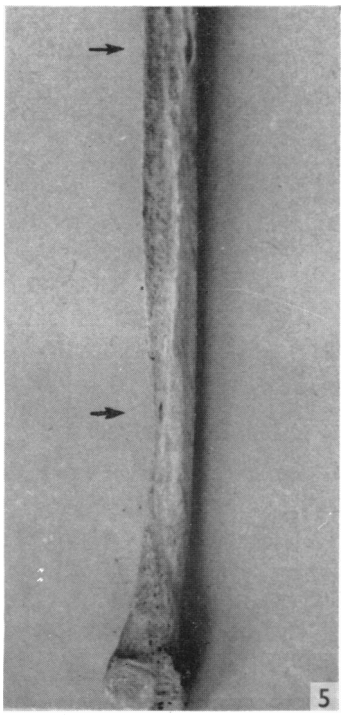
Thus of the 180 tibiae, only two had double foramina (just over 1 %). Of the 182 foramina, 141 (80 %) were in the upper third, thirty-nine in the middle third and two at the junction. All the foramina were above the middle of the bone. 135 (74 %) foramina were lateral to the vertical line, twenty on the line and the rest either just near the interosseous border or on the medial border or even on the subcutaneous medial surface just in front of the medial border. Four foramina were above the soleal line and all the rest below it (Figs. 1–3).











(*c*) *Fibulae* (Table 4).

In those specimens having double foramina, 2R(U) and 1L(U) had one each in the middle and lower third, and the remaining had them both in the middle third.

Table 4. *Fibulae—analysis of foramina*

There were no foramina in 3R(K), 2L(K), 1R(U) and 1L(U); double foramina in 3R(U) and 3L(U); all other bones had one foramen each.

	NF	I	II	III	MC	IB–MC	MC–PB	AS	LFI	HFI
R(K)	37	2	35	—	25	4	8	—	27·08	63·97
L(K)	38	1	37	—	25	2	11	—	33·23	55·17
R(U)	52	—	50	2	28	7	16	1	33·73	70·65
L(U)	52	—	50	2	22	6	24	—	34·1	70·35

NF, total number of foramina; I, II, III, corresponding third of the bone; MC, medial crest; IB–MC, between interosseous border and medial crest; MC–PB, between medial crest and posterior border; AS, anterior surface; LFI, lowest foraminal index; HFI, highest foraminal index.

In the whole series (180 bones) seven fibulae had no foramina, six had two each and the rest one each. Of the 179 foramina, 172 (96 %) were in the middle third, four in the lower third and three in the upper third. One hundred (56 %) foramina were on the medial crest and fifty-nine behind it; nine (5 %) were directed upwards (Figs. 4 and 5).

(*d*) *Humerus* (Tables 5 and 6).

Table 5. *Humeri—analysis of foramina*

Known series: with one foramen 23R and 20L; with two 15R and 17L; with three 1R and 1L; with four IR and 1L. One left humerus with a mal-united fracture was discarded.
Unknown series: with one foramen 31R and 30L; with two 18R and 18L; with three 1R and 2L.

	NF	I	II	III	IV	V	VI	MS	MB	SG	AB	PS	LFI	HFI
R(K)	60	—	2	17	38	3	—	22	23	15	—	—	30·68	74·46
L(K)	61	—	—	17	42	2	—	29	21	9	1	1	35·95	71·99
R(U)	70	—	—	17	52	1	—	29	26	14	—	1	34·92	68·87
L(U)	72	—	1	16	53	2	—	26	31	12	2	1	26·51	68·06

NF, total number of foramina; I, II, II, etc., represent the corresponding sixth of the bone; MS, anteromedial surface; MB, medial border; SG, spiral groove; AB, anterior border; PS, posterior surface well below the spiral groove; LFI, lowest foraminal index; HFI, highest foraminal index.

