THE VERTICAL AXES OF THE FEMUR AND THEIR RELATIONS. A CONTRIBUTION TO THE STUDY OF THE ERECT POSITION

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THE relations of the vertical axes of the femur to one another, as seen from the front, are most easily studied on an orthogonal tracing of the bone from the front, for the axes are readily inserted on the tracing by simple constructional procedures; and if series of bones are traced in the same standard position then comparisons may be made of the relations of their axes. The most convenient standard position in which to make the tracing is that in which the bone is placed to measure its oblique length, and in which it rests on the posterior surface of the condyles and (usually) the intertrochanteric ridge; the femur is then in the standard vertical position[1]. It is not possible, of course, to be certain that this standard position accurately reproduces in each of a series of human femora the same position relative to the position it occupied in the full extension of the standing position in the living body, for there are differences in the details of the axis of the body-weight, of spinal curvature, and of pelvic position, which will affect the antero-posterior inclination of individual bones; but apart from being small in amount, the differences in antero-posterior inclination will not affect the position of the vertical axes as seen from the front. This is also so, of course, of femora which are inclined not too much forwards, as for example the partially flexed femora of the apes. A much more important and significant difference is that which is introduced by the torsion of the femur, for it produces on the tracing a shortening of the femoral neck and, in effect, a lateral displacement of the femoral head, the amount of which will vary directly with the amount of the torsion; for if there is little torsion the neck will be almost its natural length, while if the torsion is great in amount the neck will be short on the tracing and the femoral head will be displaced laterally, as well as forwards, in relation to the lower end of the bone. This displacement of the femoral head, that is the amount of the femoral torsion, will affect the position or the direction of the femoral axes which are drawn from the femoral head to the lower end of the bone.

The tracing having been made, the infracondylar plane is drawn in on it. This plane has been assumed to be horizontal in making the further construc-

[1] The standard vertical plane of the femur is the plane tangential to the posterior surface of the condyles and the intertrochanteric ridge; it is the *horizontal* plane of the osteometer when the bone rests in the standard position on it, anterior face uppermost. (Pearson and Bell, *A Study of the Long Bones of the English Skeleton. The Femur*, p. 23. Camb. Univ. Press, 1919.)

tions; that is, it has been assumed that the latero-medial inclination of the upright bone in its proper weight-bearing position is reproduced if the condyles of the femur are placed on a horizontal plane and the bone is maintained in the standard vertical position[1]. It is obvious, of course, that in the movement of abduction at the hip-joint the medial condyle of the femur must descend and the infracondylar plane become more and more oblique; and there is a fairly general opinion that the medial condyle is at a lower level than the lateral condyle in the normal standing position[2]. It is so figured and described by Fick[3], according to whom, in standing erect on both feet with the feet apart (it is the male which is figured), the infracondylar plane slopes upwards and laterally at an angle of 3° from the horizontal and the femur is as in fig. 1. It may be calculated from the figure given by Fick that the infracondylar plane would become horizontal after a movement of adduction at the hip-joint sufficient to bring the knees together; and the femur would then be placed as in fig. 2. The relations of the anatomical axis[4] of the femur to the load axis[4] are remarkably different in the two positions, that is, there is a significant difference in the relations of the axis of the structure which is carrying the load and the "load line" of the load which is being carried. In the "Normalstellung" of Fick, the position of standing on both feet with the feet apart, the three axes of the femur intersect one another at the mid-condylar point[5], the mechanical axis being coincident with the load line and vertical in position; the axis of structure is entirely on the lateral side of the load line; and the load is equally distributed between the two condyles. In the second position (fig. 2) the anatomical axis and the load line intersect one another in the lower half of the shaft, so that the weight-carrying structure is first on the lateral side and then on the medial side of the load line of the load which is being carried; and the lateral condyle is the greater weight-bearing condyle.

[1] The articular cartilage is thicker on the medial than on the lateral condyle in 75 per cent. of (white) male femora (Ingalls, *Amer. J. Phys. Anthrop.* vol. IX, p. 355). The tracings which have been made for this study are from dried bones, which will therefore, in most instances, have taken a position slightly more vertical (0·5°–2°) than in the living subject; that is, the crossing of the load axis and the anatomical axis, which is described later, will be at a slightly higher level, and the distance between the lower ends of the axes rather more in the living subject than is shown in the tracings.

[2] This might well be held to explain the closer correlation between the maximum length of the femur and the stature than between the oblique length and the stature (see Pearson and Bell, *op. cit.* p. 5).

[3] R. Fick, *Handb. d. Anat. u. Mechanik d. Gelenke*, Bd. III, S. 522. Meyer ("Die Mechanik des Kniegelenkes," Müller's *Arch. f. Anat. u. Phys.* 1853, S. 500) definitely contradicts this statement: "Eine ganz unrichtige Angabe ist die, welche man so häufig findet, dass der innere Kondylus tiefer nach unten reiche als der aussere...."

[4] The anatomical axis of the femur is the axis of the shaft; on the tracing it passes through as many as possible of the centre points between the edges of the shaft and through the mid-condylar point. The mechanical axis of the femur is the line which joins the centre point of the head and the mid-condylar point. The load axis (or the weight line) is the vertical line from the centre point of the femoral head; it is at right angles to the horizontal infracondylar plane.

[5] Strictly speaking, it is incorrect to place the centre point of a load-carrying femur on a *curved* line, as is commonly done at the mid-condylar point; the centre point for the load should be at the centre of the *straight* line between the places where the condyles touch the infracondylar plane.

