ANTERIOR CRUCIATE LIGAMENT PROSTHESIS IN THE DOG

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THESIS

ABSTRACT

ANTERIOR CRUCIATE LIGAMENT PROSTHESIS IN THE DOG

by Bhola Nath Gupta

Replacement of the anterior cruciate ligament with a synthetic prosthesis was performed on 10 experimental dogs. The prosthesis consisted of a cord of braided dacron coated with silicone rubber as insulating material. The outer covering of silicone rubber was made radiopaque by incorporating barium sulfate.

After the 4th postoperative week, all dogs gained functional use, without lameness, of the leg with a prosthetic anterior cruciate ligament. Disuse atrophy of the muscles of the hind legs was not noticed in any case. Very slight to moderate anterior drawer movement of the tibia could be produced when the dogs were anesthetized. Rupture of the prostheses occurred in 7 dogs between the 2nd and 4th postoperative month. Confirmatory diagnoses were obtained by radiographs and post-mortem examination.

At the time of necropsy, the joint operated on appeared identical to the control joint, with the exception of some thickening of the joint capsule and, in a few cases, a cloudy appearance of the synovia. There was regeneration of the anterior cruciate ligament in 3 dogs. Histologically, the regenerated ligaments were identical to normal cruciate ligaments; however, evidence of chronic foreign body tissue reaction was present.

Superficial horizontal flaking of the articular cartilage, vertical splitting of the medial meniscus and chronic inflammatory foreign body tissue reaction of the joint capsule were observed microscopically.

Breaking strengths of normal cruciate ligaments, fascia lata, skin and braided dacron were determined on a tensile testing instrument; the average breaking load for the anterior or posterior cruciate ligament was similar. The breaking load of the braided dacron was less than for the anterior cruciate ligament, and it decreased after moist heat sterilization.

It was concluded that the prosthesis made of dacron covered with silicone rubber was unsatisfactory due to loosening of the coating and rupture of the dacron, even though the prosthesis appeared to function in a satisfactory manner initially.

ANTERIOR CRUCIATE LIGAMENT

PROSTHESIS IN THE DOG

By

Bhola Nath Gupta

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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Dedicated to my brother

Teknarayan

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INTRODUCTION

Rupture of the anterior cruciate ligament is the most common serious derangement of the canine stifle joint. Recent advancements in canine surgery have made repair of the ligament possible, but the exploration for better ligament repair and for more sophisticated techniques remains a major challenge. While the necessity for surgical repair of the ligaments of the stifle joint has been debated for a number of years, the fact that ruptured cruciate ligaments produce functional disturbances, which often predispose the joint to trauma and subsequent osteoarthritis, cannot be denied.

The usual methods of repairing the cruciate ligaments are well known. Strips of fascia, skin, ligament, tendon, and synthetic materials like nylon, teflon or dacron have been used for ligament replacement in experimental and clinical cases by different workers.

This study was designed to determine the tensile strength of cruciate ligaments, skin, fascia, and a synthetic material selected for its replacement. A clinical evaluation of a prosthesis for the anterior cruciate ligament was also conducted in experimental animals. Laboratory evaluations included: histopathologic study of the different structures involved and radiologic and hematologic studies after using the prosthesis.

The synthetic material used in this study to replace the anterior cruciate ligament in the dog was braided dacron* (polyethylene glycol terephthalate) insulated with silicone rubber.**

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*Dacron Round Suture, Size D 1-6, American Silk Sutures, Inc., Roslyn Heights, N.Y.

**Silastic,[R] Dow Corning, Midland, Michigan.

REVIEW OF THE LITERATURE

Veterinary Literature

Among the earlier references to rupture of the anterior cruciate ligament in veterinary literature was a case recorded by Brook (1932) in which a 9-1/2-year-old Scottish Terrier was struck by a car in its early puppyhood. Following the accident, the dog had intermittent pain in the stifle joint and did not use the leg completely. On physical and radiographic examinations, a diagnosis of ruptured anterior cruciate ligament was made which was confirmed on post-mortem examination.

In a discussion of the internal derangement of the stifle joint in dogs, Paatsama (1952) cited the following authors: Möller and Frick (1899), Müller (1908), Uebele (1910), Händel (1910), Carlin (1926), Schwerdtfeger (1937), Forssell (1938), and Jarosch (1940).

