■ ANNOTATION

Femoral anteversion

A NECESSARY ANGLE OR AN EVOLUTIONARY VESTIGE?

E. Tayton

From Cheltenham
General Hospital,
Cheltenham, England

In an adult man the mean femoral anteversion angle measures approximately 15°, for which the reasons have never been fully elucidated.

An assortment of simian and quadruped mammalian femora was therefore examined and the anteversion angles measured. A simple static mathematical model was then produced to explain the forces acting on the neck of the femur in the quadruped and in man. Femoral anteversion was present in all the simian and quadruped femora and ranged between 4° and 41°. It thus appears that man has retained this feature despite evolving from quadrupedal locomotion.

Quadrupeds generally mobilise with their hips flexed forwards from the vertical; in this position, it is clear that anteversion gives biomechanical advantage against predominantly vertical forces. In man with mobilisation on vertical femora, the biomechanical advantage of anteversion is against forces acting mainly in the horizontal plane. This has implications in regard to the orientation of hip replacements.

It has long been noted by anatomists that the neck of the femur in man is anteverted.¹ This knowledge was demonstrated in the anatomical drawings² by Da Vinci in the early 16th century. Various theories have been proposed to account for this, such as the rotational forces which are applied to the neck of the femur during fetal life (hence femoral anteversion), and genetic predisposition, since it has been shown that femoral anteversion varies between the different races.^{3,4} Anteversion is also present in the animal kingdom, and from an anthropological point of view, it is considered to be an example of a type-five analytical trait; that is, one which has no reliable diagnostic value with respect to significant behaviour.^{5,6}

Anteversion is defined as the angle by which the femoral neck deviates forwards from the axis of the femoral condyles, projected on to the horizontal plane, and it measures the anterior rotation of the neck of the femur around the shaft. Methods for *in vivo* measurement include the trochanteric prominence angle test and the Hermann⁷ biplanar radiological technique, although today the method of choice is considered to be CT.⁸ At birth, the normal anteversion angle is around 30°, but this reduces to approximately 15° in an adult, possibly because of the action of the internal rotators.^{9,10} Certain conditions such as cere-

bral palsy can lead to an increased angle because of muscle imbalance.¹¹ Femoral retroversion can also occur as the result of an external rotation contracture of the hip secondary to reduced uterine space.¹²

Femoral anteversion is important in total hip replacement (THR), and considerable research has been undertaken in order to establish the optimal orientation for implants. Some surgeons have advocated anteversion of the implant of 10° to 15° in an attempt to achieve optimal angles for mobility without impingement, whereas Charnley¹³ recommended 0° in order to enhance the stability of the implant.¹⁴

This paper discusses the evolutionary origins of femoral orientation and proposes a simple model which demonstrates why its existence is a biomechanical advantage in man.

A series of femora from a group of quadrupeds and a further series from a collection of simian skeletons were analysed, and theoretical forces acting on these bones were calculated in order to assess the benefits and disadvantages of different angles. A similar illustrative model was then produced for the human femur.

Materials and Methods

Anatomical assessment. The femora from a number of quadrupeds (zebra, eland, leopard, giant forest hog, sheep, cat, badger, pig and

■ E. Tayton, MBBS, MRCS, Clinical Research Fellow in Orthopaedics
Cheltenham General Hospital,
Sandford Road, Cheltenham
GL53 7AN, UK.

Correspondence should be sent to Mr E. Tayton; e-mail: edwardtayton@hotmail.com

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Fig. 1

Photograph showing measurement of the anteversion angle (30°) in the right femur of a baboon.

mouse) were examined and placed on a firm board with the anterior surface upwards and both femoral condyles in contact with the board. A photograph was then taken from the superior end pointing straight down the shaft of the femur. The anteversion angle was then measured as shown in Figures 1 and 2.

The femora from an assortment of apes, monkeys and miscellaneous other primates were similarly examined and measured (Table I).

The baboon was chosen as the main study animal because of its style of walking, being predominantly quadrupedal, and its habitat, which is divided between woodland and savannah. This is probably similar to the habitat which led to the development of bipedal locomotion in hominids.