There are considerable differences in the functions of the femur in the two postulated positions. In the second position, as in standing with the knees together or with the body-weight borne on one limb in walking, the femur is acting to the fullest advantage as a static support and, if it is "locked" in this position, with the smallest requirement of assistance from the other postural organs; while in the first position, though the weight is equally distributed

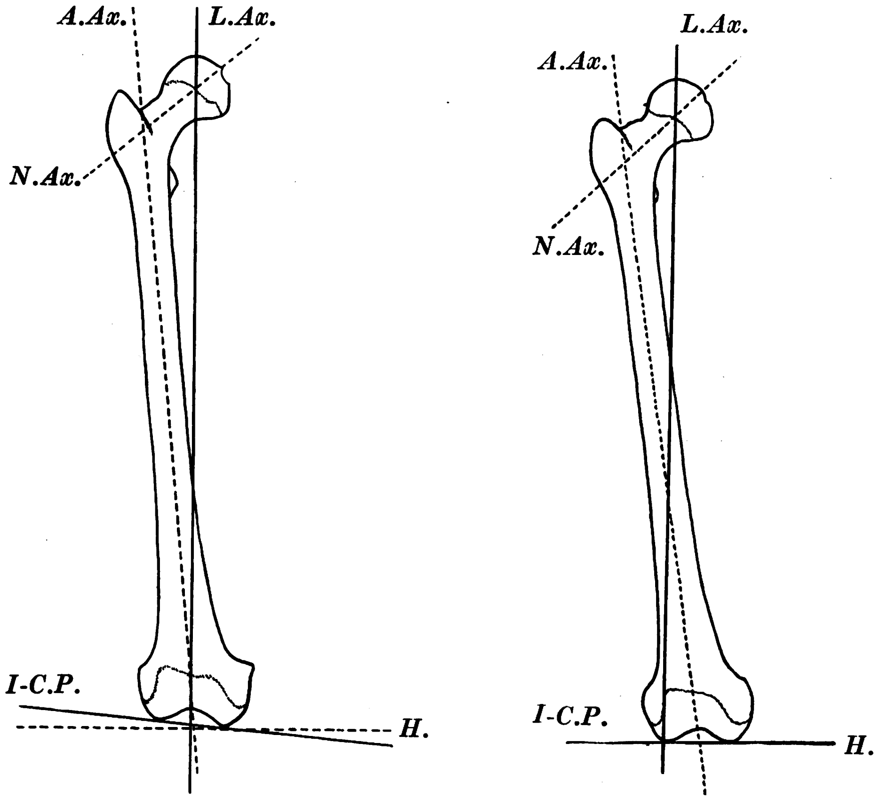

Fig. 1. Fig. 2.

Fig. 1. The position of the femur in the "Normalstellung" (Fick). The feet are apart; the infracondylar plane slopes upwards and laterally; and the mechanical axis and the load axis coincide.
Fig. 2. The position of the femur when the infracondylar plane is horizontal. The mechanical axis is not inserted.
***A.Ax.*, anatomical axis; *M.Ax.*, mechanical axis; *N.Ax.*, axis of neck; *I-C.P.*, infracondylar plane; *H.*, horizontal; *L.Ax.*, load axis.**

between the condyles, the femur will require considerable support from the other postural organs both from its own position and to balance the medial shearing action which will be present at the knee-joint. The significance of these differences will emerge more fully later. In the meantime it may be stated that in order to confirm the position of the infracondylar plane in the two positions, X-ray photographs of the knee-joint were taken of two young adult women and six males from 14 to 68 years of age in three different positions: (*a*) standing with the knees together; (*b*) standing in the most comfortable and effortless position with the feet apart; and (*c*) standing and carrying all the body-weight on one limb; and a wire plumb-line was placed to give a vertical line on the films. The results of this examination, omitting the differences between the right and left sides, are that in the females (statures 5 ft. 2 in. and 5 ft. 3 in.) the infracondylar line slopes upwards and medially with the knees together and is horizontal with the feet apart; in the boy of 14 and in the young male adults the line is horizontal with the knees together and slopes upwards and laterally with the feet apart; in the male aged 68 years the line is horizontal with the feet apart; and in all the line is horizontal ($\pm$ 1°) in bearing the weight of the body on one limb.

I have assumed therefore that there is a static position of the femur, as is used in walking, in which the infracondylar plane is horizontal, and a postural position of the femur in which there are individual and age and sex differences in the position of the plane. It may be pointed out here that the arrangement of the cancellous tissue in the lower end of the femur strongly suggests that the lateral condyle is the greater weight-bearing condyle, for this tissue is strongest and most perpendicular over the middle of the lateral condyle, while in a small area over the lateral part of the lateral condyle and in a larger area over the medial part of the medial condyle there is a lighter cancellous tissue and there are much larger intercancellous spaces. The suggestion is also implied in the known locking mechanism of the knee-joint, in which the terminal rotation of the medial condyle implies a stationary lateral condyle carrying the body-weight[1].

The axis of the shaft of the bone[2] is next drawn in. Often one straight line is sufficient for the whole length of the shaft, but if the bone is bowed in the latero-medial plane more than one line is required (fig. 4). The axis of the neck and the axis of the head[3] are then drawn in, and on the latter axis the centre point of the head is found at the intersection of the greatest diameter of the head drawn from the highest point on the surface of the head. The load axis is the vertical line drawn from the centre of the head, and it is of course at right angles to the horizontal infracondylar plane. On lines at right angles to the axis

[1] It is also supported, I believe, by the age changes which occur in the bicondylar widths of the femur and the tibia; namely, that there is a greater increase in the transverse width of the lateral condyles (femoral and tibial) than of the medial condyles. I have not yet collected sufficient material, however, to enable me to complete this study, but that there is a diminution in the amount of the medial projection of the medial tibial condyle from infancy onwards is recognised in orthopaedic surgery.

[2] See note 4, p. 2.

[3] Walmsley, *J. Anat.* vol. XLIX, p. 314. It is again to be pointed out that very rarely is the axis of the head a continuation of the axis of the neck as is implied in Pearson's term "capito-collar axis" (Pearson and Bell, *op. cit.* p. 19); for, usually, the axis of the head is more vertical than the axis of the neck and is inclined backwards from it, that is the head is retroverted on the neck. This retroversion of the head of the femur has since been more fully studied by Grünwald (*Zeitschr. f. Morph. u. Anthrop.* Bd. XXI, S. 103) who describes it to be, as I also think, a specific human character.

of the shaft I measured the width of the condylar masses, the width of each mass being measured from the axis to the farthest point of the mass[1].