According to Schroeder and Schnelle (1936), rupture of the cruciate ligaments may not be repaired completely. They reported that fixation of the joint for 3 to 6 weeks resulted in good functional recovery. A padded bandage was passed around the anterior surface of the proximal end of the tibia and fastened to the posterior bar of a Thomas splint. The leg was fixed with forward lift of the thigh towards the anterior bar and backward pull on the proximal end of the tibia to the posterior bar. For rupture of both cruciate ligaments, the same plan was followed. In addition, the tarsal joint was also fixed in more acute flexion.

Osteoarthritis of the stifle joint was reported by Schnelle (1941). Injuries to the ligaments within the joint which allowed extra motion, caused increased wear of the joint surface and resulted in osteoarthritis. He further stated that the stifle joint was the most frequent site for arthritis.

During 1941, Schroeder and Schnelle again reported a case of ruptured anterior cruciate ligament. Their conservative treatment consisted of fixing the limb in a semiflexed position under moderate traction in a Thomas splint for 3 to 6 weeks.

Nilsson (1949) published a detalied account of the lesions of the menisci and osteoarthritis on the basis of etiology, pathology, diagnosis, therapy and the prognosis of the stifle joint injuries.

Paatsama (1952) was the first to closely study canine stifle injuries. He devised a method for replacement of the ligament with a strip of fascia. This technique has become accepted universally, although more recently different materials have been suggested for the replacement. A 1-cm. wide strip of fascia lata was used as a substitute for the anterior cruciate ligament. The fascial strip retaining its distal attachment was pulled through the femoral and tibial tunnels and was then slightly twisted. The free end of the strip was sutured to the insertion of the straight patellar ligament on the tibial tuberosity. The leg was fixed in a Thomas splint for 15 days. In studying this problem experimentally in dogs, he incised the anterior cruciate ligament and observed the resulting clinical and pathologic changes. Progressive osteoarthritic changes occurred in the joint which were readily observed after 2 to 3 weeks.

Autogenous and homogeneous transplantation of the whole stifle joint was performed in dogs by Herndon and Chase (1952). In this experiment, the deeper layers of cartilage cells remained viable but some degeneration of the articular cartilages of the femur and tibia resulted. Aseptic necrosis began superficially and peripherally to the weight bearing surface of the joint. These cartilages were eventually replaced by fibrous tissue. They concluded that good results may be expected in non-weight bearing joints.

Paatsama (1954) further made a survey of the structures of the meniscus from the canine stifle joint. He obtained menisci from dogs having internal derangements of the stifle joint and examined them grossly as well as microscopically. In experimental dogs, the cruciate ligaments and menisci were removed partially or completely to study the pathologic changes due to the development of osteoarthritis. Large dogs developed the pathologic changes in a much shorter time than did the smaller ones. Increase of chromotropic substance, hyalinization, slit formation, fatty degeneration and colliquative necrosis were found in old dogs, particularly in cases of joint injuries. These changes were observed within 50 days after cutting the cruciate ligament.

New tendons and articular ligaments were prepared from fascial strips by Markowitz (1954). He reported that dog fascia was thinner and more difficult to manipulate than human fascia. An anterior cruciate ligament was prepared from a fascial strip and passed through the oblique tunnels drilled into the femur and tibia. The free ends were stitched to the periosteum and bone with silk.

Singleton (1957) briefly described the general and functional anatomy of the stifle joint in the dog. Methods for the diagnosis and treatment of some stifle abnormalities were also included with particular reference to anterior cruciate ligament repair. He used a 1-cm. wide strip of fascia lata to repair the ruptured anterior cruciate ligament. The fascial strip was rolled in gauze and soaked in physiological saline solution until used. It was threaded through the first tunnel made in the femoral condyle, passed across the joint and through the second tunnel in the tibial crest. The free end of the strip was secured by 2 screws, one of which passed through the tunnel and the other through the ligament as it emerged from the distal end of the tibial tunnel. The limb was placed in a plaster cast for 2 weeks. Usually, the dogs started using the limb 3 weeks after removal of the cast.

A thin strip of skin from the parapatellar area was used by Gibbens (1957) as a substitute for the anterior cruciate ligament. The strip was placed in 1:1000 quaternary ammonia solution to inhibit hair growth. The strip of skin was passed through the joint and the proximal end was turned downward along the lateral collateral ligament. The joint was slightly flexed and the transplant was pulled taut and anchored with steel wire to the lateral collateral ligament and fascia above and below the joint. The leg was kept in a Thomas splint for 14 days. Satisfactory recovery was reported after 6 months.

