A Racial Comparison of the Evolution of the Knee Joint

By P. KEEN

Senior Surgeon, Non-European Hospital, Johannesburg.

Man's rise to the erect posture has caused a reorientation of every part of his organism. Most of these changes have been studied in great detail and the literature on the subject is immense, but it is extraordinary how little interest has been centred on the knee joint.

In dealing with the hind or lower limb most of the interest has been centred on the foot and its evolution. D. J. Morton for instance, in discussing functional disorders of the foot, wrote:—

"No part of the body offers a more complete record of the evolution of mankind than the feet. They possess also a hidden internal mechanism which seems magically to neutralise the force of gravity. Only a man with the muscular development of a Sandow could, as in juggling, pass a 50 lb. metal ball to and fro from the palm of one hand to the other, yet a 5- or 6 year-old child, playfully running, tosses an equal load (body weight) from one foot to the other as easily and lightly as the average adult would juggle a baseball.

Feet are specifically designed by nature to give mastery over the great force of gravity. Classification of the foot with such highly specialised organs as the eye and the ear may seem surprising, but is both sound and correct. By the specialized ocular mechanism, we have direct contact and appreciation of surrounding light, as well as of reflected light waves which register the colour and form of all surrounding objects. Likewise, the specialised mechanism within our ears supplies intimate contact with the sound waves that fill the air. Human feet also are specialised structures adapted for direct interaction with gravity as imposed by vertical body posture and the bipedal mode of locomotion."

The knee joint in man, however, has changed its function even more than the foot and the specialised and relatively recent evolution to a joint which can be fully extended and even hyperextended is more dramatic, when thoroughly analysed, than any other type of evolution in the progress from the quadrupedal to the bipedal form of locomotion.

From an unimportant joint with a limited range of movement, whose main function was to cushion a relatively small amount of the force of gravity and to facilitate the propulsive movement of the body, it has become a joint designed to bear the whole weight of the body with a range of movement for which the joint is not suitably designed.

Man is the only animal which can fully extend the knee joint, and he can even hyperextend it. From a joint, which in all animals is almost entirely under muscular control, it has evolved a complicated locking mechanism on extension, and in hyperextension is almost entirely under ligamentous control.

It is not to be wondered at that in this process of evolution mechanical weaknesses should make themselves evident and the tremendous gains attained, without which the bipedal form of locomotion would be impossible, have their counterpart in certain deficiencies in the bony, ligamentous and muscular components of the knee joint.

It is important at this stage to review the course of events in the evolution of the pelvic limb from the quadrupedal to the bipedal form of locomotion. In quadrupedal animals the main function of the pelvic limbs is elevation of the posterior half of the body weight and of propulsion of the body. The centre of gravity of the body lies between the hind and forelimbs, and the hind limb functions as a propulsive lever when it exerts pressure at right angles to its axis. This is done mainly by the muscles on the posterior aspect of the thigh, biceps femoris semimembranosus and semitendinosus acting on the hip and knee joints. Once the hind limb is retracted, that is at an angle of more than 90° to the axis of the body, extension of the knee and ankle joints increases the propulsive force, and pushes the body forwards.

The following figures quoted by H. A. Haxton confirm the importance of the muscles of the posterior aspects of the thigh:

"Haughton (1873) found that these muscles constitute approximately 38%, by weight, of the muscles acting on the hip joint. The biceps femoris is particularly massive, and in a powerful and agile animal such as the tiger it forms a large triangular muscle which extends from its proximal attachment to the ischial patella, to the head of the fibula and the greater part of the anterior border of the tibia, and even into the calcaneum beside the tendo calcaneus. (Haughton, 1871, 1873.) A similar insertion for the large biceps femoris has been described in the dog (Bradley, '43; Ellenberger and Baum, 1891.) and in the horse (Bradley, '20; Luard, '35). This muscle itself accounts for about 18% of the hip-joint musculature in quadrupeds (Haughton, 1873). In the dog and horse the semitendinosus is also a very powerful muscle, the insertion of which reaches far down the tibia and, in part, to the calcaneum. Cross sections of the thighs in these animals (Ellenberger and Baum, 1891; Bradley, '20) show that the hamstring group of muscles is much bulkier than the quadriceps femoris."