Biomechanical assessment. Previous studies have shown that the forces acting through the hip during normal activities can be broken down into three components, medio-lateral (x), vertical (y), and anteroposterior (AP) (z).¹⁵⁻¹⁷ The forces experienced in the vertical plane (y) could be up to 2.5 times the mean body-weight (2000 N), with those in the AP direction as high as 300 N.

Two illustrative static mathematical models were constructed representing the forces directed through the femur of an average quadruped when placed in the anatomical position (i.e. flexed forwards from the vertical so that the anteversion angle was now pointed vertically (Fig. 3)). A femoral neck length of 10 cm was assumed. One model was constructed with the femoral neck in the neutral position,

and the other with the neck anteverted at 30° . A vertical theoretical force of 1000 N was then applied to both models for comparison of the turning moment at the neck-shaft interface.

A static model of the human femur was also constructed (Fig. 4) in order to illustrate the plane in which anteversion gave the maximum biomechanical advantage by means of reducing turning moments at the neck-shaft interface. A theoretical horizontal force of 300 N, approximately half the mean body-weight, acting in a line perpendicular to the horizontal axis of the femoral condyles (z direction) was then applied to the head of the femur, and the resulting moments calculated at the neck-shaft interface for anteversion angles of 5° , 10° , 15° and 20° (Fig. 4). For the purposes of this calculation, the femoral neck was also assumed to be 10 cm in length.

Results

The anteversion angles measured in the animals studied varied with a range of 4° to 41° (Table I). The mean anteversion in the baboon femur was 18.8° (13° to 25°).

In the standing position in a quadruped, the hip is flexed forward from the vertical, and the 'anteverted' femoral neck points in the vertical plane and no longer functions as an anteriorly angled structure. Therefore, when a theoretical vertical force is applied to the head of a femur in flexion, an anteversion angle of 30° acts to reduce the turning moment experienced at the neck-shaft interface by 13.4% (Table II).

Figure 4 shows the range in which anteversion reduces the turning moments at the neck-shaft interface in the vertical (human) femur when a horizontal force is applied, compared with a femur with no anteversion. This range is between half the anteversion angle (θ) anterior and the horizontal axis of the femoral condyles (x axis), and between half the anteversion angle lateral and a line perpendicular to this (z axis). The turning moment experienced at the neck-shaft interface decreases as the anteversion angle increases (Table III).

Discussion

Two major influences are responsible for the development of all skeletal features including femoral anteversion, namely, inheritance and environment.

Darwin's evolutionary theory¹⁸ is widely accepted, and, despite various modifications to his original publication, the overriding principle remains firm. With the discovery of the genetic code, the mechanism by which genes are stored in individual cells and how they give rise to the phenotype of the individual has been explained.¹⁹ There is therefore a blueprint for the final skeletal shape from the moment of conception which has been created over millions of years of natural selection. However, from this point on, environmental factors begin to play an important role. In particular, as Wolff²⁰ noted in 1892, external forces have an impact on skeletal form: "Every change in

Fig. 2

Photograph showing femoral anteversion angles in unrelated mammals.

Table I. The mean anteversion angles (°) of various mammalian femoral necks

Animal	Number of specimens	Mean anteversion angle (range)
Baboon	12	18.8 (13 to 25)
Gorilla	6	14.7 (9 to 18)
Grays monkey	2	16.5 (13 to 20)
Talapoin	2	12.5 (11 to 14)
Colobus	2	18.0 (17 to 19)
Chimp	1	4.0
Leopard	1	26.0
Giant forest hog	1	41.0
Eland	1	26.0
Zebra	1	33.0
Badger	2	24.0 (22 to 26)
Mouse	2	23.5 (23 to 24)
Lamb	1	20.0
Cat	1	8.0
Pig	1	32.0

