JOINT SURFACE INCONGRUITY AND ITS MAINTENANCE

AN EXPERIMENTAL STUDY

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The paper reports an experimental investigation into the mechanisms whereby the joints of living animals maintain their precise contours. The normal pattern of joint incongruity in the rabbit's hip having first been established, three groups of experimental animals underwent operative procedures designed to reduce the joint pressure to a level unrealistic in normal life. In one group the hip was dislocated by manipulation; in a second group the muscles around the hip joint were divided; and in a third group the hind limb was disarticulated through the knee. When the animals were killed at intervals of a few weeks after the operations the experimental hip joint showed increased congruity in all cases. It is concluded that in immature animals there is a mechanism in joints to control the modelling of their shapes towards an ideal incongruity, and that that mechanism is pressure sensitive.

The process of remodelling and its ability to maintain joint surfaces in their constant shape is the subject of our investigation. The importance of the precise shapes of joint surfaces has been discussed elsewhere (Bullough, Goodfellow and O'Connor 1973).

In ball and socket joints it can be shown that the ideal solid shapes which could best distribute varying loads are a spherical ball articulating within an arched dome. If the degree of asphericity of the arched dome is properly related to the compliance of the bone and cartilage the areas of contact between the two elements grow as the load increases, thus maintaining more or less constant levels of stress within the materials. All other shapes fall short of this ideal. In particular, if a ball and socket joint is constructed so that the components are perfectly congruous when at rest, the levels of stress when it is loaded far exceed the ideal (Goodfellow and O'Connor 1975).

Mammalian acetabula, including that of man, have an arched form. Under light load the contact areas are at the front and back of the acetabulum and there is a gap above, which closes as the load increases (Goodfellow and Bullough 1968). Figure 1 shows the contact areas under light load in four mammals.

![Contact prints of the acetabulum of four mammals with the areas of contact shown in white: A, rabbit; B, rhesus monkey; C, cat; D, dog.](image)

**Fig. 1**

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THE PROBLEM
If an inanimate sphere is thrust into an incongruous socket the phenomenon of creep will result in a gradual change in the resting shapes of the components so that eventually congruity is achieved and they will come to match one another, even at rest. In living animals the tendency for the components of the hip joint to become congruous is regularly resisted over periods of decades, a phenomenon which must be mediated by slight but important differential growth within the components, which allows the specific incongruities to persist. This process, which is called remodelling, may fail in old age, and it is known that some elderly human subjects exhibit passive congruity in their hip joints (Bullough et al. 1968).

If there is an active remodelling mechanism in the ends of bones capable of maintaining their precise incongruities in a constant form over long periods, it is necessary to assume the existence of some control mechanism. Since it is the function of joint surfaces to transmit load, and if it is the purpose of incongruity of the kind described to produce an isobaric state within the joint, it seemed likely that the control mechanism would be pressure sensitive.

If a pressure-sensitive feedback mechanism exists it should be possible to "switch it off" by removing the load from the joint surfaces. It might even be possible to switch it off by reducing the load across the joint surfaces to a level which is unrealistic in natural life. With the remodelling process rendered inactive or without directional control, passive congruity of the joint surfaces might be expected to result.

THE EXPERIMENTS
In these experiments the hip joint of an animal was relieved of some of its natural load-bearing function. In the first group the hip was dislocated, in the second group most of the muscles around the hip joint were divided, and in the third group the hind limb was disarticulated through the knee (Fig. 2). The animals were killed at varying intervals after these procedures, and a comparison made of the degree of congruity in the operated and unoperated hips. Six-month-old white New Zealand rabbits were employed: they were not fully mature, and their epiphyses were open.

The operations were performed under ether anaesthesia as follows.

Group I—Six animals. The right hip was dislocated by closed manipulation. Radiographs confirmed successful dislocation in five animals; in the sixth epiphysiolysis occurred. The animals were killed in pairs at one, two and three weeks after the dislocation.

Group II—Six animals. Through a longitudinal medial incision the right hip was approached and all the muscle groups surrounding it were divided. The capsule was not opened and the vessels and nerves were carefully preserved. The animals were killed in pairs at two, four and six weeks after the operation.

Group III—Six animals. A through-knee disarticulation was carried out on the right side. The animals were
killed in pairs at two, four and six weeks after disarticulation.

Method of investigation
Contact prints were made by the dye-exclusion technique using safranin (Greenwald 1970; Greenwald and Haynes 1972). First, the acetabulum and the femoral head were cleaned of all their soft-tissue attachments, and the acetabular fossa was emptied of its synovial fat pad. The femur was then placed in the acetabulum in a standard position (midway between full flexion and full extension), and manual pressure was applied. The dye (0·1 per cent safranin) was injected into the acetabulum at its free margins and through the acetabular notch. With the components still held immobile and under pressure the dye was washed away, and finally the components were taken apart. All the non-contact areas within the hip were dyed, and those in contact were not. In order to facilitate reproduction in black and white the dyed areas were painted with indian ink before the joints were photographed.