Haxton himself dissected out the quadriceps and the hamstrings in a series of specimens of the cat, rabbit and rat and found that the total weight of the hamstrings was almost exactly twice that of the quadriceps. Further he stated

"In man, on the other hand, the relative sizes of these muscles are very different. In the thigh the great quadriceps muscle mass overshadows its opponents and in fact, as Cowper showed 220 years ago, it weighs twice as much as do the hamstrings. The relative weights are, therefore, almost exactly the inverse of those found in the quadrupeds. The quadriceps is mainly a 1-joint muscle acting on the knee joint, and only a small component, the rectus femoris, acts on the hip joint. The hamstrings form a relatively small part of the musculature of the thigh, constituting only 16·68% of the hip joint muscles (Haughton, 1873). Their tendons are inserted into the proximal ends of the leg bones, and they pass quite close to the axis of the knee joint, so that they work at a considerable mechanical disadvantage in flexing the knee."

"In summary of this study in comparative anatomy it can be stated that the largest muscles in the hind limbs of quadrupeds are those which act on two or more joints, while the 1-joint muscles predominate in the lower limbs of man."

The shifting of the body's centre of gravity to a position almost vertically above the knee joint has considerably altered the muscular power required. Little muscular effort is now required of the posterior thigh muscles to maintain the erect posture and the knee joint has become part of the pedestal supporting the body weight. Solidity is the main requirement and the knee joint in man has now acquired a locking mechanism and ligamentous control, despite the great increase in range of movement, which is not far short of miraculous.

In the forward movement of the body the knee joint has also acquired a new function. In quadrupeds it is an important factor in the propulsive movement of the body, in man it is one of the main factors in resisting the forward movement of the body, caused by shifting the centre of the gravity of the body ventrally. In other words, in man the lower limb has acquired a more important braking action, and forward movement is initiated by simply shifting the centre of gravity forward, and allowing gravity to take effect.

As far as the knee joint is concerned this new function requires strong extensor muscles and hence the preponderance of the quadriceps and gastrocnemii in man over the hamstrings. As far as the knee joint is concerned the final result is that in acquiring the erect position man has had to: (1) strengthen the bony architecture of the knee joint to enable it to take the extra weight caused by the shifting of the body's centre of gravity; (2) adapt the knee joint to enable it to gain full extension and thus facilitate its participation in the pedestal function of the hind limb; (3) modify the muscles of the knee joint to enable it to assist the rest of the pelvic limb in the breaking action during forward movement.

This has been accomplished: (1) by increasing the size of the bones forming the knee joint; (2) by evolving a locking mechanism in full extension; (3) by modifying the function of the collateral and cruciate ligaments, and elaborating the medial collateral ligament; (4) by enlarging the quadriceps muscle, and narrowing the hamstrings to such an extent that the tendinous portion of one of them has probably become the long part of the medial collateral ligament.

Having established the position of the knee joint in man's bipedal form of locomotion it is now possible to fit in the comparative findings in European and Bantu knee joints into the picture.

Summarising these, it has been noted that in the bony structure of the knee joint:—

(1) Relative to its length, the European femur is wider at the level of the knee joint than the Bantu femur.

(2) The lower end of the European femur is wider than the Bantu femur when one compares the transverse and anteroposterior diameters at the level of the condyles. This is shown by the realtive indices of 77·4 and 80·5.

(3) The increase in width in the European femur appears to be due to an increase in the inter-condylar space, and there seems to be a tendency to splaying out of the condyles.

(4) The upper end of the tibia also has a rounder shape in the Bantu, as shown by the relative indices of 66·53 and 63·86.

(5) The patella in the Bantu is relatively smaller.

(6) The tibio-femoral index in the Bantu was 86·1 as compared to 82·1 in the European.

In the ligamentous structure of the knee joint the following comparative findings have been noted:—

(7) The medial collateral ligament is a larger and more complex structure in the Bantu.

(8) The medial collateral ligament has a much closer relation to the adductor magnus tendon in the Bantu.

(9) The fibular collateral ligament is stronger in the Bantu.

(10) The cruciate ligaments are thicker in the Bantu and have a more vertical course in both planes.

(11) The anterior cruciate is more intimately fused with the medial meniscus in the Bantu.

(12) The menisci are less mobile in the Bantu.

How do these findings fit into the evolution of the knee joint from the quadrupedal to the bipedal form of locomotion?

