WEIGHT-BEARING AREAS IN THE HUMAN HIP JOINT

A. S. GREENWALD, CLEVELAND, OHIO, UNITED STATES OF AMERICA, and
D. W. HAYNES, OXFORD, ENGLAND

From the Nuffield Orthopaedic Centre, Oxford

The transmission of forces through the articulating surfaces of the human hip joint has been investigated by many workers. Harrison, Schajowicz and Trueta (1953) speculated that because of the trabecular arrangement within the femoral head there were defined pressure areas on the articular surfaces. Attempts to show these areas were made by Goodfellow and Bullough (1968) by manually compressing the joint and using a dye transfer technique. They concluded that a triangular area on the roof of the acetabulum, and presumably a corresponding area on the femoral head, were not involved in weight-bearing in the young subject, whereas in the elderly, weight-bearing of all the articular surfaces often became complete.

Dynamic in vivo measurements of the forces acting on the hip joint have been made by Rydell (1966) and Paul (1967). Rydell measured the forces acting directly through the hip with an instrumented Austin Moore prosthesis. Although his results gave a quantitative estimate of the forces involved, they cannot be related to the normal intact joint. Indirect measurements of the forces acting on the normal intact hip joint with a force plate,

FIG. 1
The joint orientation apparatus.
cinematography, anthropometric measurements and electromyography were made by Paul (loc. cit.). He calculated the resultant forces transmitted through the hip joint during the stance and swing phases of normal walking. With the information derived from Paul's study it would be possible to simulate these forces in an in vitro experiment to determine the weight-bearing areas of the hip joint. The purpose of this communication is to report the results of such experiments.

MATERIALS AND METHODS

Human adult hip joints were obtained at necropsy and stored in sealed polythene bags at —20 degrees Celsius until used. The specimens were thawed for the experiment and the soft tissue was removed leaving the joint capsule intact. The joint was put into an extended position, the anterior capsular ligaments being thus drawn tight. From this position the joint was flexed an estimated 10 degrees to a position that was neutral in respect of rotation, abduction and adduction. With the joint held in this position an incision was made in the capsule along the free margin of the acetabular labrum. With a fine-tip felt pen a line was drawn on the femoral surface along the margin of the acetabulum. A further line was drawn at right angles across the original, marking both the acetabulum and the femoral head. These lines were subsequently used to relocate the joint in its neutral position.

The capsule was removed and the joint disarticulated. The articular surfaces were examined macroscopically for abnormalities. Forty-nine cadaveric specimens were free from fibrillation or erosion and were accepted for study. In addition two fresh surgical specimens which were not frozen were also tested.

To obtain positions other than the neutral, the joint was mounted into an orientation apparatus which allowed the joint to be marked in the various positions of the walking cycle (Fig. 1). The femoral head and acetabulum were attached to mounting plates with pins and methacrylate and placed in a loading frame designed specifically to allow joints to be placed in any position and a known load to be applied and measured (Greenwald 1969, 1970). The machine comprised a hydraulic ram for the application of loads and a dynamometer with attached strain instruments for measuring the applied forces (Figs. 2 and 3). The joint was aligned in the frame in the desired position for testing by using the ink markings. A polythene bag was pulled over the joint and secured (Fig. 4). Inlet and outlet tubes were attached to the mounting plates through which Ringer's solution maintained at 37 degrees Celsius and pH 7-1 was circulated for ten to fifteen minutes to allow for temperature adjustments and soaking of cartilage.
The appropriate physiological load was applied to the hip joint and measured. The bath of Ringer's solution was replaced by a circulating dye solution of 0.1 per cent Safranin in Ringer's solution at 37 degrees Celsius and pH 7.1 staining the non-contact areas. The dye was drained away and the joint washed again with Ringer's solution. The load was removed from the joint. The loading, staining and unloading sequence lasted approximately one minute.

The joint bag was detached and the joint disarticulated and removed from the loading frame. A grid of fine mesh square gauze was placed over the femoral head and secured with a rubber band. The periphery of the contact zone was traced on to both the mesh grid and the femoral head with a fine-tipped felt pen (Fig. 5). Photographs were taken of the acetabulum and femoral head to record the contact areas.

To study the effect of load reduction on the size of the contact areas, the joint was again placed in the loading frame and aligned to the same orientation. The same loading and staining sequence was followed to obtain the contact pattern under a lighter load.

On completion of the experiments the femoral head and acetabulum were removed from the mounting plates and placed in 10 per cent neutral formalin for radiological and histological examination. The contact areas outlined on the mesh grid were traced on to polar graphs (Figs. 6 and 7) and their areas measured with a planimeter.

