THE SIGNIFICANCE OF THE POSTERIOR CRUCIATE LIGAMENT IN THE STABILITY OF THE KNEE

AN EXPERIMENTAL STUDY IN DOGS

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The significance of the posterior cruciate ligament in the stability of the knee was investigated in dogs and it was compared with that of the anterior cruciate ligament by studying the changes produced in the knee after transection of either ligament. Osteophyte formation and changes in articular cartilage were less prominent after division of the posterior cruciate ligament. A complete longitudinal tear of the medial meniscus was found in eight out of the 10 dogs who had undergone section of the anterior cruciate but in none of the 10 with section of the posterior cruciate. It appears that, in dogs at least, the posterior cruciate ligament is less important than the anterior in the stability of the knee.

Although the number of ruptures of the posterior cruciate ligament is progressively increasing, the significance of this ligament in the stability of the knee has not yet been clarified. Until a few years ago clinical and experimental research was focused on the anterior cruciate ligament, but recently the posterior cruciate ligament has become the subject of interest. Hughston *et al.* (1976, 1980) considered the posterior cruciate ligament as the main stabiliser. By contrast, Dandy and Pusey (1982) reported after a mean follow-up of 7.2 years that many patients with unrepaired tears of the posterior cruciate ligament had maintained good function.

In our experimental work the role of the posterior cruciate ligament in the stability of the knee was investigated in dogs and it was compared to the role of the anterior cruciate. This was done by studying the joint changes which were progressively produced after section of the posterior or anterior cruciate ligament, since it has been proved that there is a direct relationship between the amount of the change and the degree of instability (Marshall and Olsson 1971; O'Donoghue *et al.* 1971). Dogs were chosen as the experimental animals because their knees and cruciate ligaments are similar to those of man anatomically and functionally. In addition, the role of the posterior cruciate ligament *per se* cannot be studied in man because in clinical practice rupture of this

ligament is nearly always accompanied by coincident damage to the capsule or other ligaments.

While animal experiments concerning the significance of the anterior cruciate ligament have been carried out by various authors (Marshall 1969; Marshall and Olsson 1971) such an investigation on the posterior cruciate does not appear to have been reported as yet in the English literature.

MATERIAL AND METHODS

Twenty-one adult mongrel dogs weighing 14 to 20 kilograms were used. Skeletal maturity and absence of deformities were established by anteroposterior and lateral radiographs of both knees. The dogs were divided into 10 pairs, each pair being of the same sex, weight and body shape; while the twenty-first dog was selected for a sham operation.

In all dogs the procedure was performed on the right knee. In one dog of each pair the posterior cruciate ligament was sectioned and in the other the anterior cruciate. The procedure was carried out under general anaesthesia induced by intravenous pentobarbital sodium. The section of either cruciate was performed through a medial parapatellar arthrotomy and the patella was dislocated to the opposite side. With the knee flexed the ligament was cut at the middle of its length by a curved knife. Care was taken not to damage the articular cartilage or other structures of the joint. After the section, the posterior or anterior drawer sign became positive. The operation was completed by closure of the joint in two layers (capsule and skin). The leg was not immobilised. The same procedure was followed for the sham operation where arthrotomy only was performed. The left knee of all animals remained intact to serve as a control.

All dogs were housed in an area measuring 150 square metres so that they could run and jump. They were clinically checked daily until wound healing and weekly thereafter.

The dogs were killed by an overdose of intravenous pentobarbital sodium: two dogs (one pair) at four months, four (two pairs) at five months, and 14 (seven pairs) at six months after section of the cruciate ligament. The dog with a sham operation was killed six months after the operation.

Immediately after death the range of movement and the stability of the knee were examined. The knee joints of both legs were then

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Fig. 1

Fig. 2

Femoral (Fig. 1) and tibial (Fig. 2) condyles of a dog. The black area indicates the site from where the bone blocks were taken for histology.

removed, radiographed, and carefully dissected and inspected. Bone blocks with covering articular cartilage were taken for histological examination from the femoral condyles, tibial plateau and patella from the right and the left knees (Figs 1 and 2). Specimens were also taken from the capsule. These specimens were fixed in a 10 per cent solution of neutral formalin. The bone blocks were decalcified in a 10 per cent solution of nitric acid. All specimens were embedded in paraffin wax, cut into sections seven micrometers thick, and stained with haematoxylin and eosin.

RESULTS

The dogs started bearing weight on the operated limb two to four days after the operation. The wound healed uneventfully in 18 of the dogs; in two there was a slight delaying in skin healing. Haemarthrosis occurred in one dog after division of the posterior cruciate ligament; this was drained by aspiration. In none of the dogs was there any evidence of infection.

All dogs, except the one which had had the sham operation, limped after operation. The limp decreased progressively and became minimal by the end of the study.

The posterior or anterior drawer sign could be demonstrated during the whole period of study in all knees with transected posterior or anterior cruciate ligaments respectively. In most of the dogs in whom the anterior cruciate had been cut there was also a clicking sound which was elicited during flexion toward the end of the study.

