THE DISTRIBUTION OF LOAD ACROSS THE KNEE

A COMPARISON OF STATIC AND DYNAMIC MEASUREMENTS

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An anteroposterior radiograph of the leg to include the hip and ankle, taken with the patient standing, provides an estimate of the line of load-bearing at the knee. Gait analysis may be used to determine the way in which the load in the knee is shared between the medial and lateral compartments during normal walking. A comparison of the results from the two methods, carried out on a group of 47 patients, led to the conclusion that both calculations are required for the successful outcome of a tibial osteotomy or a total arthroplasty.

The distribution of compressive force in the knee is of particular interest when operations are performed which modify the alignment of the knee in the coronal plane. This paper compares the estimated distribution of joint loading obtained from radiographs of static knees with the measurements provided by dynamic gait analysis.

The significance of varus or valgus deformities in the coronal plane has been recognised as an important factor in the development of osteoarthritis of the lateral and medial compartments of the knee (Maquet 1976). Overloading causes progressive loss of articular cartilage and will ultimately lead to microfractures and collapse. The operation of tibial osteotomy was designed to correct the deformity and hence restore the normal pattern of load-bearing (Jackson and Waugh 1961). The angulation at the knee has been measured on anteroposterior radiographs, taken with the patient standing, by drawing lines down the centre of the shafts of the femur and of the tibia; from which the necessary correction to achieve the normal tibiofemoral valgus angulation of seven degrees (Kettelkamp *et al.* 1976) can then be calculated. Some authors have suggested that a few degrees of overcorrection are desirable (Kettelkamp *et al.* 1976; Maquet 1976). More recently, radiographs of the whole leg from hip to ankle, taken when standing, have been used to demonstrate the mechanical axis, which is a line drawn from the centre of the head of the femur to the centre of the superior surface of the body of the talus. This line normally passes either through or very near to the centre of the knee (Hagstedt 1974; Koshino and Tsuchiya 1979). Deviation of the line to one or other side of the joint has been

taken to imply excessive load-bearing on one compartment. If correction is to be achieved at osteotomy, the line on the radiograph should be restored to the centre of the joint or just into the opposite side.

Fig. 1

Hypothetical distribution of load in the knee with respect to the coronal angle.

The dynamic functional load can be evaluated routinely by a method of gait analysis which has been adapted for clinical use (Johnson and Waugh 1979). This provides an estimate of the division of load between the medial and lateral compartments of the knee during the stance phase of walking.

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HYPOTHESIS

It has been shown by Kettelkamp and Chao (1972) that the medial and lateral compressive forces at the knee may be computed from measurements taken from radiographs of a standing subject. Their results indicated that the load-sharing was related to the angle between the tibial and femoral axes.

Reduced to its simplest form, the hypothesis of Figure 1 may be proposed. This suggests that for knees with angulations which are more varus than an assumed neutral the load is predominantly in the medial compartment, while for knees which are more valgus than neutral the load is predominantly lateral. If the prediction made by this hypothesis is true, then a radiograph of the static knee may be used to indicate the

expected site of maximal loading. In order to test the hypothesis, the location of the neutral angle has to be found. Gait analysis is then used to determine the load in the knee during walking.

MATERIAL AND METHOD

Since 1976 patients at Harlow Wood Orthopaedic Hospital have, whenever possible, had anteroposterior radiographs taken of the whole leg before tibial osteotomy or knee replacement in order to measure the angular deformity in the coronal plane and find the site of the mechanical axis. In 1977 a laboratory for gait analysis was set up at the Queen's Medical Centre in Nottingham and, since then, the differential loading on each side of the knee has been estimated for most patients before and after tibial osteotomy or arthroplasty.

Fifty-two long radiographs were available for 47 patients (five having had radiographs taken of both legs) who had also had gait analysis carried out. No selection was made except to exclude unsatisfactory radiographs, in particular those in which the femoral head was not defined well enough for its centre to be gauged. The patients all had either osteoarthritis or rheumatoid arthritis of the knee. The radiographs had been taken with the patient standing and putting as much weight as possible on the affected leg. The cassette was 900 × 350 millimetres and the distance from tube to film was 800 millimetres. The tube was moved from the proximal end to the distal so that an image of the whole leg was obtained, the exposure being varied.

The mechanical axis was drawn on each radiograph (Figs 2 and 3). The relationship of this line to the centre of the knee was evaluated by using an arbitrary classification in which the upper end of the tibia had been divided into seven equal zones (Fig. 4). The central zone (Zone

Fig. 2

Figure 2—Example of long-leg radiograph to illustrate construction of mechanical axis. Figure 3—In a knee with neutral angulation the mechanical axis passes between the tibial spines.

Fig. 3

Fig. 4

Division of proximal end of tibia into zones to define intersection of mechanical axis.

0) lay between the tibial spinous processes and this was the section through which the mechanical axis in the knee with normal tibiofemoral angulation (Fig. 3) should pass. The rest of the plateau was divided into three zones on each side. If the line fell outside the bone it was regarded as being in Zone 4. The tibiofemoral angle in the coronal plane was also measured from this radiograph.