Out of 179 humeri, seventy five (42 %) had more than one foramen. Of the 263 foramina, 185 (70 %) were in the fourth sixth and sixty-seven (25·5 %) in the third sixth. Of the 263 foramina, 106 (40 %) were on the anteromedial surface, 101 (40 %)

Fig. 1. Tibia showing the nutrient foramen above the soleal line.

Fig. 2. Tibia showing the nutrient foramen on the subcutaneous medial surface just in front of the medial border.

Fig. 3. Tibia showing two nutrient foramina.

Fig. 4. Fibula showing the nutrient foramen directed upwards.

Fig. 5. Fibula showing two nutrient foramina, one directed upwards and the other downwards.

on the medial border, and fifty (19 %) in the spiral groove. In specimens (seventy-five) having multiple foramina, thirty-eight (51 %) had one each in the spiral groove and on the anteromedial surface or medial border. In one specimen there were as many as three foramina in the spiral groove.

Table 6. *Humeri with multiple foramina*

	NF	MB+SG	MS+SG	MB+MB	MB+MS	MS+MS	MB+PS	AB+SG	MISC.
R(K)	37	8	3	—	1	3	—	—	2
L(K)	41	5	2	2	4	4	—	—	2
R(U)	39	5	7	3	3	—	—	—	1
L(U)	42	3	5	3	4	1	1	1	2

Abbreviations as in Table 5. MB+SG means that one foramen was on the medial border and the other in the spiral groove, MB+MB means that one foramen was on the medial border and the other also on the medial border, and so on. MISC, miscellaneous.

In the miscellaneous group 1R(K) had one foramen on MB and three in SG; 1R(K) had two on MB and one in SG; 1L(K) had two on MS and one in SG; 1L(K) had one on MS, one on MB and two in SG; 1R(U) and 1L(U) each had one on MS and two in SG; and 1L(U) had one on MS, one on MB and one in SG.

(*e*) *Radius* (Table 7)

Table 7. *Radii—analysis of foramina*

With no foramina 3R(K) and 1L(K); with two foramina 4R(K), 3L(K) and 1R(U); all other bones had one foramen.

	NF	I	U–M	II	III	AS	AB	IB	PS	LFI	HFI
R(K)	41	13	2	26	—	16	13	10	2	27	48
L(K)	42	16	—	26	—	20	11	6	5	28	45
R(U)	51	16	—	35	—	34	7	6	4	29·63	44·61
L(U)	50	22	1	27	—	30	7	7	6	26·95	45·83

NF, number of foramina; I. II, III, corresponding third of the bone; U–M, junction of upper and middle third; AS, anterior surface; AB, anterior border; IB, interosseous border; PS, posterior surface; LFI, lowest foraminal index; HFI, highest foraminal index.

Out of 180 radii, four had no foramina, and eight had double foramina. Of the 184 foramina, 114 (62 %) were in the middle third, sixty-seven (36 %) in the upper third and three at the junction. All the foramina were in the upper half of the bone. Of the 184 foramina, 138 (75 %) were on the anterior surface reaching as far as to be on the anterior border, twenty-nine were on the interosseous border and seventeen (9 %) on the posterior surface.

In those specimens having double foramina, either both were on the anterior surface or one was on the anterior surface and the other on the posterior.

(*f*) *Ulnae* (Table 8).

Table 8. *Ulnae—analysis of foramina*

All bones had one foramen except IR(K) and 1L(K) with no foramina and 4R(K), 3L(K), 1R(U) and 2L(U) with double foramina.

	NF	I	U–M	II	III	AS	AB	IB	LFI	HFI
R(K)	43	11	—	32	—	32	8	3	24·4	54·3
L(K)	42	13	1	28	—	29	8	5	23·63	59·51
R(U)	51	21	2	28	—	33	11	7	24·42	50·76
L(U)	52	21	2	29	—	43	5	4	27·53	53·11

NF, total number of foramina; I, II, III, corresponding third of the bone; U–M, junction of upper and middle third; AS, anterior surface; AB, anterior border; IB, interosseous border; LFI, lowest foraminal index; HFI, highest foraminal index.