Radiographic findings. In three dogs killed six months after section of the anterior cruciate ligament, osteophytes at the lateral femoral condyle (intercondylar fossa) could be demonstrated in the anteroposterior radiographs (Fig. 3). In another, killed four months after division of the anterior cruciate, osteophytes were visible at the tibial spine. No osteophytes could be seen radiologically in the knees of the dogs which had undergone section of the posterior cruciate ligament or the sham operation. No special radiographs (for example, tunnel views) were taken.

Macroscopic findings. In both groups the severed ligament

Fig. 3

Radiograph of both knees of a dog killed six months after division of the anterior cruciate ligament. An osteophyte is clearly seen at the lateral femoral condyle of the right knee.

had atrophied and only remnants at the site of origin were detected.

In eight out of the 10 dogs with sectioned anterior cruciate ligaments a complete longitudinal tear (bucket handle) of the medial meniscus was found (Fig. 4). In most of them the meniscus was totally disorganised. A

Fig. 4

A bucket-handle tear in the medial meniscus in a dog killed six months after anterior cruciate ligament section.

complete longitudinal tear of the medial meniscus was found even in the dog killed four months after section of the anterior cruciate. In the other two animals, superficial breaks of the medial meniscus were noticed, and such breaks appeared also in the lateral meniscus of three dogs of the same group. In none of the dogs with section of the posterior cruciate ligament was a tear of the meniscus encountered. In only one were superficial breaks of the medial meniscus noticed (Fig. 5) while in another such changes were found in the control joint as well.

Fig. 5

Superficial breaks on the medial meniscus of a dog killed six months after posterior cruciate ligament section.

Large osteophytes were observed in the operated knees of all dogs with section of the anterior cruciate ligaments even in that killed at four months. There were two standard locations of osteophytes in this group. The first, seen in all 10 dogs, was at the intercondylar margin of the lateral femoral condyle near the trochlea where the anterior cruciate enters the intercondylar fossa (Fig. 6). The second one, present in eight dogs, was located at the posterior edge of the medial tibial plateau (Fig. 7). Here the large osteophyte produced marked increase of the anteroposterior diameter of the medial tibial condyle. In the dogs with section of the posterior cruciate the

osteophyte formation was much less striking. Small prominences were seen in only five dogs at the intercondylar margin of the medial femoral condyle and were considered as osteophytes only after histological confirmation.

No gross changes were noticed in the control joints, except in one where the anterior cruciate ligament had completely disappeared, probably due to an old injury, and this was accompanied by osteophytic formation, marked changes in the articular cartilage and a longitudinal tear of the posterior horn of the medial meniscus. In the dog that had had the sham operation both knees were macroscopically normal.

It was evident when comparing the two dogs of each pair that the macroscopic changes were much less severe in the dog with section of the posterior cruciate ligament. **Histology.** Osteophytes and changes in the articular cartilage were the main histological findings.

The osteophytes in the dogs with severed anterior cruciate ligaments were impressive under the microscope. In the great majority they were large, had completely merged with the pre-existing bone and were incorporated into the femoral or tibial condyles (Figs 8 and 9). They were covered with fibrocartilage and their trabeculae had a more irregular arrangement than the normal bone. Apart from the osteophytes at the lateral femoral condyle and the posterior edge of the medial tibial plateau which were macroscopically evident, histological examination in this group revealed also osteophytes at the tibial spine (five dogs), the medial and lateral edges of the tibial plateau (four dogs) and the medial femoral condyle (two dogs). The osteophytes in the dogs with section of the posterior cruciate ligament were microscopically small, immature and without (or with very little) continuity with the pre-existing bone (Fig. 10). The histological examination simply confirmed the presence of osteophytes at the medial femoral condyle in five dogs and revealed a small osteophyte at the tibial spine in another. No osteophytes were discovered in the control joints except the one with no anterior cruciate ligament.

Fig. 6

Fig. 7

Figure 6 Large osteophyte macroscopically seen at the lateral femoral condyle of a dog killed five months after division of the anterior cruciate ligament. Figure 7 Osteophyte formation macroscopically seen at the posterior edge of the medial tibial condyle of the right knee of a dog killed six months after section of the anterior cruciate ligament.

Fig. 8

Fig. 9

Figure 8—Histological section of the femoral condyles of a dog killed five months after division of the anterior cruciate ligament. Large osteophyte is protruding in the intercondylar groove. It has already established complete communication with the pre-existing bone (haematoxylin and eosin, $\times 3$). Figure 9—Histological section of the medial tibial condyle (posterior edge) of a dog killed six months after section of the anterior cruciate ligament. Large osteophyte communicating with the pre-existing bone is shown (haematoxylin and eosin, $\times 3.7$).

Fig. 10

A small osteophyte at the medial femoral condyle of a dog killed six months after section of the posterior cruciate ligament. There is no complete communication with the preformed bone (haematoxylin and eosin, $\times 12$).