Titkemeyer and Brinker (1958) used a 3/8-inch wide fascial strip for replacement of the anterior cruciate ligament. The primary skin incision was continued medially below the joint. The distal attachment of the fascial strip remained intact and the free end of the strip was passed through the drilled holes in the femur and tibia and securely sutured to the patellar (quadriceps femoris) tendon. Good results were reported after keeping the limb in a Thomas splint for 3 weeks.

Rathor (1959) reported on a comparative study using the tendon of the peroneus longus muscle, skin and strips of fascia lata as substitutes for the anterior cruciate ligament. After surgery the leg was fixed in a Thomas splint for 3 weeks. On clinical examination after 8 to 9 weeks, most of the dogs had a normal gait while walking or running but a moderate degree of anterior drawer movement was noticed in all dogs. In some cases, arthritic changes were seen and the articular cartilage underwent aseptic necrosis. Rathor concluded that the transplantation of tendon in the stifle joint was superior to fascia or skin.

Chastain (1959) used a strip of skin for the repair of anterior cruciate and medial collateral ligaments in experimental dogs. The skin strip was kept in 1:1000 aqueous quaternary ammonia solution until used. The femoral tunnel was drilled from the medial side at the origin of the medial collateral ligament. The skin strip was passed through the femoral and tibial tunnels. The distal and proximal ends of the transplant were sutured with femoral and tibial insertions of the medial collateral ligament, respectively. The leg was immobilized in a Thomas splint for 14 days.

Johnson (1960) described an operation in which braided nylon was substituted for the anterior cruciate ligament. The prosthesis consisted of several strands of braided nylon which were passed through holes drilled in the femur and tibia. The proximal and distal ends of the prosthesis were anchored to Sherman type vitallium screws suitably fixed transversely to the lateral femoral condyle and the medial surface of the tibia below the tibial tuberosity. The leg was immobilized in a Thomas splint for 2 to 3 weeks.

Leonard (1960) modified Paatsama's technique of fascial replacement for rupture of the anterior cruciate ligament. The tibial hole was drilled at the tibial insertion of the anterior cruciate ligament and was directed toward the flat surface of the tibia just medial to the tibial crest and slightly distal to the medial condyle. The joint capsule and the fascial opening were closed with stainless steel wire. The leg was not splinted.

Emery and Rostrup (1960) used teflon fabric woven material for the replacement of the anterior cruciate ligament in experimental dogs. After passing the teflon prosthesis through the femoral and tibial tunnels, the upper end of the teflon was knotted to itself and the lower end was stapled to bone on the medial side and then sutured to itself with silk. Using this technique, slight drawer movement was detected postsurgically. The leg was immobilized in a single hip spica for 3 weeks. After 3 months, anterior drawer movement was still present in all operated stifle joints. At post-mortem examination, fraying of the teflon was noticed in some dogs.

Berge and Westhues (1961) reported the use of braided nylon as the anterior cruciate ligament prosthesis. A set of 2 converging tunnels, 1 cm. apart, were drilled into the femoral and tibial condyles laterally and medially, respectively. The 2 sets of tunnels converged at the origin and insertion of the anterior cruciate ligament. Two to 4 folds of nylon filament were passed through the tibial tunnel, then to the femoral tunnel and again to the 2nd femoral tunnel and finally pulled through the 2nd tibial tunnel. The ends were pulled taut and a few square knots were placed medially.

In dogs and cats, Leighton (1961) used a strip of skin to replace the ruptured anterior cruciate ligament. After passing the skin strip through the femoral and tibial tunnels, the free ends were sutured to fascia with wire. The leg was fixed in a Schroeder-Thomas splint. A reasonably functional joint resulted. In his experience, skin proved to be better than fascia transplantation.

Foster _et al_. (1963) reported on closed joint repair of anterior cruciate ligament rupture in dogs. A 1/4-inch wide strip of skin was taken from the edge of the incision and used as the prosthetic ligament without opening the joint capsule. A pin was directed ventromedially so as to drill through the lateral condyle of the femur into the joint cavity and exit from the tibia, medial to the tibial crest. A strip of skin was passed through femoral and tibial tunnels. A 2nd hole was drilled through the tibial crest and the distal end of the strip was passed through it. Finally, both ends of the strip were sutured on the lateral aspect of the stifle joint.

Vaughan (1963) replaced the anterior cruciate ligament with fascia, skin and nylon separately on 3 groups of dogs. No external support was provided to the operated limb. The dogs were observed for only 3 months. Radiographs of the treated joints were taken every month, and no untoward bone or joint changes were detected. He made a comparative study of 3 types of prostheses and found that the whole thickness skin was superior to either fascia or nylon as a replacement material for the anterior cruciate ligament.