the form and function of bones, or of their function alone, is followed by certain definite changes in their internal architecture and equally definite secondary alteration in their external conformation, in accordance with mathematical laws." The underlying process to this concept has now been clarified. Bone can be divided into a series of basic multicellular units, which act either to create or to reabsorb it. Cells within these units are sensitive to strains, and have genetically-determined threshold ranges above or below which they will respond. When the strain on the bone repeatedly exceeds a certain level (minimum effective

strain), growth will be stimulated to strengthen it. Likewise, if the strain is repeatedly below a certain level, bone will be reabsorbed, and if it falls within the two levels, then resorption and production are equal.²¹ Thus, as well as growing to a genetically-predetermined shape and size, bone will also alter itself to form a shape which is most efficient to withstand the forces which are applied to it (although even this response may be genetically determined).

With the constant pressure to evolve, some of the early physical adaptations of a species, which increased initial survival advantage, may become redundant as the organism progresses. An example of this is the coccyx.

The earliest bipedal hominids identified so far are the Australopithecines, with the best preserved proximal femoral fossil being the 'Maka' femur, from *Australopithecus afarensis*, who lived approximately 3.5 million years ago. Unfortunately, the femoral condyles are not preserved and therefore an anteversion angle cannot be measured accurately. However, a detailed comparative anatomical study using other bony features as markers, such as the lesser trochanter, indicates that this femoral neck is orientated in a position similar to that of modern man.²² Because of the lack of well-preserved fossil material, there is no hard evidence, but the Maka femur supports the view that our first bipedal ancestors also had anteverted femoral necks.

Before this, our lineage points towards a quadrupedal primate, adapted to life in trees, and although earlier ape species have been suggested as the progenitors of man, e.g. *Ramapithecus*, 5.5 million years ago and *Proconsul*, 18 million years ago, the missing link has yet to be identified.²³

Fig. 3

Diagram showing the vertical forces acting on a quadruped femur, which is flexed such that the anteversion angle is pointing upwards. A, posterior view, 1000 N vertical force, no anteversion; B, posterior view, 1000 N vertical force, 30° anteversion; C, lateral view.

Table II. Turning moment when a vertical force acts on the anteriorly flexed femur of a quadruped

Anteversion angle (°)	Vertical force (Newtons)	Turning moment (Nm)
0	1000	100.0
30	1000	86.6

Accepting the current theory of evolution, modern man has retained many of the original traits of his ancestors, but has modified many of them in order to make himself more successful.

This study has shown that the presence of femoral anteversion was present in all the quadrupedal apes examined, and probably throughout most of the quadrupedal mammalian world (Fig. 2). It therefore seems likely that this feature has persisted throughout our evolution from quadruped to biped. It has not been fully explained why there is this similarity between animals, but the answer must be that it is advantageous for the animal to have bones with this particular morphology. One explanation may lie in the fact that four-legged animals do not stand or mobilise with the femur in the vertical position, but rather with it flexed forwards. This results in rotation of the femoral neck so that it points anterosuperiorly in an approximate angle of 90° with the plane of the margins of the acetabulum. This was first described by Le Damany²⁴ in 1908 who noted that it was only man who differed.

Fig. 4

Three-dimensional and axial views of the human femur. The shaded area indicates the range in which anteversion gives biomechanical advantage in the horizontal plane by reducing the turning movement. θ , anteversion angle; X, medial to lateral; Y, vertical; Z, anterior to posterior.

A further study using instrumented hip implants in sheep has shown that during the stance phase, the forces through the head of the femur are transmitted mainly from the anterosuperomedial direction in relation to the shaft of the femur.¹⁵ Simple observation has indicated that ovine femora remain flexed (anteriorly angulated from the vertical) throughout most of the walking phase, which means that in relation to the ground, the direction of the force tends more towards the vertical. As illustrated by Figure 3, anteversion gives biomechanical advantage to the vertical component of this force by reducing the turning moment experienced in the neck of the femur, and hence reducing stress on the bone. The femoral anteversion angle in the quadruped is equivalent to the neck-shaft angle in man and has the same biomechanical advantages.

