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The position of the nutrient foramen in the growing tibia and femur of the rat

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INTRODUCTION

The position of the principal nutrient foramen and the direction of the nutrient canal in mammalian bones are variable and may alter during growth.

Humphry (1861) suggested that the position of the nutrient artery and the direction of its canal were determined by the interaction of interstitial growth of periosteum and appositional growth of bone. This would result in periosteum sliding over the surface of the bone, more particularly towards the growing end. An oblique canal would then be laid down for the nutrient artery with its outer opening nearer the growing end of the bone.

Payton (1934) studied the matter further in pigs, using madder root staining. In both femur and tibia he found that resorption of bone occurred on the proximal side of the foramen and deposition on the distal side. He concluded that different growth rates at the two ends of the bone did not affect the position of the nutrient canal. Lacroix (1951) verified Humphry's findings, and in addition suggested that the pull of muscle attachments on periosteum explained certain anomalous nutrient foramina directions, e.g. in the rabbit's femur.

The aim of this investigation was to examine the movement of the nutrient foramen during growth and to elucidate the factors responsible for it.

MATERIALS AND METHODS

Three groups of five young female albino rats aged 40, 49 and 59 days were used. Younger rats could not be used as the bones were too fragile. The rats were killed with ether and the hind limbs removed. The flesh was softened by boiling in a pressure cooker for 30 minutes, and the bones were then scraped clean and stored in 10 % neutral formol.

The epiphyses of the femora and tibiae were removed manually and the lengths of the resulting shafts and the positions of the nutrient foramina were measured using the fixed points shown in Figure 1. A travelling microscope with a Vernier scale was used, permitting lengths to be measured to an accuracy of 0·01 mm.

Histological sections of femora and tibiae were obtained after fixation in 10 % neutral formol for several days. Decalcification was carried out using Gooding and Stewart's fluid, completeness of decalcification being verified by radiography. The specimens were then dehydrated and embedded in paraffin. Sections were cut at 10 μm and stained with haematoxylin and eosin.

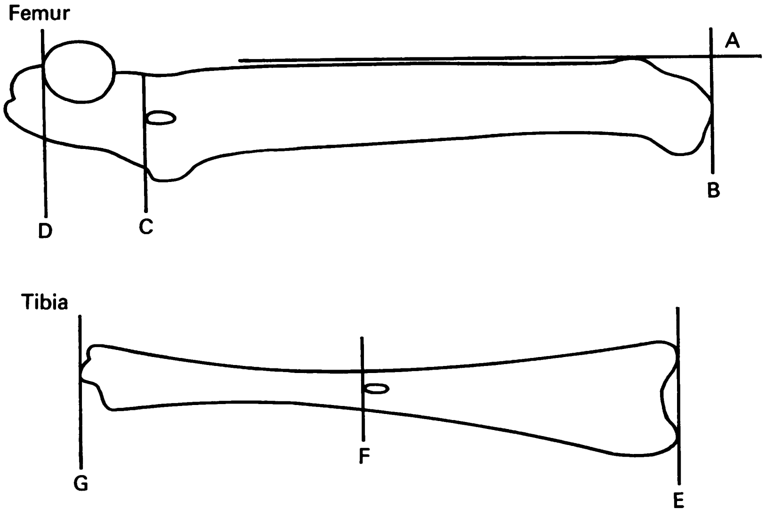

Fig. 1. Diagram to show the method of measuring the lengths of the femoral and tibial shafts *after removal of epiphyses*, and of determining the position of the nutrient foramen. In the femur, the horizontal hairline (A) was arranged parallel to the anterior surface of the shaft. The vertical hairline was then moved to coincide with the distal end (B), the proximal lip of the nutrient foramen (C), and the proximal side of the metaphysis of the femoral head (D). In the tibia, the vertical hairline was arranged to coincide with the two proximal metaphyseal protuberances (E). The positions of the distal lip of the nutrient foramen (F) and the distal end of the shaft (G) were then found.

Table 1. *Shaft length measurements of femur and tibia in the rat*

(Mean lengths in mm ±S.E.M.)