Ormrod (1963) made reference to an ingenious method of Singleton for repair of the anterior cruciate ligament rupture. The latter used a multistrand monofilament nylon prosthesis without recourse to screws. The ends of the nylon strands were passed through converging tunnels drilled in the lateral femoral condyle and emerging at the proximal attachment of the anterior cruciate ligament into the intercondyloid fossa. A loop was thus formed that bore against the lateral surface of the bone when the prosthesis was drawn tight. A 2nd system of tunnels was drilled from 2 points on the medial aspect of the tibia below the level of the tibial tuberosity. The 2 tunnels converged at the normal point of distal attachment of the anterior cruciate ligament. The ends of the loop were passed through these tunnels and tied against the bone.

Stainless steel buttons were used by Ormrod (1963) to hold the multistrand monofilament nylon as the anterior cruciate ligament prosthesis. Both ends of the monofilament nylon, previously passed through the 2 holes of a small stainless steel button, were threaded through the femoral tunnel and drawn anteriorly through the open stifle joint. This button served the purpose of a toggle against the lateral femoral condyle, laterally. The free ends of the prosthesis were passed through the tibial tunnel and finally through a transverse tunnel below the tibial crest. Another stainless steel button was threaded onto the nylon filaments and tied off against the button on the lateral side of the tibia.

Pearson and Garret (1964) used a modification of Paatsama's technique employing a strip of fascia lata. They did not feel it essential to fix the leg in a Thomas splint when nonabsorbable suture material had been used to close the joint capsule and fascia.

Teflon mesh was used by Butler (1964) as a prosthetic material for repair of ruptured anterior cruciate ligaments. In this experiment 9 dogs (4 were clinic cases) and 6 cats (1 was a clinic case) were used. A teflon strip was passed through femoral and tibial tunnels. Its proximal end was sutured with stainless steel wire to the tendon of origin of the long digital extensor muscle laterally. The distal end of the teflon strip was then passed through the transverse hole made through the tibial crest and was brought forward and around the anterior aspect of the tibial crest to a point where it originally entered the hole on the medial aspect. At this point the teflon was tied to itself so as to anchor the distal end of the prosthesis. No external splint was applied. Butler mentioned that the teflon prosthesis was completely infiltrated with fibroblasts and connective tissue fibers between the teflon fibers and that 6 months after surgery it appeared as a smooth glistening ligament.

Strande (1964) made a study of the replacement of the anterior cruciate ligament in the dog by the tendon of flexor digitalis pedis longus. The tendon was dissected free and cut through outside the medial malleolus. The free end of the tendon was passed through the tunnels made in the tibia and femur, respectively, and finally sutured to the lateral collateral ligament with size 00 silk. The leg was fixed in a Thomas splint for 14 days.

Leighton (1964) reported the rupture of the feline anterior cruciate ligament, but this condition was not found as commonly as in the dog. He used strips of skin for repair, followed by immobilization with a Thomas splint for 1 week.

A drill guide for use in repair of ruptured cruciate ligaments in the dog was designed by Brinker _et al_. (1965). They concluded that it aided materially in accomplishing the main objective of replacing the substitute for the ruptured anterior cruciate ligament in its proper anatomical position.

In an article pertaining to the diagnosis of stifle lameness in the dog, Keller (1965) pointed out that etiological factors such as luxation or subluxation, fractures, torn ligaments, congenital abnormalities and chronic arthritis must be considered. He also described the different methods of examination of the stifle joint.

Dueland (1966) introduced a new surgical technique for replacement of the anterior cruciate ligament in dogs based upon a procedure developed for man by Jones (1963). Dueland used a strip of tissue composed of quadriceps tendon, a V-shaped piece of anterior patella and the middle third of the patellar tendon to replace the anterior cruciate ligament. A 1/4 to 3/8-inch wide strip of tendon was separated by 2 parallel incisions. This strip was left attached to the patella in the middle and tibia distally. A rotary dental drill unit was used to cut a wedge-shaped piece of bone from the anterior middle third of the patella without disturbing the articular surface. This new ligament was passed through the drilled hole in the femur. Ideally the patellar piece wedged firmly within the femoral tunnel. The free end of the strip was sutured to the lateral femoral fascia. The leg was fixed in a Thomas splint for 4 weeks. Functional recovery was achieved in 5 to 12 weeks.

Ryan and Drompp (1966) also used the patellar tendon to replace the anterior cruciate ligament in dogs. They used the same technique as described by Dueland (1966). After surgical operation, the leg was fixed in a cylinder cast of wire screen.