This study has provided a simple model which applies a theoretical force acting on the femur in the horizontal plane to different anteversion angles. It has simplified what in reality is an extremely complex dynamic force acting in a three-dimensional (3D) plane. Most significantly, the anteversion angle reduces the turning moment around the neck-shaft intersection of the femur when a horizontal force is applied in the region highlighted in Figure 3. Although in reality this situation is more complicated since the force has 3D components and is dynamic, the basic principles hold true. The anteversion angle gives biomechanical advantage against the horizontal components of a dynamic force during the time that it falls within the specified area, anteromedial to the femoral head.

Table III. Turning moments experienced in various degrees of anteversion in the human femur when a force acts perpendicular to the axis of the femoral condyles

Anteversion angle (°)	Z component of horizontal force (Newtons)	Turning moment (Nm)
0	300	30.0
5	300	29.9
10	300	29.5
15	300	29.0
20	300	28.2

A comprehensive set of dynamic forces acting on the head of the femur during different daily activities was provided by a study which involved two human subjects with instrumented prosthetic hemiarthroplasty of the hip.¹⁶ As expected, the predominant direction of the force was vertically downwards because of the body-weight. For this component of the force, the neck-shaft angle created a biomechanical advantage by reducing the moment arm to the neck-shaft interface and at the same time allowed the maintenance of neck length. There were, however, considerable horizontal components to the force acting through the head of the femur, which were always from the antero-medial direction during the stance phase. The predominant force during the swing phase was also anteromedial. These directions of the force were also noted even if the magnitude of the force increased such as during running and stair climbing.

A similar more recent study looked at forces acting on instrumented femoral components in four patients who had undergone THR.¹⁷ Again, the largest component of the force measured was found to be acting in the vertical direction, but there was also a considerable component acting in the horizontal plane. During the stance phase, this was almost always from the anteromedial direction, and during routine activities such as stair-walking was measured as being up to 50% of the total body-weight. In this particular study, forces were also measured acting outside the area over which femoral anteversion gave biomechanical advantage, but this was predominantly during the swing phase, and the forces experienced were not of the same magnitude. It could therefore be said that in this study, the mean component of the horizontal force was still coming from the anteromedial direction. This point is further illustrated by the fact that displacement of the femoral head is mainly dorsal in fractures of the femoral neck and slipped capital femoral epiphysis, and that cemented femoral prostheses rotate in the posterior direction over time.²⁵

It should of course be noted that the anteversion angle is not an isolated entity, but is intrinsically related to the neck-shaft angle, which itself is subject to varus and valgus variations. Anteversion simply represents the anterior component of a 3D neck-shaft angle. It is probable that the 3D neck-shaft angle is orientated to the position which gives most advantage to the resistance of all the various

forces acting across the joint while maintaining effective mechanical leverage and allowing a wide range of movement. It is, however, for the horizontal components of the forces acting on the femoral head that human femoral anteversion gives biomechanical advantage, and this becomes increasingly important when these forces are at their greatest.

Somewhat surprisingly, the decrease in turning moment at 15° of anteversion compared with 0° is only 3.4%, which does not seem very large. However, if this is considered in the long term, the total reduction in stress across the femoral neck is considerable.

The presence of femoral anteversion is well known in the human hip, but it is also a consistent finding in most quadrupedal animals which have a completely different system of transfer of weight. In four-legged animals, the anteversion acts as an effective mechanism for transferring predominantly vertical forces from the pelvis down to the shaft of the anteriorly-flexed femur. In man, this action is performed by the neck-shaft angle.

Nevertheless, human femoral anteversion is not an evolutionary vestige. It is a result of forces acting through the hip during daily activities, and it is biomechanically advantageous during movement by reducing the horizontal turning moments experienced in the neck of the femur. This has clinical importance in hip replacement and in the positioning of implants in order to reduce the strain on the bone surrounding the femoral component and hence limiting the potential for loosening. It also increases the range of movement of the replacement without causing impingement, and therefore enhances stability.