Age of rats (days)		40	49	59
Distance from distal end of shaft to nutrient foramen	Tibia	14·84±0·25	16·59±0·28	16·88±0·28
	Femur	14·73±0·13	16·81±0·30	18·30±0·32
Distance from proximal end of shaft to nutrient foramen	Tibia	9·85±0·20	11·64±0·24	13·14±0·25
	Femur	5·48±0·09	6·26±0·18	6·81±0·18
Distance from distal end of shaft to foramen as % shaft length	Tibia	60·1±0·47	58·77±0·51	56·22±0·40
	Femur	72·9±0·46	72·89±0·49	72·89±0·37

RESULTS

The shaft length measurements of the femora and tibiae at 40, 49 and 59 days are given in Table 1, indicating in particular the distance of each end of the shaft from the nutrient foramen and its relative position. These results are shown graphically in Figure 2, where it can be seen that, with increasing age, there is a relative but not absolute movement of the nutrient foramen towards the distal end of the shaft of the tibia. No such movement occurs in the femur.

Figure 3 shows that the absolute distances from the nutrient foramen of the tibia to each end of the shaft increase at an equal rate during the first period (40–49 days). In the second period (49–59 days), the distance from the foramen to the distal end increases at a much smaller rate than the distance to the proximal end, the ratio being 1:5. Figure 4 should be compared with Figure 3. It shows that in the femur the corresponding ratio is the same for both the first and second periods, being 2·7:1, distal:proximal.

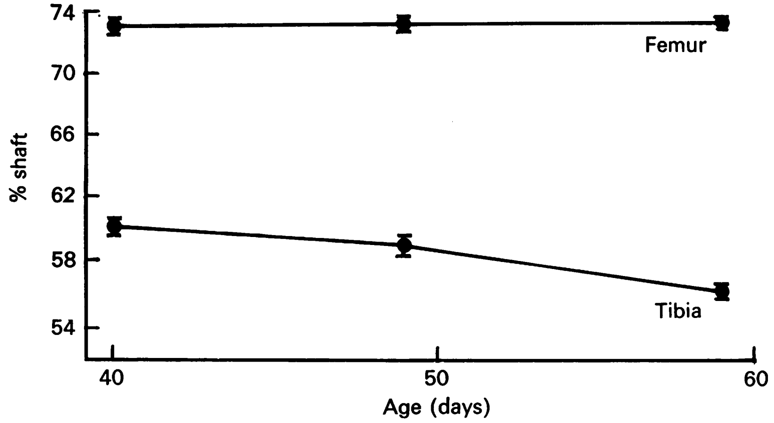

Fig. 2. Graph showing distance of nutrient foramen from distal end of shaft relative to total length, compared with age.

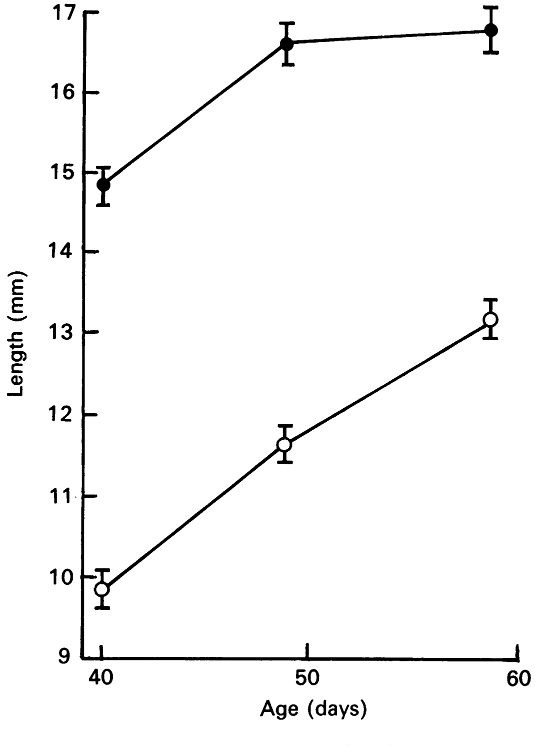

Fig. 3. Graph showing mean distance ± S.E.M. from nutrient foramen to each end of tibial shaft, compared with age. ●, distance to distal end; ○, distance to proximal end.