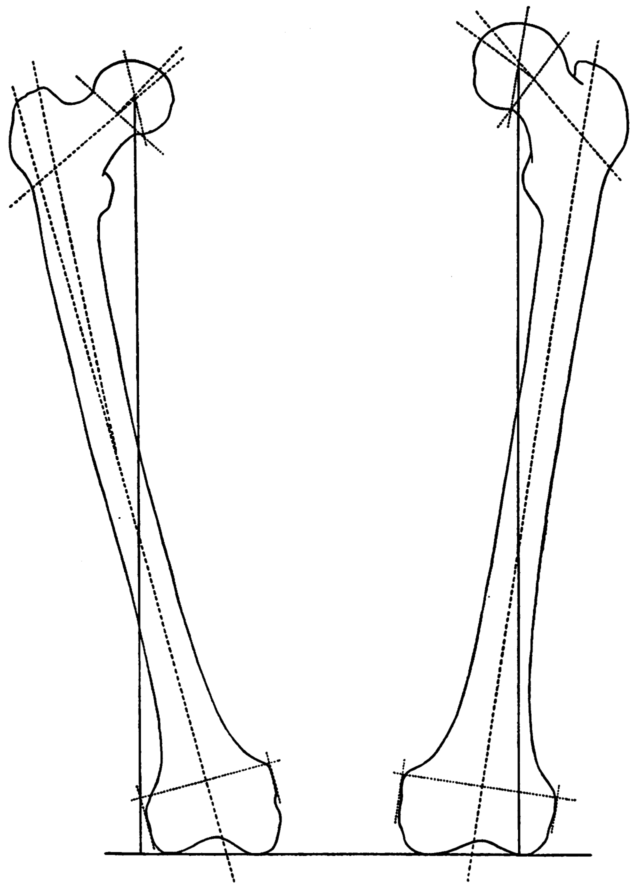

Fig. 3. Fig. 4.

Fig. 3. Modern female femur (¼ nat. size). Oblique length, 41·8 cm.; angle of inclination, 15°; angle of neck, 119°; angle of torsion, 6°; lateral condyle, 3·55 cm.; medial condyle, 3·45 cm.; shaft of femur bowed in upper part; retorsion of head absent.

Fig. 4. Modern male femur (¼ nat. size). Oblique length, 43·9 cm.; angle of inclination 9°; angle of neck, 131°; angle of torsion, 18°; lateral condyle, 3·95 cm.; medial condyle, 4·20 cm.; shaft of femur straight; retorsion of head present.

In the modern male femur the load axis crosses the anatomical axis in the lower third of the bone and passes through the lateral condyle at the place where

[1] This measurement is one which can only be used, as it is here, for gross comparative purposes, for it is a subdivision of an epiphysis by a character of a diaphysis and its variation will be affected by the variation of the diaphysis. A reliable measurement would require to be more directly related to the function of the epiphysis, but the comparative changes which are demonstrated by this measurement in the series of bones given below are of a magnitude great enough to be expressed by it. (The relation of epiphysis and diaphysis referred to here is discussed by Seitz, *Amer. J. Phys. Anthrop.* vol. VI, p. 37, and Ingalls, *ibid.* vol. VII, p. 223.)

it touches the infracondylar plane or just on the medial or the lateral side of this place (fig. 4). There is some variation in the position of the load axis, more commonly in my short series of ten bones in the lateral direction, and I have even found the axis to join the infracondylar line outside the lateral condyle; and as a rule it is more lateral in left bones than in right bones. The measurement of the medial condyle exceeds the measurement of the lateral condyle by 2·5 mm. in this bone (fig. 4), but there is a considerable variation in the proportion of the condyles measured in this way[1]; always, however, the medial condyle has exceeded the lateral condyle, and most commonly by 2–4 mm.

In the modern female femur the load line is more laterally placed than in the male, that is, it crosses the anatomical axis at a higher level and passes through the edge of the lateral condyle or even entirely lateral to it (fig. 3)[2]. The transverse measurement of the lateral condyle in this specimen exceeds the transverse measurement of the medial condyle by 1 mm.; but in the female also there is a considerable variation in the proportion of the condyles, and in my short series of ten bones the medial condyle, as in the male, was usually the larger but by a lesser amount (1–2 mm.).

In the negro male femur the position of the load axis is through the lateral part of the lateral condyle (fig. 5)[2].

The lateral condyle of the femur is thus even more the weight-bearing condyle in the female (and the negro male, Ingalls) than in the male; and this is also expressed, I believe, in the fact that the maximum antero-posterior length of the lateral condyle exceeds that measurement of the medial condyle by a greater amount in the female (and negro male) than in the male[3]. The position of the load axis, it is seen, since it is almost the same in the short (white) female and long negro male bones, is not determined simply by the length of the femur; nor are the inclination of the femur and the position of the load axis determined simply by the width of the pelvis between the acetabula, for in the negro male the acetabula are 15 mm. closer together than in the white male. It may also be pointed out here that, on mechanical principles, the higher

[1] See note 1, p. 288.

[2] This difference in the position of the load line in the male and the female is entirely in accord with the results obtained by Ingalls (*Amer. J. Phys. Anthrop.* vol. x, p. 393). He determined the position of the centre of the femoral head when projected on to the condyles, and found that in the (white) female (and in the negro male) the position was more lateral than in the (white) male. It is also in accord with Pearson's results (*op. cit.* p. 217): "The centre of the head falls externally to the mid-trochlear vertical. The amount (i.e. the distance from the mid-trochlear vertical) is absolutely greater in the female than the male...."