In the articular cartilage, two types of changes were taken into account and evaluated: the morphological features and arrangement of the chondrocytes; and the integrity of the articular surface. Both types were classified according to McDevitt, Gilbertson and Muir (1977). The chondrocytic changes were seen at the articular cartilage of the femur, tibia and patella and were classified into three grades: increased cell density (Figs 11 and 12), occasional cell "doublets", and clones of two or more cells. The changes in the articular surface were mainly seen at the tibial plateau, towards the tibial spine, and were classified into five grades: intact surface, slight roughening, roughening and small clefts, roughening and fissures in the middle zone, and total disruption of the surface layer (Figs 13 to 15). When comparing the two dogs of each pair it was found that the changes in the articular cartilage were less severe in the dog with a damaged posterior cruciate ligament than in the other.

Fig. 11

Fig. 12

Figure 11—Articular cartilage from the medial tibial condyle of a dog killed six months after posterior cruciate ligament section. There is roughening of the articular surface and an increased cell density. Figure 12—The control joint for comparison (haematoxylin and eosin, $\times 44$).

Fig. 13

Fig. 14

Fig. 15

Articular cartilage of the tibial condyles of three dogs killed six, four and six months respectively after division of the anterior cruciate ligament. Figure 13—Roughening and small clefts. Figure 14—Roughening and fissures. Figure 15—Disruption of the surface (haematoxylin and eosin, $\times 11$).

However, the difference between the two groups was not as striking as the difference in osteophyte formation. Slight changes in the articular cartilage were noticed at the control joint of five dogs, four of which belonged to the anterior cruciate group. No microscopic changes were seen in the knees of the dog that underwent the sham operation.

In all dogs a thickening of the capsule was histologically present at the operated knee.

DISCUSSION

Meniscal tears, osteophyte formation and changes in the articular cartilage were the main findings of this experimental work.

In eight out of 10 dogs with section of the anterior cruciate ligament a complete bucket-handle tear of the medial meniscus was found. None of the dogs with section of the posterior cruciate showed such tears. Meniscal tears in dogs after experimental division of the anterior cruciate ligament have been reported by others (Marshall and Olsson 1971; Gilbertson 1975; McDevitt *et al.* 1977). It has been also reported that rupture of the anterior cruciate combined with tears of the menisci are seen in dogs clinically (Tirgari and Vaughan 1975). Furthermore, the coexistence of an anterior cruciate rupture with a longitudinal tear of the medial meniscus is often encountered in men (Palmer 1938; Kennedy, Weinberg and Wilson 1974; Smillie 1978; McDaniel and Dameron 1980). This experimental work confirms the view that in dogs at least it is the rupture of the anterior cruciate which occurs first and the meniscal tear is a late result of this injury.

The tear of the medial meniscus should be attributed to the rotatory instability, which is progressively produced after section of the anterior cruciate ligament. The medial collateral ligament, in an effort to prevent anterior displacement of the tibia, then becomes lax and subsequently cannot prevent lateral rotation of the tibia, as has been described in man (Fowler 1980). Meniscal tear

does not follow section of the posterior cruciate ligament probably because injury to this ligament does not produce rotatory instability. That rupture of the posterior cruciate does not lead to rotatory instability has been reported in human knees (Hughston *et al.* 1976). Trickey (1980) also recently suggested that untreated posterior instability in man "does not predispose to meniscal tears or to late osteoarthritis".

Osteophytes after injury of the anterior cruciate ligament in dogs have been observed experimentally (Marshall 1969; Marshall and Olsson 1971; Gilbertson 1975) and in clinical practice (Tirgari and Vaughan 1975). They are attributed to the instability of the knee. The mechanism of their production is as yet uncertain. Probably the repeated stretching of the synovial membrane at its insertion may lead to vascular proliferation and therefore to new bone formation. This means that initially a mechanical factor exists resulting directly or indirectly in a vascular one (Gilbertson 1975).

Osteophytes, which were small, immature, and present in only one location, were discovered in only six dogs with cut posterior cruciate ligaments. Large, mature osteophytes were noticed in all dogs after division of the anterior cruciate and were present in many locations.

Section of the posterior cruciate ligament also produced less severe changes in the articular cartilage than did section of the anterior ligament, though the difference was not so impressive as it was with the osteophytes. It was also noticed that there was no direct relationship between these changes and the osteophyte formation. It must be admitted, however, that the evaluation of the articular cartilage changes is not as easy as in the case of the osteophytes.

From the findings of this study it appears that section of the posterior cruciate ligament in dogs produced minimal and less pronounced changes in the knee than did section of the anterior cruciate. It may therefore be assumed that the role of the posterior cruciate ligament in the stability of the knee in these

animals is less important than that of the anterior cruciate ligament. It seems very likely that this is due to the fact that division of the posterior cruciate ligament produces very little rotatory instability or none.

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