Of the 188 foramina, 117 (62%) were in the middle third, sixty-six (35%) in the upper third and five at the junction. There were 137 (73%) foramina on the anterior surface, thirty-two on the anterior border and nineteen on the interosseous border.

Direction of the foramina

In all bones except nine fibulae, namely 1R(K), 1L(K), 3R(U) and 4L(U), the direction of the foramina was normal. Out of these nine fibulae, in which the foramen was directed upwards three had double foramina with one foramen being directed upwards and the other down, whereas in the remaining six there was a single foramen directed upwards. All the upwardly directed foramina were situated much below the middle of the bone. The obliquity of the foramina was similar in young bones as in older ones. Similarly, there was no change in the obliquity when the foramina were in the centre of the bone as compared to when they were nearer the ends. The foramina in the tibia were the most oblique ones, so much so that they were practically vertical. Foramina in the femur appeared to be the least oblique as compared to the other bones.

Reciprocity

In those bones having double foramina, reciprocity between their sizes was clearly seen in only the humerus, thus, if the foramen on the anteromedial surface or medial border was larger, that in the spiral groove was smaller and vice-versa. The size of the foramina, in general, was larger in younger bones.

Symmetry

Foramina similar in number were taken as partial symmetry, whereas those similar in number and position were taken as complete symmetry (Table 9).

Table 9. *Percentage symmetry of foramina*

Bone	Partial symmetry	Complete symmetry	Total
Femur	20	30	50
Tibia	—	75	75
Fibula	—	50	50
Humerus	23	15	38
Radius	—	57	57
Ulna	—	47	47

DISCUSSION

The arrangement of the diaphysial nutrient foramina in the long bones usually follows a definite pattern. There are often two nutrient foramina in the femur and the humerus whereas in the other bones they are normally single. In the femur the nutrient foramina are restricted to the linea aspera or its immediate neighbourhood in the middle third of the bone (Fig. 6). In the humerus the foramina occur just below the middle of the bone or in the spiral groove or frequently in both these situations. In the tibia the foramen occurs in the upper third of the bone lateral to the vertical

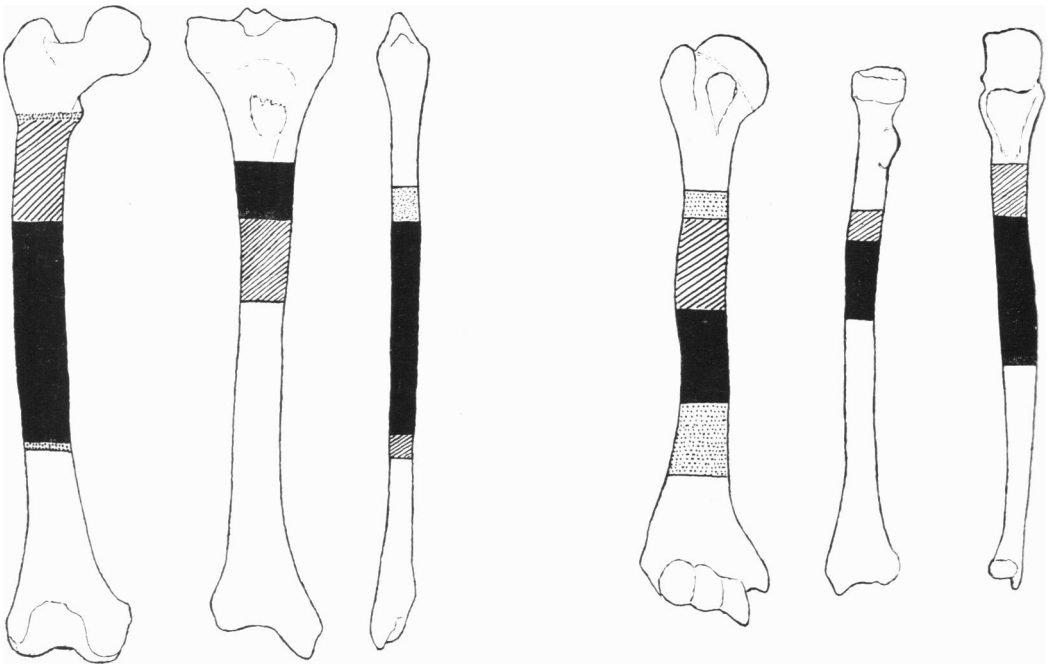


Fig. 6. Comparison of the position of the nutrient foramina in the various bones studied. The dark areas represent the usual position (commonest). The striped areas represent the area of lesser frequency. The dotted areas show the rare positions for the foramina. (All drawn to scale.)