[3] The following figures of the maximum antero-posterior length are from Pearson's table (*op. cit.* p. 405):

	(*a*) Lateral condyle mm.	(*b*) Medial condyle mm.	$\Delta\ a-b$
London male	62·44	62·06	+0·38
London female	56·12	55·56	+0·56
Negro male	61·9	59·3	+2·6
Negro female	56·2	53·1	+3·1
Gorilla	51·2	62·7	−11·5
Chimpanzee	43·4	51·5	−8·1

crossing of the two lines—anatomical axis and load axis—permits a greater gracility of the femoral shaft in the transmission of the same load, and that herein lies the factor which determines the greater gracility of the negro femur. It is also evident that the bowing which would take place in a yielding femur

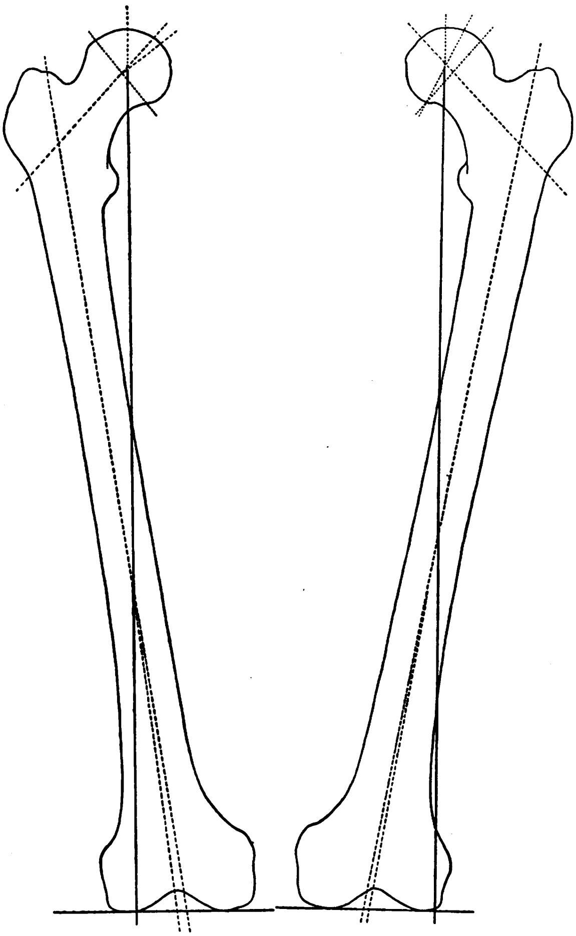

Fig. 5. Negro male femora (from the collection of Trinity College, Dublin) (½ nat. size).

	Right	Left
Oblique length	46·5 cm.	46·6 cm.
Angle of inclination ...	7° and 9°	10·5° and 9·5°
Angle of neck	129°	126°

Shafts of both femora are concave laterally in lower parts.

would be convex laterally in the upper part, above the crossing (fig. 3), and convex medially below (fig. 5), and as does occur in genu valgum.

In the Neanderthal femora—the tracings were made from casts of the femora at Bonn and of the Spy No. 1 femur—the load axis intersects the anatomical axis at or just above the lower articular margin and passes through, or close to, the mid-condylar point; the tendency to change from the mid-point is towards the lateral side (fig. 6). The weight of the body therefore is distributed equally, or nearly equally, on the two condyles and it is unlikely

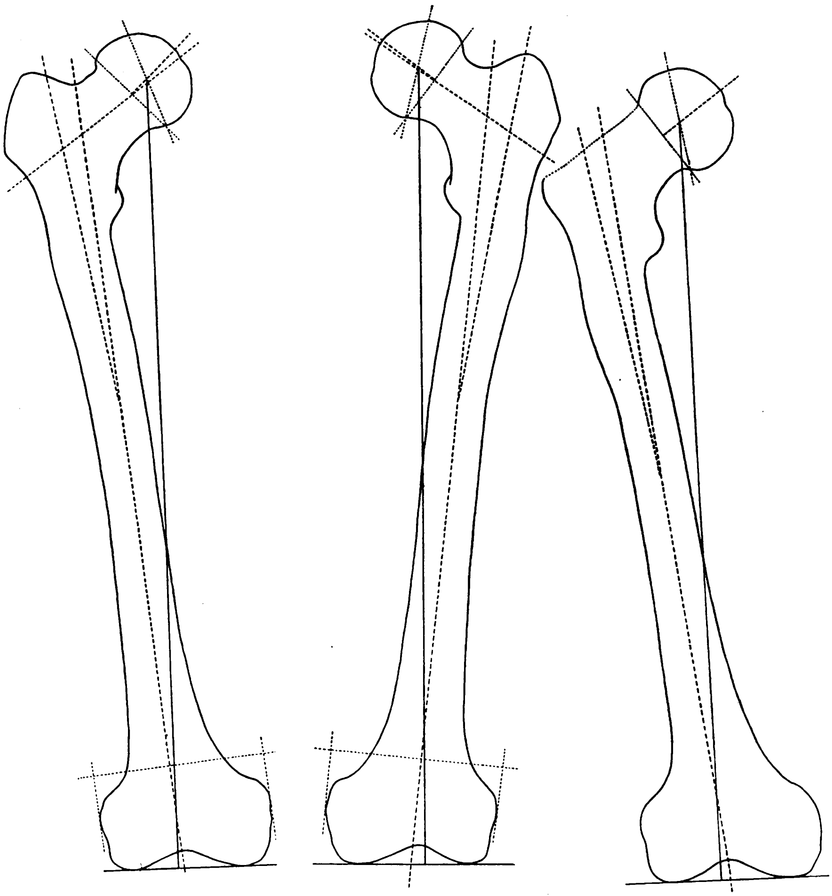

Fig. 6. The Neanderthal femora, right and left, and the Spy femur (½ nat. size).