RESULTS

The contact maps demonstrate that with normal loads the entire articular surface of the acetabulum is involved in weight-bearing (Figs. 8 and 9). This contact area is reproduced on the articular surface of the femoral head and its position determined by the attitude of the femur to the acetabulum during the walking cycle. The contact area includes the anterior, superior and posterior aspects of the femoral head. A band of articular cartilage on the inferior and perifoveal regions always remains a non-contact area. The peripheral areas of the articular surfaces are brought into contact only at the extreme limits of the walking cycle. In the intact joint the band of articular cartilage on the inferior surface of the femoral head does not make contact with a corresponding hyaline cartilage surface. It is covered instead by the ligament of the femoral head and the adjacent soft tissue of the fossa. The peripheral
FIG. 4
The joint components mounted into the loading frame and aligned to the ink markings.

FIG. 5
Mesh grid used to record the contact areas on the femoral head.
areas which make occasional contact are seldom involved in weight-bearing as they usually make contact with the fibrocartilaginous tissue of the labrum.

With reduced loads (25 per cent of body weight and less) partial contact areas occur within the existing full contact area. The dome of the acetabulum and the corresponding surface of the femoral head are not included in these partial contact areas (Figs. 10 to 13).

**FIG. 6**
Figure 6—Contact areas outlined on the mesh grid. The green regions denote the partial contact areas. **FIG. 7**—The same contact areas as in Figure 6, traced on to a polar graph.

**FIG. 8**
The contact areas obtained from a normal 51-year-old right male femoral head (Fig. 8) and acetabulum (Fig. 9) in the neutral position under load of 1.6 times the body weight. The contact areas remain unstained.

**FIG. 9**

These reduced loads occur during the swing phase of the walking cycle. In many specimens from aged subjects partial contact areas could not be obtained.

The area of full contact ranged between 22.19 and 33.68 square centimetres (average 26.77 square centimetres) and covered approximately 70 per cent of the articular surface of the femoral head.
Radiological and histological examination did not reveal any damage due to freezing or compression of the joints. There was no difference in the relative size or position of the contact areas between the cadaveric and the surgical specimens.

**FIG. 12**
The same joint as shown in Figures 8 and 9 under a reduced load of 0.2 times the body weight. The dye has now stained the superior surfaces of the femoral head (Fig. 10) and acetabulum (Fig. 11), leaving contact areas on the anterior (Fig. 12) and posterior surfaces (Fig. 13).

**DISCUSSION**

The results indicate that during the stance phase of the walking cycle the entire articular surface of the acetabulum is weight-bearing and the size of the contact area is independent of load. During part of the swing phase only the anterior and posterior surfaces are loaded, and the size of the contact area is dependent on load. The biomechanical mechanism of load transfer across the weight-bearing areas is the subject of current investigations.

The results suggest that the dome of the acetabulum is subjected to rapidly fluctuating degrees of load during the walking cycle. The change in the forces to which this part of the acetabulum is subjected varies from the unloaded condition to maximum weight-bearing. Because of rotational movement there is no single area on the femoral head which is constantly subjected to a similar change in load bearing. Goodfellow and Bullough (1968) and Byers,
Contepomi and Farkas (1970) recorded cartilage degeneration occurring frequently in the dome of the acetabulum. The relationship between the change in load and the presence of cartilage degeneration is of considerable interest but is so far unresolved.

This study also provides quantitative support for the theory propounded by Harrison, Schajowicz and True (1953). The areas which they designated as “pressure areas” correspond closely to the contact areas detected in this investigation and the “non-pressure areas” correspond to non-contact areas. They reported that in 71 per cent of the femoral heads examined early degenerative changes were present in non-pressure areas. In 26 per cent of the heads they recorded degenerative changes in both pressure and non-pressure areas. They concluded that the absence of joint pressure may be deleterious to the maintenance of hyaline cartilage. Byers, Contepomi and Farkas (loc. cit.) observed similar areas of degenerative change which they classified as “non-progressive” or age related and “progressive” or disease related. The non-progressive lesions occur within non-contact areas and the progressive lesions in contact areas.

If it is accepted that, whatever their cause, cartilage lesions are followed by fibrillation, it seems inevitable that in contact areas mechanical forces will lead to accelerated destruction of abnormal cartilage. In non-contact areas damaged cartilage may be protected from such forces and so disintegrate at a slower rate.

Whether weight-bearing is itself a causal factor in the initial degeneration of hyaline cartilage remains unanswered.

SUMMARY

1. A specially designed loading apparatus and dyeing technique have been used to demonstrate the weight-bearing areas in fifty-one normal adult hip joints.
2. Under loads and positions typical of the stance phase of walking the entire articular surface of the acetabulum is involved in weight-bearing. This contact area is reproduced on the femoral head, and its position determined by the attitude of the femur to the acetabulum.
3. With loads typical of the swing phase, the dome of the acetabulum and corresponding areas on the femoral head are not involved in weight-bearing.
4. The results are compared with the conclusions of previous investigators and their possible significance with regard to joint degeneration is discussed.

We wish to thank the Arthritis and Rheumatism Council for financial support and Dr C. G. Woods for helpful discussions.

REFERENCES