Taking them in order:—

1, 2 and 4. The bony architecture of the knee joint in the European suggests that it is better fitted to act in weight bearing, being more massive and wider.

3. The widening of the intercondylar space which has given the European knee joint a larger weight bearing area, has weakened it as far as the function of the cruciates is concerned. The cruciates are more oblique in both planes in the European and have lost to a greater extent their original function as internal collateral ligaments.

5. In the Bantu the relatively smaller patella (a sesamoid in the quadriceps tendon) suggests that the increase in size of the quadriceps, so important in the bipedal form of locomotion, has not reached the same stage as in the European.

6. The tibio-femoral index in the two races suggests that in the Bantu this index tends to the simian type.

7. and 8. If, as has been suggested, the superficial long fibres of the medial collateral ligament are the remnants of the sciatic portion of the adductor magnus, then it would appear that the Bantu knee joint has retained an earlier stage of its evolution. The marked distinction and easy separation of the deep short fibres from the long superficial fibres in the Bantu strengthens this viewpoint.

10. The relatively larger size of the cruciates in the Bantu, and their more vertical direction in both planes, due mainly to the narrower intercondylar space, makes them more effective as collateral ligaments, but less effective in preventing antero-posterior movement of the tibia on the femur. This also suggests that the cruciates in the Bantu have maintained to a greater degree their original function.

11. and 12. The closer association of the anterior cruciate and the medial meniscus and the relatively reduced mobility of the menisci in the Bantu both suggest that the Bantu knee joint has not evolved to the same extent as the European knee joint as far as the erect posture is concerned.

It would therefore appear that all the differences noted in the knee joint in the two races fit into the pattern of the evolution of the knee joint from the quadrupedal to the bipedal form of locomotion and that the Bantu knee joint is relatively more retarded.

In other words the European knee joint has progressed further and adopted a more specialised form of the erect function. This does not necessarily mean that the European knee joint is a better knee joint. In fact it will be shown that in acquiring this specialised stability it has made itself more vulnerable to certain types of trauma, but it would appear that the European knee joint is slightly more suited to carrying the body weight and to ensuring safer and more rapid forward movement in walking. Whether this applies to running as well is doubtful, and this aspect, which has not been investigated in this thesis will be considered and discussed later.

Is it possible now to fit the pathological differences noted in the two races into this evolutionary pattern?

Briefly the differences noted are:—

(1) That para-articular ossification in the region of the medial collateral ligament is much more common in the Bantu than in the European.

(2) that post traumatic osteo-arthritis in the knee joint is more common in the Bantu than in the European. and has an earlier age-incidence.

(3) that meniscal injuries in the knee joint are much more common in the European than in the Bantu.

Para-articular Ossification or Pellegrimi-Stieds Syndrome:

The following points have been reasonably well established:

(1) that trauma is the commonest cause of this condition.

(2) that periosteal avulsion near the adductor tubercle accounts for the majority of these cases.

(3) that the ossification does not actually take place in the ligament itself but mostly on its outer surface and in the spaces between the ligament, the adductor muscle tendon and the condyle of the femur.

(4) that the characteristic crescent-moon shape of the ossified area is due to the shaping of the haematoma by the fascial coverings of the region.

(5) that the lesion behaves clinically like the ossifying process of a myositis ossificans and that the treatment is similar.

Is it possible to associate the anatomical differences noted in this area with this tendency on the part of the Bantu to injury and subsequent ossification? The closer anatomical relation between the adductor magnus tendon and the upper insertion of the medial collateral ligament would appear to be a vulnerable area in the Bantu knee joint. As has been noted, in the European it is only rarely that fibres pass from the adductor magnus tendon to the upper insertion of the medial collateral ligament and the usual finding is a distinct gap. In the Bantu, however, it has been noted that in the large majority of cases there is a close relation between the adductor magnus tendon and the medial collateral ligament.

This poor anatomical connection between two fixed points (the adductor tubercle and upper insertion of the medial collateral ligament) can have little or no functional effect and can only be a vulnerable area.

It is suggested that the type of knee with two insertions and numerous fibres connecting the two is particularly prone to periosteal avulsion and subsequent ossification.