	Neanderthal right	Neanderthal left		Spy	
Oblique length	44·15 cm.	44·5 cm.	(44·4)	42·8 cm.	(42·85)
Angle of inclination	5·5°	6·0°	(5·5°)	7·0°	(7°)
Angle of neck	115·5°	114°	(123·5°)	—	(112°)
Angle of torsion	7°	6°	(6°)	—	(16°)
Lateral condyle	4·05 cm.	—		—	
Medial condyle	4·95 „	—	(8·96 bicondylar width)		

(The figures in brackets are the measurements given by Pearson. He measures the angle of the neck by a method which includes a character of the epiphysial head.)

that there could be a rotatory locking mechanism at the knee-joint; and this unlikelihood is strengthened by the high ellipticity of the head of the femur which would not favour the rotation at the hip-joint. The medial femoral condyle, measured transversely from the anatomical axis, is larger than the lateral condyle by a considerably greater amount than in the modern male. The angle of inclination of the shaft is about one-half that of modern bones, that is, from the acetabulum the femora are more vertical, and at their lower ends the two bones are wider apart than modern femora are when placed on the same horizontal infracondylar plane. The Neanderthal femora correspond in position to the abduction position in modern Man when the feet are apart; that is, in Neanderthal Man the femora, lying wholly or almost wholly on the lateral side of the load axis, are not acting of themselves as static body supports but are supports which would require considerable activity of the muscles of the hip- and knee-joints. It is a safe assumption that the lower limb of Neanderthal Man was more muscular than in modern Man. The functional characters of the femur all support the conclusion of the greater muscularity of the lower limb, and at the same time are, I think, positive evidence that the bone did not function as a static support as it does in modern Man; I refer especially to the great antero-posterior bowing, the absence of pilastering, the features of the hypotrochanteric region, and the small angle of torsion. There should be added to these a further character, which is not specifically pointed out in the studies of Schwalbe, Klaatsch, or Boule, namely that there is also a bowing of the femur when looked at from the front (fig. 6). On static principles the bowing would be expected to be convex laterally in the upper part of the bones, but in the three femora it is in the opposite direction. This feature, the lateral concavity of the upper part of the femur, was not present in any other bone, Primate or human, that I have drawn; it need not be pointed out that it is not due to the great expansion of the lateral lip of the hypotrochanteric fossa there is in all Neanderthal femora, and it is, I think—like the muscular features of the hypotrochanteric region—an expression of the activity of the extensor muscles of the hip in maintaining the femur stationary in the almost erect standing position.

In the gorilla (fig. 7) the load line passes through the medial part of the medial condyle. There is a great increase in the relative size of the medial condyle, measured transversely to the anatomical axis; and the maximum antero-posterior length of the medial condyle greatly exceeds that of the lateral condyle[1]. It is the medial condyle which now bears the greater weight. The femur, relative to the position in modern Man, is in a position of even greater abduction than the Neanderthal femora; and it is to be noted in this regard that the gorilla femur does not possess the functional characters of the Neanderthal bones which indicate the use of the femur, even as a muscle supported structure, in the stationary standing position.

In the chimpanzee (fig. 8) the load line passes entirely medial to the medial condyle. The whole bone is therefore on the lateral side of the axis of weight, and as in the gorilla the medial condyle must be the weight-bearing condyle.

This group of bones, then, from the chimpanzee to the modern female (and negro male) forms a series in which there are such changes in the position of the

[1] See note 3, p. 289.

femur that there is a progressive shifting of the load line of the bone from within the medial condyle to without the lateral condyle. It remains to be determined, however, whether this series is a true continuous series and represents the changes in the form of the bone which bring about latero-medial displacement of the lower end of the femur that has taken place in the acquirement of the

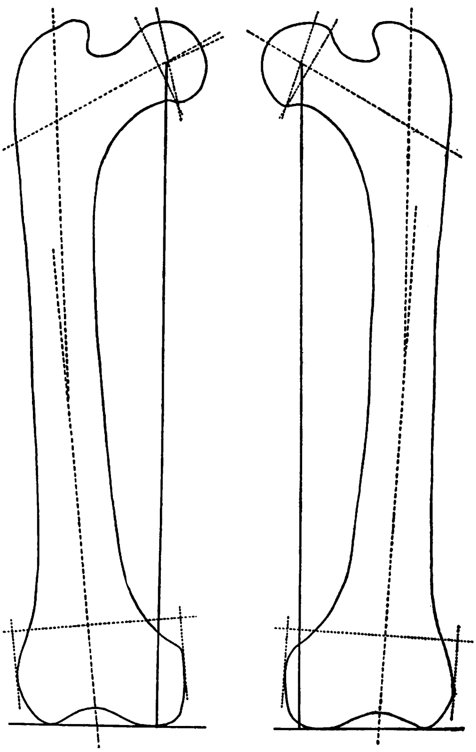

Fig. 7.

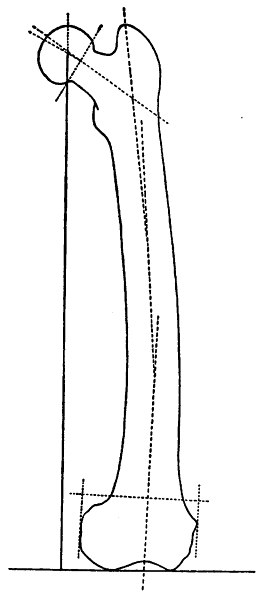

Fig. 8.

Fig. 7. The right and left femora of an adult male gorilla (¼ nat. size).

	Right	Left
Oblique length	37·45 cm.	37·5 cm.
Angle of inclination	3·3°	3·5°
Angle of neck	116·5°	119°
Medial condyle	4·9 cm.	5·15 cm.
Lateral condyle	4·0 ,,	3·85 ,,

Fig. 8. The femur of an adult female chimpanzee (¼ nat. size).

modern human upright posture. It is a matter of ordinary observation that the femur has been displaced in the latero-medial as well as the antero-posterior direction under the trunk, and under the body-weight, in the modern human posture, but that the displacement has been so far medially that the femur is in a totally new and static relation to the body-weight, and is normally in a position of genu valgum, has not been so widely recognised.

