THE RESPONSE OF ARTICULAR CARTILAGE TO WEIGHT-BEARING AGAINST METAL

A STUDY OF HEMIARTHROPLASTY OF THE HIP IN THE DOG

RICHARD L. CRUESS, DESMOND C. KWOK, PHAM NGOC DUC,
MARY ANN LECAVALIER, GENG-TING DANG

From McGill University, Montreal

Hemiarthroplasty of the hip and some other joints has been used for many years with satisfactory results, but the fate of articular cartilage when weight-bearing against metal has not been reported. Replacement of the head of the femur was carried out in one hip of each of 26 dogs, and the changes in acetabular cartilage studied at intervals of up to 24 weeks. There was early loss of proteoglycan, followed by surface damage to the cartilage, progressive degenerative changes, and growth of pannus from the articular margins. At 24 weeks after operation there was little remaining articular cartilage, while intense subchondral activity suggested that the bony skeleton was being remodelled to conform to the shape of the prosthesis. This study is not intended to suggest that hemiarthroplasty does not help patients.

The replacement of one side of a joint with a metal prosthesis which moves against articular cartilage is well established as a beneficial operation (Thompson 1954; Moore 1957; Hinchey and Day 1964; Salvati and Wilson 1973). The femoral head is most frequently replaced in this way, but hemiarthroplasty has also been used at the shoulder (Neer 1955), and at other joints (MacIntosh 1958; Jones 1969; Levitt 1973). Since satisfactory femoral head replacements were developed 30 years ago, very many operations of this type have given good results, but no study has yet been made of the reaction of articular cartilage to weight-bearing against metal. This paper reports the response of articular cartilage to hemiarthroplasty of the hip in the dog. The aim is to shed light upon the changes which follow the operation and not in any way to condemn hemiarthroplasty as a clinical procedure.

MATERIALS AND METHODS

Vitallium prostheses with heads whose diameters increased in 0.5 mm steps from 18 to 22 mm were designed and manufactured by Howmedica for insertion into dogs (Fig. 1). At operation a posterolateral approach

was used and a "T" incision made in the capsule of the joint. The hip was then dislocated and the ligamentum teres cut. The femoral head was removed with an osteotomy saw, the correct neck length being ensured by

Fig. 1

Photograph of samples of the prostheses used.

reference to a prosthesis. A template graded in 0.5 mm steps was used to gauge the size of the implant, a method reported as being the most accurate available (Harris *et al.* 1975). The femur was prepared with a special reamer and the prosthesis inserted after injection of methyl-methacrylate cement. A specially designed pusher was used, with care to maintain 15° of anteversion at final seating. The hip was then reduced and shown to be stable before the capsule and then the wound was sutured. A sham operation was done on the opposite control hip, up to and including the capsular incision, but not the dislocation.

R. L. Cruess, MD, Dean
D. C. Kwok, MD, Research Associate
M. A. Lecavalier, BSc
Faculty of Medicine, McGill University, 3655 Drummond Street,
Montreal, Quebec H3G 1Y6, Canada.
P. N. Duc, MD
P.O. Box 966, Chandler, Quebec J0C 1K0, Canada.
G-T. Dang, MD, Research Associate
The Third Teaching Hospital, Beijing Medical College, Beijing,
People's Republic of China.
Requests for reprints should be sent to Dr R. L. Cruess.

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0301-620X/84/4106 \$2.00

Twenty-four animals were used and killed at various intervals after operation: five at two weeks, six at four weeks, three at six weeks, three at 12 weeks, three at 18 weeks, and four at 24 weeks. All the animals were given oral antibiotics for five days after operation. None of them were immobilised; they were allowed normal activity in their cages and were also exercised regularly. All the dogs were walking and fully weight-bearing from one to seven days after operation; no animal limped. Complications included three dislocations; two of these yielded to closed reduction, but the third required open reduction and this animal was withdrawn from the study. Two superficial wound infections involved the suture material only and there were no deep wound infections.

Radiographs were taken postoperatively and at monthly intervals. After sacrifice, the following investigations were done. Photographs were taken of the acetabulum on both control and experimental sides. Each acetabulum was then transected vertically through its centre. One half was used for light microscopy after staining with haematoxylin and eosin, toluidine blue, or safranin-O (Rosenberg 1971). Safranin-O enables assessment of proteoglycan content, as it binds on a mole-to-mole basis with this constituent of cartilage matrix. The histological grading of Mankin *et al.* (1971) was used on the safranin-O stained sections to assess the level of degenerative change. This was done by a single observer without knowledge of the history of the acetabulum.