line which arises from the soleal line and runs vertically downwards. The fibula has one foramen in its middle third. In the radius the foramen is, invariably, above the middle of the bone, whereas in the ulna, it is in the middle third and in both, the foramen most frequently occurs on the anterior surface nearer either the anterior or interosseous border. There is some symmetry in the position of the foramina on the two sides. It appears that many factors may work independently or together to give rise to anomalous foramina.

The nutrient artery to a long bone may have various sources of origin, e.g. in the femur it may arise from the medial circumflex femoral or from any artery parallel to the diaphysis; in the tibia the origin can be directly from the popliteal (this can explain

the position of the foramen well above the soleal line) or from the posterior tibial; in the fibula from one or more branches of the peroneal; in the humerus either from the brachial as one or many branches, or from the profunda as one or many branches, or from the muscular branches of these arteries; in the radius from the anterior or even the posterior interosseous (this explains the foramina on the posterior surface of the radius); and in the ulna from the ulnar or any of its muscular branches. The reciprocity in sizes of the foramina in the humerus would suggest that one of them would be the main nutrient foramen and the other the accessory one and hence the main nutrient artery can arise either from the brachial or the profunda artery. In femora having duplicated foramina both should be treated as main ones, the presence of which is not surprising in view of the length of the bone.

It has been suggested that the direction of the nutrient foramina is determined by the growing end of the bone. The growing end is supposed to grow at least twice as fast as the other end. This theory fails to explain the abnormal direction of the foramina. According to the theory of periosteal slip, foramina which are in the centre of the shaft would be less oblique than those at the periphery. My observations fail to support this assumption.

Lütken (1950) found about 1 % distally directed foramina in the femora, and according to Hughes (1952) anomalous canals are found most frequently in the femur. For these anomalous canals, Hughes (1952) has provided an explanation (not proved experimentally) of unequal arterial growth, according to which, if unit lengths of an artery lying close to a long bone do not grow at equal rates anomalous canals can occur.

In this series, anomalous canals were found in about 5 % fibulae alone. Could this be due to the peculiar ossification of the bone? Is it possible that in the fibula one end may act as the growing end for a time and then subsequently the other? The upwardly directed foramina were low down on the bone. If the nutrient artery to these fibulae arose from the lower part of the peroneal artery, the anomalous direction could be explained on this assumption. In those fibulae where one foramen was directed upwards and the other downwards, it is suggested that each end acted alternately as the growing end. If the two canals, one normally and the other inversely directed, are roughly in the middle third of the shaft, and if we were to accept the 'arterial theory', then the growth difference in the segments of the peroneal artery would have to be so extreme that it could not be the cause of the opposite direction of the foramina. The growing end theory cannot be ruled out; at best, instead of only one theory (Hughes, 1952) explaining the anomalous foramina all factors may be appropriately and proportionately responsible in individual bones.

SUMMARY

1080 long bones of the limbs have been studied for the number, position, direction, obliquity, symmetry, etc., of the diaphysial nutrient foramina. Since in the known series 480 bones belonging to forty complete skeletons have been studied and the study has been extended to younger age groups, it has been possible to compare as to which bone is vulnerable to variations. Variations in the direction of the foramina have been found only in the fibula. The various theories for the normal and abnormal

direction of the foramina are briefly discussed. A possible explanation for the occurrence of the anomalous foramina in the fibula is added.

I am grateful to Professor D. T. Kolte for providing me all facilities for this work.

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