References

1. Gray H. *Anatomy descriptive and surgical*. London: John W. Parker and Son, 1858.
2. Da Vinci L. *Paris Manuscript K*. 1503-08. (Bibliothèque de l'institut de France)
3. Backman S. The proximal end of the femur. *Acta Radiol* 1957;146(Suppl):1-166.
4. Umebese P, Adeyekan A, Moin M. Radiological assessment of femoral neck-shaft and anteversion angles in adult Nigerian hips. *Niger Postgrad Med J* 2005;12:106-9.
5. Kuo TY, Skedros JD, Bloebaum RD. Comparisons of human, primate, and canine femora: implications for biomaterials testing in total hip replacement. *J Biomed Mater Res* 1998;40:475-89.
6. Lovejoy CO, Cohn MJ, White TD. Morphological analysis of the mammalian postcranium: a developmental perspective. *Proc Natl Acad Sci USA* 1999;96:13247-52.
7. Hermann KC, Egund N. Measuring anteversion in the femoral neck from routine radiographs. *Acta Radiol* 1999;40:557-9.
8. Delialioglu MO, Tasbas BA, Bayrakci K, et al. Alternative reliable techniques in femoral torsion measurement. *J Pediatr Orthop B* 2006;15:28-33.

9. **Fabry G, MacEwen GD, Shands AR.** Torsion of the femur: a follow-up study in normal and abnormal conditions. *J Bone Joint Surg [Am]* 1973;55-A:1726-38.
10. **Shands A, Steele M.** Torsion of the femur: a follow-up report on the use of the Dunlop method for its determination. *J Bone Joint Surg [Am]* 1958;40-A:803-16.
11. **Beals RK.** Developmental changes in the femur and acetabulum in spastic paraplegia and diplegia. *Dev Med Child Neurol* 1969;11:303-13.
12. **Lange F, Pitzen P.** Zur anatomie des oberen femurendes. *Z Orthop Chir* 1921;41:105-34.
13. **Charnley J.** Total hip replacement by low friction arthroplasty. *Clin Orthop* 1970;72:7-21.
14. **Seki M, Yausa N, Ohkuni K.** Analysis of optimal range of socket orientations in total hip arthroplasty with the use of computer-aided design simulation. *J Orthop Res* 1998;16:513-17.
15. **Bergmann G, Siraky J, Rohlmann A, Koerbel R.** A comparison of hip joint forces in sheep, dog and man. *J Biomechanics* 1984;17:907-21.
16. **Rydell NW.** Forces acting in the femoral-head prosthesis: a study on strain gauge supplied prostheses in living persons. *Acta Orthop Scand* 1966;37(Suppl 88):1-132.
17. **Bergmann G, Deuretzbacher G, Heller M, et al.** Hip contact forces and gait patterns from routine activities. *J Biomech* 2001;34:859-71.
18. **Darwin C.** *On the origin of the species by means of natural selection, or the preservation of favoured races in the struggle for life.* London: John Murray, 1859.
19. **Crick F, Watson J.** The molecular structure of nucleic acids. *Nature* 1953;171:737-8.
20. **Wolff J.** *Das Gesetz der transformation der knochen.* Berlin: Hirschwald, 1892.
21. **Frost HM.** Structural adaptations to mechanical usage: a three-way rule for lamellar bone modelling. *Comp Vet Orthop Trauma* 1988;1:7-17.
22. **Lovejoy CO, Meindl RS, Ohman JC, Heiple KG, White TD.** The Maka femur and its bearing on the antiquity of human walking: applying contemporary concepts of morphogenesis to the human fossil record. *Am J Phys Anthropol* 2002;119:97-133.
23. **Simons EL.** The early relatives of man. *Sci Am* 1964;211:50-62.
24. **Le Damany P.** Die angeborene huftgelenksverrenkung: ihre ursachen: ihr mechanismus: ihr anthropologische bedeutung. *Ztschr F Orthop Chir* 1908;21:129.
25. **Sundberg M, Besjakov J, von Schewelow T, Carlsson M.** Movement patterns of the C-stem femoral component: an RSA study of 33 primary total hip arthroplasties followed for two years. *J Bone Joint Surg [Br]* 2005;87-B:1352-6.