The other half of the acetabulum was prepared for electron microscopy by fixation in 2% glutaraldehyde in 0.10 molar sodium phosphate at pH 7.4. The specimens

were then rinsed in sodium phosphate buffer, dehydrated in acetone, critical point dried, mounted on aluminium stubs and coated with gold palladium. They were examined in a Philips 500 scanning electron microscope.

RESULTS

Radiographs showed the position of the prostheses, but did not demonstrate any change in joint space or medial protrusion of the acetabulum (Figs 2 and 3). They did prove that reduction and position were well maintained.

Fig. 2

Fig. 3

Radiographs of both hips of a dog after the insertion of a prosthesis. Figure 2—Good position is maintained after 12 weeks. Figure 3—No change at 24 weeks.

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Photographs of the acetabula of dogs at various stages after operation. Figure 4—The experimental side six weeks after operation; the superior part of the acetabulum is at the top, with the fovea below. Early pannus is seen at the margins of the cartilage with inflammation of synovial tissue and of the fat pad within the fossa. There is a suggestion of granulation tissue in the more central areas of cartilage. Figure 5—At 12 weeks, pannus is more organised and is advancing across the articular cartilage. The upper blade of the forceps is under pannus. Figure 6—By 18 weeks, a well-organised area of pannus is seen, some of which is grasped by the forceps. Figure 7—At 24 weeks, the control acetabulum (right), appears normal whereas the experimental acetabulum (left), has only small islands of cartilage remaining near the acetabular fossa.

Photographs showed early inflammation which rapidly subsided. At six weeks (Fig. 4), there was discoloration of the synovial membrane and in the region of the acetabular fossa. There was some irregularity of the cartilage surface with pannus growing across it. At 12 weeks (Fig. 5), the pannus was more mature and less discoloured, but covered a larger part of the acetabulum. By 18 weeks (Fig. 6), there was still some redness in the surrounding synovial membrane, but the pannus was better organised and continued to advance. After 24 weeks (Fig. 7), in two dogs, there was no evidence of any remaining acetabular cartilage.

Scanning electron microscopy. This confirmed and emphasised the surface changes of the articular cartilage seen on light microscopy. In the controls, the cartilage displayed a slightly undulating, intact surface (Fig. 17). By six weeks gross irregularities were visible in the experimental hips, with exposed chondrocytes (Figs 18 and 19). At the conclusion of the experiment (Fig. 20), intense destruction of the surface of the articular cartilage was seen.

Grading of degeneration. The grading method reported by Mankin *et al.* (1971) was applied and plotted against the time since operation. There was a slow but steady

Fig. 8

Fig. 9

Micrographs of cartilage from control joints. Figure 8—Two weeks after operation, showing normal staining of the central and deeper zones of cartilage (safranin-O, $\times 55$). Figure 9—Normal lamina splendens after four weeks (toluidine blue, $\times 150$).

Histology. The cartilage of every control acetabulum retained normal metachromatic staining (Fig. 8) and its surface remained intact (Fig. 9). At two weeks, there was some loss of metachromatic staining in the experimental hips (Fig. 10), with focal areas of normal colour being found only in the deeper layers next to chondrocytes. By four weeks (Fig. 11), the surface had often become frayed with exposed surface chondrocytes visible on light microscopy. After six to eight weeks (Fig. 12), this loss of normal surface was more dramatic, with a greater loss of metachromasia; intense subchondral activity was seen, which included invasion of cartilage by granulation tissue from the underlying bone. By 12 weeks, well-established pannus was growing from the margins (Fig. 13) and destruction of cartilage deep to the pannus was seen. At 18 weeks, pannus appeared to be more aggressive and to be actively infiltrating the cartilage (Fig. 14). At 24 weeks, there were many areas of exposed bone, with intense cellular activity in the spaces between the bony spicules (Figs 15 and 16).

deterioration (Fig. 21), and no normal cartilage was found later than six weeks after operation.