RESULTS

Controls—A preliminary examination of the hip joints of twelve rabbits at several differing stages of maturity revealed a constant pattern of incongruity under light load. In all eighteen control hips this pattern was reproduced and can be seen in the left hips of all the animals illustrated in the figures.

Group I—In the five animals in which dislocation was successfully achieved the joints were still dislocated at the time of death. All showed increased congruity and loss of the normal area of non-contact on the “roof” of the acetabulum (that part immediately opposite to the acetabular notch). Figure 3 demonstrates the acetabula of an animal killed at one week. Figure 4 shows the femoral heads of an animal killed at three weeks, for the dye-exclusion technique reveals the contact areas on both components of the joint equally well.

Group II—Figures 5, 6 and 7 show the pattern of acetabular contact in three animals at two, four and six weeks after division of the hip muscles, and they are representative of the group.

Group III—Figures 8, 9 and 10 show similar results in three animals killed two, four and six weeks after disarticulation of the leg through the knee.

DISCUSSION

The controls—The particular form of incongruity that characterises the healthy rabbit hip is a close replica of that found in all the other mammals examined, including man.

It has been shown, in man, that the degree of incongruity in the normal hip is such that, under a load well within the physiological range, the compliance of the bone and cartilage allows total contact to be achieved. The incongruities of the resting shapes can therefore only be demonstrated when light loads are applied. The loads applied in these experiments were not measured and were only “standard” in that we attempted to reproduce the same manual pressure from specimen to specimen. In the control joints the same method has regularly produced the same pattern, and we have not encountered a normal joint in which the surfaces appeared congruous by this technique, which we have found to be reliable.
Increased contact areas on right acetabulum in three animals killed at two weeks (Fig. 5), four weeks (Fig. 6) and six weeks (Fig. 7) after division of muscles (Group II).

Increased contact areas on right acetabulum in three animals two weeks (Fig. 8), four weeks (Fig. 9) and six weeks (Fig. 10) after disarticulation through knee (Group III).
The experiments—Figure 11 suggests the hypothesis that our experiments were designed to test.

The first experiment (Group I) is open to several objections. It is a crude method which may have introduced several variations other than the one aimed at—namely the “switching off” of the control mechanism of growth by reducing pressure at the articular surfaces. Nor is it in the least an original observation that dysplasia of the immature hip quickly follows dislocation of it (Langenskiöld, Sarpio and Michelsson 1962), though it is perhaps surprising that the dysplasia can result in the joint becoming a better fit (in one sense) than normal.

The second experiment (Group II) is perhaps more significant, for in these animals the joint was left intact and only the muscles surrounding it were divided to produce a “flail joint”. But even this experiment is open to the criticism that the blood supply of the bones may have been impaired and the situation confused by the presence of a haematoma.

We therefore performed the third series of experiments (Group III) in which we simply shortened the hind leg by disarticulation through the knee, achieving as nearly as possible a pure alteration in the biomechanics of the hip by reducing its load-bearing function.

The results—The observation of increased congruity in all the experimental hips is capable of two interpretations. Either the resting shapes of the components became more nearly similar during the experiment, or the resting shapes stayed the same, and the compliance of the materials of which they were made increased. We cannot at present be sure which of these changes we are observing, or whether both are at work. However, in Groups II and III no significant change was observed in the articular cartilage of the experimental hips (Fig. 12). Hall (1969) has shown that degenerative changes in the cartilage do occur in response to diminished load, but
that many weeks are needed for these changes to develop. In our animals increased congruity was achieved within a week or two, and we conclude that this must therefore represent a change in the shape of the bony elements—achieved by remodelling—and that it cannot be attributed to degeneration of the articular cartilage.

All the animals used were immature—their epiphyses were not yet closed. We used immature specimens because the high growth rate in them might be expected to magnify the effects of an alteration in load-bearing.

**CONCLUSION**

The hypothesis put forward at the beginning of this paper, that there is a mechanism in joints to control the modelling of their shapes towards an ideal of incongruity, and that that mechanism is pressure sensitive, gains support from the experimental evidence presented. Since we believe that the exact shapes of the opposed surfaces in a joint are an essential feature of its design and render it capable of transmitting physiological loads without inducing unphysiological stresses, we consider that this mechanism deserves more thorough study than it has yet received.

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**REFERENCES**