Histology of the epiphyseal plates of the femur and tibia show the normal picture of endochondral ossification (Figs. 5, 6) with easily identifiable zones: resting, proliferating and hypertrophic, and a narrow zone of calcification which abuts against the cancellous metaphysis. The sections demonstrate that the epiphyseal plate at the growing end of a femur or tibia (Fig. 5) is much thicker than that at the

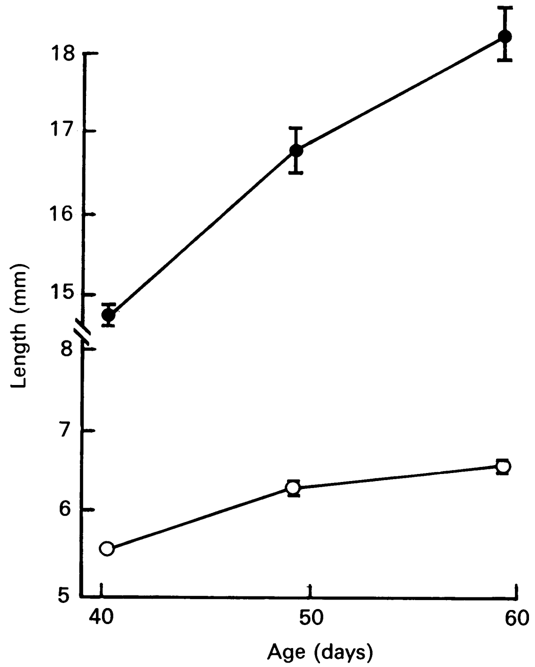

Fig. 4. Graph showing mean distance ± s.e.m. from nutrient foramen to each end of femoral shaft, compared with age. ●, distance to distal end; ○, distance to proximal end.

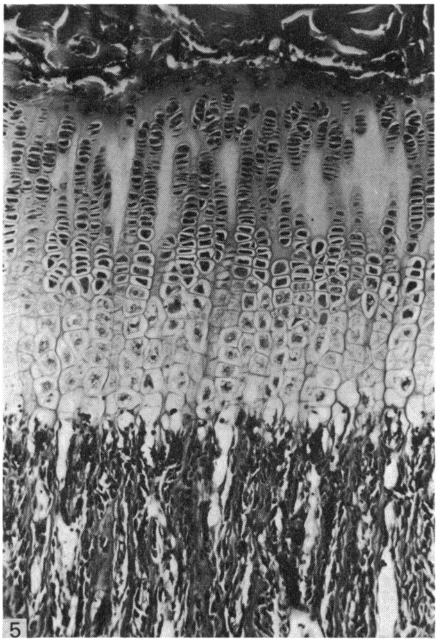

Fig. 5. Photomicrograph of the epiphyseal plate from the proximal (growing) end of the rat tibia at 38 days of age. See text for description. Haematoxylin and eosin. × 50.

Fig. 6. Photomicrograph of the epiphyseal plate from the distal (non-growing) end of the same tibia as in Fig. 5. Note how much thinner the cartilage is compared with the proximal end. Haematoxylin and eosin. × 50.

non-growing end (Fig. 6). This appearance was observed throughout the first and second periods in both femora and tibiae.

DISCUSSION

The results show that during a period of rapid growth the rat tibial nutrient foramen moves relatively towards the distal end of the shaft. This contrasts with the behaviour of the femoral nutrient foramen, whose relative position remains constant.

Well known factors which may affect nutrient foramen position are the growth rates at the two ends of the shaft, and bone remodelling. If differences in growth rates at the epiphyseal plates alone were to account for nutrient foramen position, then growth at each end would have to be proportional to the distance from the foramen in order to maintain its constant position. In the femur this appears to be the case, the foramen's relative position being constant during the period of observation (73 % of shaft length from the growing end). On the other hand, in the tibia the foramen is initially nearer the growing (proximal) end. Hence it would be expected to move relatively towards the non-growing (distal) end. In the first period, however (Fig. 3), the growth rate from the foramen to each end is about the same, although the distal epiphyseal plate is known to have much less activity than the proximal plate in the tibia. This growth differential is shown in Figures 5 and 6, assuming that growth rate is proportional to plate thickness (Moss-Salentijn, 1974). It seems clear that the equal growth in length from the foramen to each end of the tibia cannot be accounted for entirely by epiphyseal plate activity. There must be a real movement of the foramen proximally.