Any undue or unnatural strain on the adductor magnus tendon or the medial collateral ligament would result in the fibres of this weak link tearing and as these fibres pass over and are attached to the periosteum in this area, it would be natural to expect periosteal tearing in a large percentage of cases. The resulting haematoma containing released osteoblasts would tend to fill the natural spaces in this area, and the fascial coverings would mould it to the classical crescent shape.

It is therefore suggested that the anatomical differences noted in this area in the two races account for the frequency of this form of para-articular ossification in the Bantu.

Post Traumatic osteo-arthritis:

Is it possible to account for the relative frequency and earlier appearance of this condition in the Bantu in the light of this discussion?

Osteo-arthritis is a degenerative form of arthritis, and though septic foci, poor general health and other factors have been incriminated, *wear and tear in a pressure bearing joint is a basic factor in the etiology of the pathological picture of osteo-arthritis.*

It is not surprising therefore, that the lower limb and spine are the commonest sites of osteo-arthritis, both in the European and in the Bantu. These two regions in quadrupeds do not function particularly as weight bearing joints, and it is not surprising that they should be the first to suffer in the bipedal position.

It is interesting to note that in Europeans statistical figures show that the spine is the commonest site of osteo-arthritis whereas in the Bantu, the knee joint takes first place in the frequency list. Meniscal lesions are a common cause of osteo-arthritis in Europeans, and yet in the Bantu, despite the absence of meniscal lesions, osteo-arthritis is still relatively more common. This suggests that the Bantu knee joint is not as well equipped for weight bearing as the European joint, and reacts to the same wear and tear more rapidly by showing signs of osteo-arthritis.

If it is accepted that the Bantu knee joint has not reached the specialised form of weight bearing of the European knee joint, and has retained to a greater extent the characteristics of the quadrupedal knee joint, then it must be accepted that the Bantu knee joint is more likely to suffer from the wear and tear of weight bearing, and it would be natural to expect an earlier appearance of osteo-arthritis.

The relative frequency of meniscal lesions in the European:

The anatomical and physiological differences noted in this discussion are:—

(1) That the menisci have a greater range of mobility in the European as compared to the Bantu.

(2) That there is a closer ligamentous relation between the anterior cruciate and the medial meniscus of the Bantu as compared with those of the European.

There seems little doubt that the extra mobility anteriorly of the European medial meniscus is due to the fuller extension and hyperextension of the European knee joint, and that this has led to a stretching and disappearance of the fibres which in lower animals pass from the anterior cruciate to the anterior horn of the medial meniscus and help to keep it in position.

Thus a similar condition exists between the anterior cruciate and the medial meniscus as exists between the medial collateral ligament and the tendon of the adductor magnus.

In one case it has led to a vulnerable area in the Bantu and in the other case has left a comparable vulnerability in the European.

It would appear that it is possible to explain the pathological differences in terms of the comparative anatomy of the knee joints of the European and the Bantu which in turn is an expression of their evolution from the quadrupedal to the bipedal form of locomotion.

It cannot be emphasised too strongly that the differences noted in the two races are not genetic racial differences in the anthrological sense, but simply differences acquired by varying approaches to the functions and use of the knee joint.

The Bantu knee joint has maintained a more natural function, because it has not had to acquire additional modifications which the above of the knee joint in the western world has necessitated. The way we teach our children to walk and stand, the wearing of shoes with heels, strenuous games, gymnastics and so on, have all put additional unnatural strains on the various components of the knee joint, which over many generations have had to modify their functions to cope with the new demands.

THE DIANNE PEARMAN AWARD

A floating trophy and its miniature together with a cash award of R10.00 will go to the outstanding South African blind physiotherapy student each year.

The Dianne Pearman Memorial Award has been created after the tragic passing of Miss Dianne Pearman in March 1963. Since Miss Pearman played a very important part in the building up of the Blind Physiotherapists' Group, in addition to numerous activities in physiotherapy as well as other circles, it was thought that her memory should live on in the form of an award made to the best blind South African physiotherapy student each year. At present students in London have only been eligible and the award was made to Mr. S. Jakobs who has just completed his training in London in 1963. As from 1964 we hope that blind students training in Pretoria will also be in the selection. In addition to a cash prize, a floating trophy is to be presented and the winner retains a miniature trophy.

May Dianne Pearman's high ideals live on in this way and inspire and encourage new, young students of the future.