It is necessary, I think, in the first place, to recognise that a distinction should be made between the "upright posture" of the apes and the upright posture of the human subject. The former is an uprightness only in locomotion and, since locomotion is not a postural state of a balanced body but essentially involves a loss of balance and the active contraction of muscles, it cannot truly be considered to be a posture; while the latter is a true postural position, for it is capable of being maintained while stationary. All parts of the human lower limb, in this conception, are specialised for standing still upright; that is, in addition to the ape limb of locomotion, the human limb is a static support for the body-weight with the aid only of almost the smallest possible amount of the postural activity of the limb muscles. The bones of the limb are required to bear the body-weight with the aid only of the postural activity of the muscles and in the absence of their displacement contraction; and this has been accomplished by, (*a*) the bringing of the bones latero-medially under the body-weight until they cross the load line of the load to be carried; (*b*) the full extension of the thigh and leg bones vertically on one another; and (*c*) the locking of the bone most active in locomotion (the femur) in the position of medial displacement and extension at its upper and lower ends. The joint-locking mechanisms are matters of the joint ligaments and the configuration of the epiphysial articular surfaces, but the limb displacements, both from the side and the front, are primarily the result of active muscle contractions and are in fact, as nearly as possible, the terminal positions which occur, alternately in the two limbs, in upright climbing and in rapid bipedal terrestrial motion. In these activities the bones are but a small part of the supporting mechanism of transitory positions, and they do not react in their form as static structures; they are, as it were, solely for the attachment of the muscles. But when, in the human limb, as in parts of the quadruped limb, they assume static functions in the positions of extreme displacement[1] they must alter their form.

The factors which can influence the position of the two vertical femoral axes relative to one another, the infracondylar plane always being maintained horizontal, and so be concerned in the alteration of the form of the bone, are: (*a*) the amount of the inclination of the shaft; (*b*) the length of the shaft; (*c*) the size of the angle of the neck; (*d*) the length of the neck; (*e*) the presence or absence of latero-medial bowing of the shaft; and (*f*) the amount of the total torsion of the femur, in which is included the component of the retorsion. It is not necessary to describe the manner in which each of these factors acts on the position of the load axis nor, for the purpose of the present study, to analyse the changes which occur in them from the ape to modern Man[2]; but I wish to

[1] It may be expressed in the form of a paradox, that, so far as the position of the bones of the thigh and leg is concerned, the human subject stands still in the erect position with the feet together by having assumed bilaterally the position of the extreme alternate unilateral displacements of rapid bipedal movement.

[2] It will be noted that all of these factors, except for some small component of the torsion which may be an epiphysial change, are diaphysial changes; the inclination of the shaft, for example, depends very largely on the difference in the rates of growth on the medial and lateral sides of its

suggest that they are, as it were, compensatory to one another and have such a correlation that, in any form, acting together, each of them positively or negatively, they maintain the load axis in the position proper to it.

Each of these factors is a condition of the human femur which alters very greatly during the growth of the bone from birth to adult age. I therefore

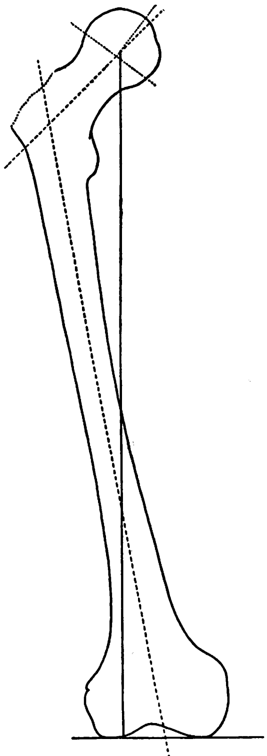

Fig. 9.

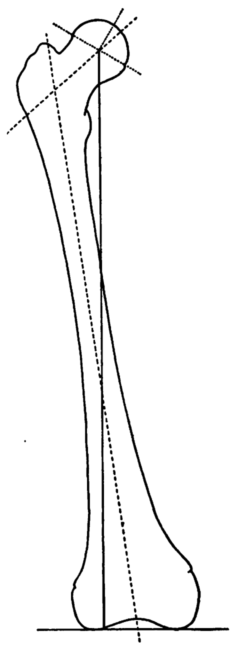

Fig. 10.

Fig. 9. The femur at 18 years (¼ nat. size). Oblique length, 38·75 cm.; angle of inclination, 10°; length of neck, 5 cm.; angle of neck, 125°.

Fig. 10. The femur at 14 years (¼ nat. size). Oblique length, 22·3 cm.; angle of inclination, 8°; length of neck, 3·1 cm.; angle of neck, 123°.

examined the position of the lines in a number of young femora; this would form a test, I considered, of the correlation of the activity of the factors, for the changes which occur in some of them, for example the decrease in the size of

(diaphysial) growth surfaces, and the neck of the femur is only a high specialisation of the transverse diameter of the shaft. I hope in a further communication to deal specially with the rôle of the torsion of the femur, for it is, I think, the most recent character of the modern bone and is associated with the modern upright posture. It is a means by which the head of the femur is displaced laterally over the lower end and so assists to carry the load axis from the mid-condylar position to the position through the lateral condyle; and also, at the same time, it is a means by which, as seen from the lateral side, the shaft of the femur is displaced backwards, so that the axis of the body-weight which passes behind the line joining the centres of the two femoral heads, and so extends the hip-joints, is carried in front of the knee-joints and so also effects their extension.

the angle of the neck, would displace the load line in a medial direction, while the changes which occur in others of them, for example the increase in the angle of inclination, would displace the line in a lateral direction. At 18 years of age the load line passes through the lateral condyle, and its position and its relations to the anatomical axis are as in an adult bone (fig. 9). This position and relation of the load line are maintained, I found, with a remarkable constancy in the bones I studied at 14 years (fig. 10), at 10 years (fig. 11), and at approximately