It is known that the mammalian tibia increases in girth mostly on its posterior surface (Tomlin, Henry & Kon, 1953; Smith, 1960; Brookes, 1963). In view of the extreme obliquity in the tibia of its nutrient artery, the real movement of the foramen proximally may be accounted for by nutrient canal extension as the tibia increases in girth (Figs. 7, 8).

From 49 to 59 days of age there is five times as much growth from the proximal end of the tibial shaft to the foramen as from the distal end. This is compatible with the histological evidence of greater activity at the proximal epiphyseal plate, and less real movement of the foramen may occur during this second period. Fusion of the distal epiphysis of the rat tibia with the shaft was found by Dawson (1925) to occur at 90 days of age. Presumably at 59 days of age this process will not have begun.

Bone remodelling, such as Payton (1934) found to occur in the pig's tibia, does not need to be invoked to explain the results found here It may of course be occurring, but the present results suggest that it is of little significance in the rat's tibia, which more closely resembles the human tibia in shape.

It may be concluded that, in the tibia, the nutrient foramen is not a fixed point during growth. For the limited period studied here, the two most important factors influencing the position of the nutrient foramen would appear to be (*a*) different growth rates at the two ends of the shaft, and (*b*) extension of the oblique nutrient canal by tibial growth in girth, occasioning thereby a real movement of the foramen.

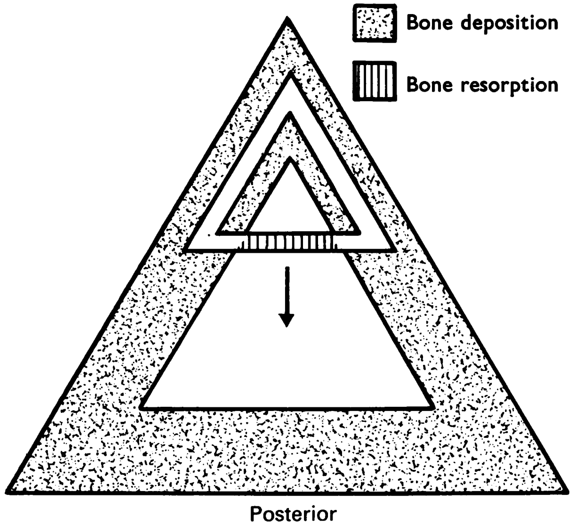

Fig. 7. Diagram to show how the tibia grows in girth mostly on its posterior aspect. (Modified from Brookes, 1971.)

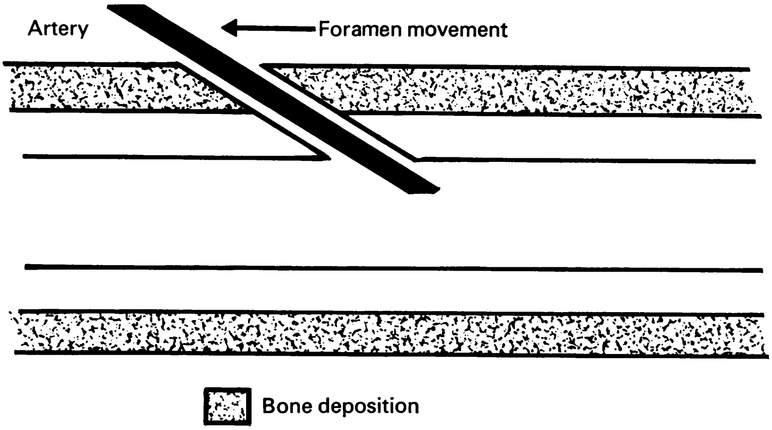

Fig. 8. Diagram showing the influence of growth in girth on the position of the nutrient foramen.

SUMMARY

In rats of 40, 49 and 59 days of age the positions of the femoral and tibial nutrient foramina were determined by direct measurement, using a travelling microscope. The femoral nutrient foramen remained constant in position with increasing age, whereas the tibial nutrient foramen moved relatively nearer to the distal end of the shaft. In the case of the femur this can be accounted for entirely by differences in growth rates at the epiphyseal plates of the femur compensating for the disproportion in the distances of the foramen from the two plates. In the tibia, however, extension of the extremely oblique nutrient canal as the bone increases in girth is also involved. Bone remodelling in the vicinity of the canal is not necessary to explain the results.

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