DISCUSSION

The results are striking and consistent. Weight-bearing against metal caused the articular cartilage and subchondral bone of the dog's acetabulum to respond in an impressive, if predictable fashion. The cartilage maintained its structural integrity for a limited period of time, but with early loss of glycosaminoglycan. Between two and four weeks after the insertion of the prosthesis, the articular surface looked frayed when examined both by light microscopy and by scanning electron microscopy. This breaching of the superficial layer became more severe and there was increasing loss of proteoglycan. Pannus appeared to grow from the margins of the articular cartilage, starting from around the acetabular labrum and fossa. In several animals it appeared to be aggressive at an early stage, with invasion of the articular cartilage. After this, until the end of the study, articular

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Micrographs of cartilage from dog's hips after hemiarthroplasty. Figure 10—After two weeks the surface is intact but metachromatic staining is shown only in the area immediately around chondrocytes in the mid and deep zones (safranin-O, $\times 85$). Figure 11—At four weeks the surface is lost and exposed tangential chondrocytes are seen (toluidine blue, $\times 110$). Figure 12—By six weeks more loss of metachromatic staining is seen, and fraying of the surface. Intense subchondral cellular activity is visible, with invasion of cartilage on the right of the picture (safranin-O, $\times 85$). Figure 13—After 12 weeks there is growth of pannus over the margins of the cartilage, with loss of staining at the interface (toluidine blue, $\times 85$). Figure 14—By 18 weeks very aggressive pannus is seen more centrally over the cartilage (toluidine blue, $\times 85$). Figure 15—At 24 weeks exposed bone is demonstrated, with fibrous granulation tissue in its interstices (safranin-O, $\times 85$). Figure 16—At 24 weeks after insertion of the prosthesis there is very active remodelling of the subchondral bone near the acetabular fossa, with invasion by granulation tissue (haematoxylin and eosin, $\times 85$).

cartilage showed increasing degeneration with loss of proteoglycan, and of superficial and deep cartilage, and further ingrowth of pannus. By six to eight weeks there was invasion of cartilage by granulation tissue from subchondral bone.

Subchondral bone showed increasing cellular activity, probably due to remodelling in response to new mechanical demands. In all the control animals the postoperative inflammation settled rapidly and the hip remained essentially normal. It is important to stress that

some of which are lysosomal in nature (Ehrlich *et al.* 1975; 1977). This helps to explain the early loss of glycosaminoglycans. It is also established that a decrease in glycosaminoglycans alters the biomechanical properties of articular cartilage, causing it to become softer and to lose its elastic recoil (Kempson *et al.* 1973). This may lead to the possibility of "fracture" of surface collagen fibres in the lamina splendens (Freeman 1972), and thus explain the early loss of surface integrity. Once this has occurred, the biomechanical strength of cartilage is

Fig. 17

Fig. 18

Fig. 19

Fig. 20

Scanning electron micrographs of the surface of the acetabular cartilage. Figure 17—Shows the normal surface characteristics in a control joint four weeks after mock operation ($\times 1250$). Figure 18—At six weeks the loss of normal surface and the early formation of clefts are visible ($\times 800$). Figure 19—At 12 weeks after the insertion of the prosthesis exposed chondrocytes are seen ($\times 3200$). Figure 20—At the end of the experimental period of 24 weeks, the surface is extremely irregular with fibrin deposits and deep clefts ($\times 800$).

no experimental hip showed normal cartilage after six weeks. The longer the period since the insertion of the prosthesis, the more severe was the damage. Some pilot studies were done with metal heads which were too large or too small for the acetabulum, but no correlation between abnormal head size and the changes in reaction of the joints was found and details of these trials are therefore not reported.

The results in this series are so uniform that an attempt at explanation is warranted. It is probable that articulation against a rigid metallic surface puts abnormal stress upon articular cartilage, although no relevant biomechanical reports are to be found in the literature. It is established that increased stress on articular cartilage causes increased release of degradative enzymes, at least

Fig. 21

The relation between the histological grade of degenerative change (0 to 14) and the time, in weeks, since the insertion of the prosthesis. All control hips were normal.

further compromised leading to progressive destruction. In both experimental models of degenerative arthritis and in human material, the chondrocytes appear to increase their rate of synthesis in order to replace the lost glycosaminoglycans (Ehrlich *et al.* 1975). Although not studied in this present series, the retention of metachromatic staining around chondrocytes supports the idea that increased synthesis was occurring.