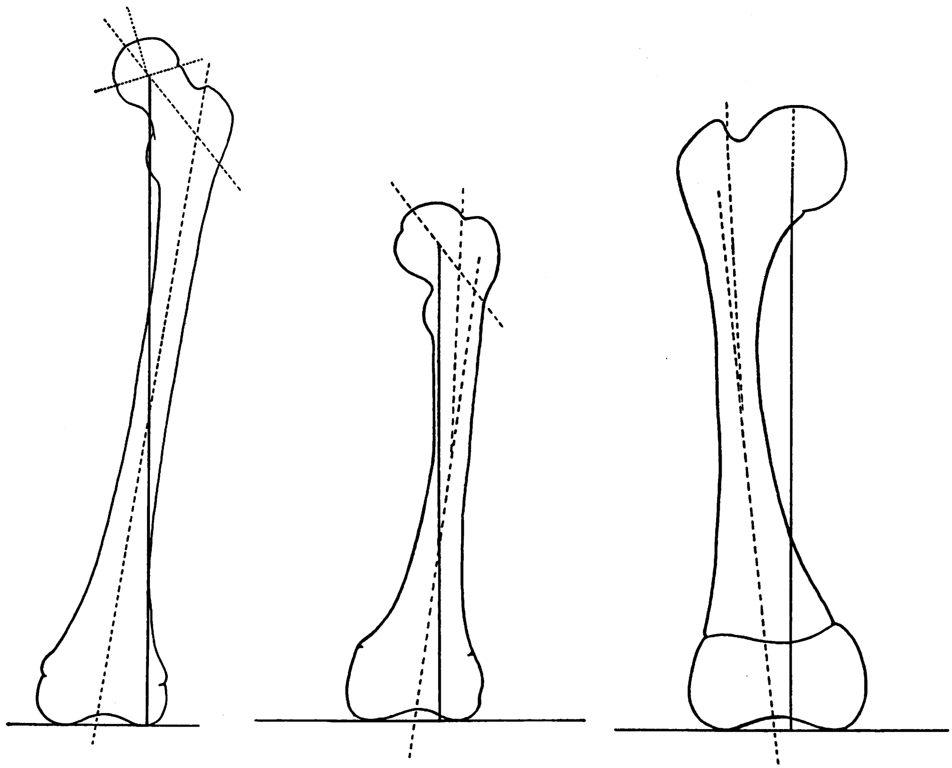

Fig. 11. Fig. 12. Fig. 13.

Fig. 11. The femur at 10 years (⅓ nat. size). Oblique length, 17·35 cm.; angle of inclination, 9·5°; length of neck, 2·9 cm.; angle of neck, 132°.

Fig. 12. The femur at approximately 3 years (½ nat. size). Oblique length, 13·6 cm.; angle of inclination, 8°; length of neck, 0·7 cm. angle of neck, 140°.

Fig. 13. The femur at birth (an enlarged tracing has been reduced). Angle of inclination, 6°.

3 years of age (fig. 12); so that in spite of the changes in the form of the bone the position of the load line, which seems to be defined with the onset of upright standing and walking, is most accurately maintained. At birth (fig. 13) the axes are uncrossed and the load line passes through the medial condyle. The change in position to the lateral condyle must take place between birth and 3 years of age. The position at birth certainly suggests that the series, at least from the gorilla onwards, is a continuous series and that the change to the lateral

condyle as the weight-bearing condyle is a recent human acquisition[1]. This conclusion is also indicated, I think, when the variability of the antero-posterior condylar lengths is examined. In the adult the lateral condyle is less variable than the medial condyle, but in the new-born the medial condyle is less variable than the lateral condyle; and the emphasis of this difference is increased when it is remembered that only in one other character—the inferior articular width—does the femoral variability of the new-born exceed the variability of the adult. It is as if the species character is still undefined, for the greater variability of the lateral condyle in early life I take to be an expression of its essentially human character and of the recentness of its acquisition, and that it is relatively longer, in relation to the medial condyle, than it will be in later life is, I take it, an accentuation of an early human, Neanderthaloid, character and in contrast with the Pithecoid relationship, which is the reverse.

I next made a tracing of the gibbon femur (fig. 14), and on it found that the load line has much the same position as in the gorilla. The statical conditions are more favourable in the gibbon for an upright walk with an extended lower limb than in the chimpanzee, and are such that they suggest that the chimpanzee is not part of the continuous series, but that in respect of its gait the chimpanzee is a retrogression. In *Dryopithecus rhenanus* (fig. 15)[2] the relationship of the femur to its functional requirements is, as the recent work[3] on the bones would lead one to expect, as it is in the gibbon.

The positionof the load line in ***Pithecanthropus*** is, as in the male negro, through the lateral part of the lateral condyle (fig. 16)[4]. In this respect also, therefore, namely the position of the bone as a functioning structure, as has so often been pointed out of its other characters, the Trinal femur is fully modern; in this respect, as in its gracility and straightness, and in the size and form of its head and of its lower epiphysis, with the two exceptions, it resembles the negro bone. In the two exceptions, the relative lengths of the condyles and the convexity of the popliteal surface, it diverges towards the gibbon (rather than towards the gorilla), but not more than some modern femora do; and it will be noted that in the relative size of the condyles, measured transversely from the anatomical axis, there is the same divergence. There is little doubt but that the Trinal femur was fully extended at the hip; the bone shows the convexity

[1] The evidence is, I think, that the change occurred in late Paleolithic time, that is, that it is present for the first time in Cromagnon Man. I have not yet been able to obtain the material for this part of this study, but I should like to point out that the Klaatsch reconstruction of the *Homo mousteriensis* (Hauseri) femur, as examined on a photograph, makes the bone to be a weight-bearing structure of a pattern akin to that of the chimpanzee.

[2] The tracing was made from the cast at the Brit. Mus. Nat. Hist. and I am grateful for the permission given me to insert it here.

[3] Gieseler, *Verh. Ges. Phys. Anthrop.* 1926, S. 34. Abel, *Die Stellung des Menschen im Rahmen der Wirbeltiere*, 1931.

[4] The tracing was made from Damon's cast. If the construction is made on Dubois' fig. 1 (a view from in front) the load line would pass further laterally and on the lateral side of the lateral condyle, while if it is made on his fig. 3 (a view from the back) the line would lie in the position it has in this tracing.

forwards of the neck, though it is only slight, the retroversion of the head on the neck, and the capsular ridge and groove on the anterior surface of the neck, which some years ago I associated with full extension at the hip in the locked position of bearing weight[1].