The method of gait analysis has already been described (Johnson and Waugh 1979). A six-component Kistler force-plate was used to estimate the foot-to-floor reaction. A three-channel polarised-light goniometer recorded the angle between the thigh and calf in the sagittal plane, and also the angle between the lower leg and the floor in the coronal and sagittal planes. The moment of flexion-extension about the knee and the moment of adduction-abduction were computed. This information allowed an estimation of the total force on the joint during the stance phase (Morrison 1968). The relative proportion of load taken by the medial and lateral compartments of the knee could also be computed and expressed as a percentage of the total load on the joint (Johnson and Waugh 1979).

RESULTS

The tibiofemoral angle was plotted against the zone into which the mechanical axis fell in each radiograph (Fig. 5). There was, as might be expected, a high degree of correlation between the tibiofemoral angle and the site of mechanical axis when the latter was within the area of the knee. When the mechanical axis fell outside the bone (Zone 4) there was a wide range of tibiofemoral angles. When the mechanical axis went through the centre of the knee (Zone 0) there was a valgus angulation of five degrees, a result which supports the supposition that this is the normal tibiofemoral valgus angle. This is taken to be the neutral angle.

The information on the graph (Fig. 5) was also used to predict the angulation of the knee at which the load would be entirely carried by the medial or the lateral plateau. Intersection of the mechanical axis with the Zones 3 gave these points, which occurred at a varus angle of 4 degrees and at a valgus angle of 15 degrees (Fig. 5). The value of these points as predictors of the loading of the joint is discussed below.

The measurements provided by gait analysis were plotted as shown in Figure 6. Of the 52 values obtained, 20 (39 per cent) indicated a higher load on the medial side even though the angle of the knee was more valgus than neutral. Furthermore, there was no corresponding indication of a higher load on the lateral side of knees

with varus angulation. Thus the entire set of results pointed to more medial loading than the hypothesis (Fig. 1) would have predicted.

On the basis of the results from gait analysis, the hypothesis must be rejected. This means that examination of a radiograph of a static knee cannot provide even an approximate estimate of the distribution of the load.

Fig. 6

Results of gait analysis: 20 of the 52 joints lie in the shaded area.

Fig. 5

Results from 52 long-leg radiographs showing intersection of mechanical axis. The solid line is the best fit through all points from Zone 3 lateral to Zone 3 medial.

DISCUSSION

Maquet (1976) has argued that when the body is stationary the resultant force on the knee must pass through the centre of gravity of the total load-bearing surface of the knee. In the coronal plane, this line lies within the central zone (Zone 0 in Fig. 4). Because this line of force must also pass through the ankle and, if continued, will normally pass through the centre of the hip, then the location of the line should be an indicator of load-bearing at the knee. The results from dynamic gait analysis have shown that this is not so. For a normal valgus tibiofemoral angulation, the load was predominantly medial; these results agreed with other reports (Morrison 1970; Harrington 1976). When the knee had a varus deformity the load on the medial plateau rapidly approached 100 per cent of the total load on the joint. For valgus deformities, however, the load remained medial in 20 out of 28 cases (71 per cent).

The explanation for the lack of correlation between the mechanical axis and the weight-bearing in the knee is in the difference between the static and the dynamic situations. In a static normal knee (Fig. 7) the vertical reaction from the floor passes through the centre of the knee, and no horizontal forces exist; the load is shared equally between the lateral and medial compartments. In a varus knee (Fig. 8), again standing still, the load passes medially to the centre of the knee, and the load on the medial compartment is correspondingly greater. In a

normal knee at the centre of the stance phase (Fig. 9) force-platform measurements have indicated that there will now be an additional horizontal component to the floor reaction, causing the vector to be directed medially to the knee (Morrison 1968; Johnson, Waugh and

Fig. 7

Fig. 8

Fig. 9

Vectors of floor reaction. Figure 7—Normal knee, static. Figure 8—Varus knee, static. Figure 9—Normal knee, dynamic.

Oborne 1978); the effect of this will be to increase the load in the medial plateau, as shown in Figure 8.

Results from gait analysis have indicated that the division of load between the lateral and medial

compartments of the knee will usually be more medial than might be predicted from a static analysis, except when there is a varus deformity of more than five degrees, when both methods will predict the same result.

There are technical difficulties implicit in each method. Long radiographs of the leg are difficult to standardise. If there is a flexion deformity of the knee then any degree of rotation of the limb will suggest an abnormal tibiofemoral valgus angulation. Moreover, many patients with painful knees might not be able to stand still on one leg long enough for it to be certain that the radiograph is, in fact, taken during load-bearing. Our method of gait analysis is also not possible with every patient for whom an operation may be indicated. Although the calculation can be carried out if the patient is using one stick, the presence of a walking frame will make it impossible to obtain a satisfactory reading from the goniometer. It is also more satisfactory if the patient is able to take a stride of 450 millimetres, so that the feet are apart and not both on the force-platform at the same time.

The value of radiographs of the whole leg is therefore restricted to calculating the angle necessary to correct the deformity present. Gait analysis, on the other hand, does not show the correction necessary, but it can measure the distribution of load during walking, and serial observations might, for example, indicate progressive deterioration after an operation for knee replacement. We feel that for all patients undergoing tibial osteotomy or knee replacement there should be both a standing radiograph and a gait analysis so that the state of the joint is well known. It is, perhaps, even more important that these observations should be repeated at regular intervals so that changes in angulation and load-bearing can be detected and their significance be evaluated particularly with regard to prognosis.

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