The cause of the early ingrowth of pannus is not known, but it does seem to be a uniform response to degradative processes within the joint. Bone remodelling in the subchondral region seems to be in response to new mechanical demands arising from the presence of a metallic femoral head (Radin 1976). There is little available information on the role of synovial fluid in lubrication or in nutrition of articular cartilage after hemiarthroplasty. Changes in these important physiological functions may also contribute to degeneration.

Despite the dramatic changes shown to be taking

place in their hip joints, none of the dogs showed pain and all appeared to walk and jump without difficulty. It can be misleading to compare the results of animal experiments and human disease, but some parallels should be pointed out. It is the distinct impression of the authors, although it is not well documented in the literature, that after hemiarthroplasty of the human hip, the cartilage of the acetabulum is never completely normal. A sufficiently long follow-up shows the bony acetabulum, and hence the cartilage interval, always corresponding to the outline of the femoral head. This would indicate that the changes here reported in dogs may be similar to the reaction in human hips.

It must again be emphasised that this report is not meant to discredit the value of hemiarthroplasty in the human patient, when this is properly carried out for the correct clinical indications. It aims to describe, and to begin to explain, what happens when cartilage articulates against metal.

This investigation was supported by a grant from the Medical Research Council of Canada.

REFERENCES

- Ehrlich MG, Mankin HJ, Jones H, Grossman A, Crispen C, Ancona D. Biochemical confirmation of an experimental osteoarthritis model. *J Bone Joint Surg [Am]* 1975;57-A:392-6.
- Ehrlich MG, Mankin HJ, Jones H, Wright R, Crispen C, Vigliani G. Collagenase and collagenase inhibitors in osteoarthritic and normal human cartilage. *J Clin Invest* 1977;59:226-33.
- Freeman MAR. The pathogenesis of primary osteoarthritis: an hypothesis. In: Apley AG, ed. *Modern trends in orthopaedics-6*. London: Butterworth, 1972;40-94.
- Harris WH, Rushfeldt PD, Carlson CE, Scholler J-M, Mann RW. Pressure distribution in the hip and selection of hemiarthroplasty. In: The Hip Society. *The Hip: Proceedings of the Third Open Scientific Meeting of the Hip Society*. St Louis: CV Mosby, 1975:93-8.
- Hinchey JJ, Day PL. Primary prosthetic replacement in fresh femoral neck fractures: a review of 294 consecutive cases. *J Bone Joint Surg [Am]* 1964;46-A:223-40.
- Jones WN. Mold arthroplasty of the knee joint. *Clin Orthop* 1969;66:82-9.
- Kempson GE, Muir H, Pollard C, Tuke M. The tensile properties of the cartilage of human femoral condyles related to the content of collagen and glycosaminoglycans. *Biochim Biophys Acta* 1973;297:456-72.
- Levitt RL. A long-term evaluation of patellar prostheses. *Clin Orthop* 1973;97:153-7.
- MacIntosh DL. Hemiarthroplasty of the knee using a space occupying prosthesis for painful varus and valgus deformities. *J Bone Joint Surg [Am]* 1958;40-A:1431.
- Mankin HJ, Dorfman H, Lippiello L, Zarins A. Biochemical and metabolic abnormalities in articular cartilage from osteo-arthritic human hips. II: correlation of morphology with biochemical and metabolic data. *J Bone Joint Surg [Am]* 1971;53-A:523-37.
- Moore AT. The self-locking metal hip prosthesis. *J Bone Joint Surg [Am]* 1957;39-A:811-27.
- Neer CS II. Articular replacement for the humeral head. *J Bone Joint Surg [Am]* 1955;37-A:215-28.
- Radin EL. Aetiology of osteoarthritis. *Clin Rheum Dis* 1976;2(3):509-22.
- Rosenberg L. Chemical basis for the histological use of safranin O in the study of articular cartilage. *J Bone Joint Surg [Am]* 1971;53-A:69-82.
- Salvati EA, Wilson PD Jr. Long-term results of femoral-head replacement. *J Bone Joint Surg [Am]* 1973;55-A:516-24.
- Thompson FR. Two and a half years' experience with a vitallium intramedullary hip prosthesis. *J Bone Joint Surg [Am]* 1954;36-A:489-500.