The results of this examination of the *Pithecanthropus* femur as a functioning structure are thus in direct opposition to the continuous series *Pithe-*

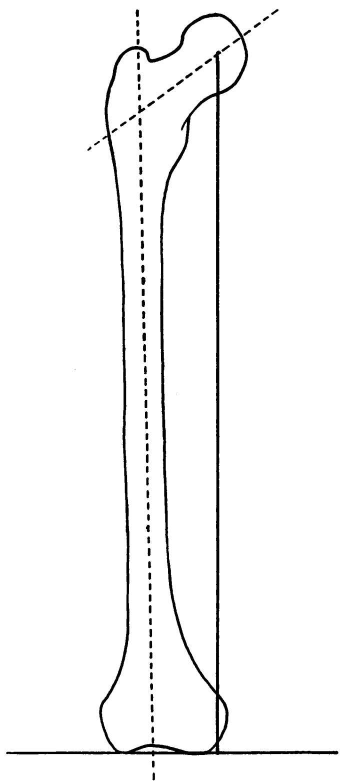

Fig. 14.

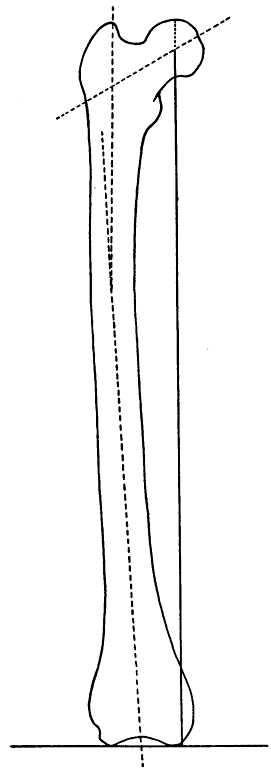

Fig. 15.

Fig. 14. The femur of the gibbon.
Fig. 15. The femur of *Dryopithecus rhenanus* (⅓ nat. size).

canthropus—Neanderthal—Recent Man, as was maintained, in respect of their gait, by Schwalbe[2], even allowing, I think, for the contention that the upright gait was not the cause but only a prop for the development of the brain, and its implication, as is contained in Dubois' position[3], that the two things, the development of the brain and the full upright human posture, might possibly

[1] Walmsley, *J. Anat.* vol. XLIX, 1915.

[2] Schwalbe maintained the sequence even in a posthumously published paper (*Zeitschr. f. Morph. u. Anthrop.* Bd. XXI, 1921).

[3] Namely, that the femur of *Pithecanthropus* has human characters because he was erect and has those characters without being human.

have occurred separately and apart from one another; and they prove that there is no justification for Bümuller's view that *Pithecanthropus* should be renamed *Hylobates giganticus*. They demonstrate, I think, that the human phylum, in respect of its gait and posture, originated in a form which, though able to be in movement with the body erect and the lower limbs well extended,

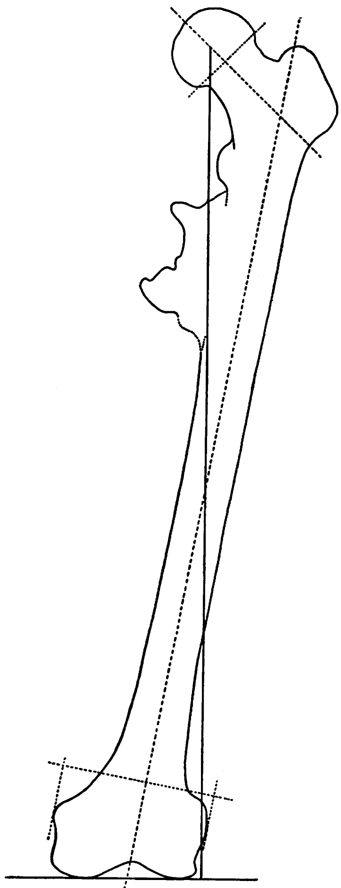

Fig. 16. The femur of *Pithecanthropus erectus* (¼ nat. size). (The figures in brackets are the measurements given by Dubois.) Oblique length, 45·65 cm. (45·2 cm.); angle of inclination, 11·25° (12°); length of neck, 4·1 cm. (5·15 cm.); angle of neck, 124° (124°); medial condyle, 4·4 cm. lateral condyle, 3·6 cm.
(The figure given for the length of the neck shows well the effect of the torsion of 15°. The figure given for the oblique length is correct for the cast in my possession.)

was unable to stand still in the erect posture; that this form, probably through an increased rapidity of its movements in bipedal locomotion, acquired a still further extension of the femur at the hip and of the leg at the knee; and that through the fully extended position of rapid movement with the whole body-weight being carried on and over each limb alternately, the form of the femur was so altered, at first by the growth changes which increased its latero-medial obliquity, that the load line of the bone moved laterally from the medial condyle, the bone itself assumed static functions, and standing still erect as a true postural attitude became possible. This state is represented first in the Neanderthal femora, in which, however, the static functions are still small in amount. The nearly erect standing still position of Neanderthal Man was maintained almost entirely by the activity of the extensor muscle groups: and the implication of course is that the direct line of modern human descent "has passed through the Neanderthal type or something very closely akin to it" (Pearson)[1]. The full static functions of the femur were assumed later and, as I think the evidence is, in Neanthropic Man; and was associated with the increased obliquity, the pilastering, and the increase of torsion, which are now present, and the diminution of the great bowing and of the muscular exaggerations of the trochanteric and hypotrochanteric regions which are characteristic of Neanderthal femora. There is a continuous rise of human character, as Pearson has shown, in the features of the femur from the gibbon to Cro-magnon Man; and in modern femora there is a recession or, as I would prefer to consider, a refinement through a more rigid selection of the amount to their need. The femora of the modern apes do not lie within this series, for though the gorilla may be close to its commencement the chimpanzee (and the orang) are regressions from its commencement (towards quadrupedism, Morton)[2]; and, the evidence, I think, is very clear, the *Pithecanthropus* femur is modern, though there appear in it as in other modern femora features which were dominant in the earlier evolutionary stages of the bone.

I wish to thank Miss M. E. Rea for the care and the skill she has given to the making of the diagrams for this paper and which alone have ensured their accuracy.

[1] Schwalbe's discussion (*Zeitschr. f. Morph. u. Anthrop.* Bd. IX, 1906) as to whether Neanderthal Man is or is not on the direct line of descent would thus lose a good deal of its cogency.

[2] Morton, *J. Morph. and Phys.* vol. XLIII, p. 147 (1926).