Strande (1966a, b) made a further report for repair of the anterior cruciate ligament using the patellar tendon and a triangular piece of patella. He employed the same technique as developed by Jones (1963). The free end of the newly constructed ligament was sutured to the lateral collateral ligament with size 00 stainless steel wire. The limb was immobilized in a Thomas splint for 14 days.

Childers (1966) described a simple surgical procedure for repair of the ruptured anterior cruciate ligament without opening the joint capsule. After making skin incision, 10 interrupted Lembert inverting sutures were placed 5 mm. apart in the underlying fascia over the lateral surface of the stifle joint. Chromic cat gut was used and maximum tension was applied over the sutured fascia. The use of the Thomas splint to fix the leg after surgery was advised. Encouraging results have been reported using this technique.

The Tensile Strength of Selected Body Tissues

Gratz (1931) first reported on the tensile strength and elasticity of human fascia lata. Test material was obtained from the thighs of patients who were at the time undergoing operations. A small piece of fascia lata was kept in saline-moistened gauze and the tensile strength determined on a standard tension machine used for the general testing of engineering materials. Elapsed time between removal of the test piece of fascia lata and actual testing of the material varied from 2 to 18 hours. A 66-pound pull was enough to break an 0.6 inch wide and 0.014 inch thick piece of fascia lata.

Mason and Allen (1941) studied extensively the rate of tendon healing in dogs. Their evaluations were based on the tensile strength of the healing tendon. Tendons of the extensor carpi radialis and flexor carpi ulnaris muscles were divided transversely and then sutured with silk. The leg was immobilized in a plaster cast to hold the sutured tendon in relaxation. The tensile strength of the sutured tendon was determined on a spring scale at intervals varying from 2 to 68 days.

Kernwein (1942) implanted tendon into bone in dogs and then measured its tensile strength. The tendon of the extensor carpi radialis longus muscle was transplanted bilaterally into the radius. The breaking strength of its natural insertion into the bone was also tested and more than 50 pounds was required to separate the tendon from bone. The musculo-tendinous junction separated in some dogs with a pull of 27 to 38 pounds. It was deduced that the tensile strength of the normal physiological fixation of the tendon to bone was greater than the musculo-tendinous junction.

Mathur and McDonald (1949) determined the breaking strength of the lateral and medial menisci of the knee of man and dog. They used a specially designed instrument which held the ends of the meniscus with metal clamps. One end was fixed to the horizontal bar on the top of the instrument and weights were added gradually to the platform at its bottom. In most of the cases, the medial meniscus of the stifle joint of dogs was found weaker than the lateral one. The breaking strength of the lateral and medial menisci varied from 21 to 60 pounds.

Harrison and Adler (1956) tested the tensile strength of calendered weave of nylon before and after use as a vascular prosthesis in experimental dogs. The tensile strength was determined with an "Instron" apparatus. There was a loss of 83% of tensile strength of nylon after 6 months' use. They stated that,

> "One would expect hydrolysis to occur when the material is subjected to the body fluids and slightly elevated temperatures over a long period of time. Proteolytic enzymes might aid in the hydrolysis by attacking the amide group of the nylon polymer. The loss in strength of nylon is thought to be due more to the chemical degradation than the physical force to which it is subjected."

Gort and Rostrup (1959) tested the breaking strength of the medial collateral ligament of canine stifle joints. They used teflon fabric for its reconstruction. The breaking strength of normal and reconstructed medial collateral ligaments was determined on a Baldwin Hydraulic Tester

No. 6-35. The femur and tibia were amputated from the proximal and distal third, respectively. The joint capsule and all the ligaments of the stifle joint were divided except the teflon prosthetic ligament in one limb and the medial collateral ligament of the opposite limb.

The tensile strength of the canine anterior cruciate ligament was tested by Emery and Rostrup (1960). The hind legs were amputated from the proximal and distal third of the femur, tibia, and fibula, respectively. The soft tissues around the bones were excised and all the femoro-tibial attachments were divided except the anterior cruciate ligament. Its breaking strength was tested with a Baldwin Hydraulic Tester No. 6-35. The ligament was torn free from its tibial attachment when 70 to 100 pounds of tension were applied.

An attempt was made by Ryan and Drompp (1966) to evaluate the weight which would be required to break the normal anterior cruciate ligament of dogs. In 3 cases, a total weight of 181 pounds was not sufficient to break the ligament. Unfortunately, the weight platform of the testing machine, used in the experiment, could not hold more than 181 pounds. However, they were able to determine the breaking strength of reconstructed anterior cruciate ligament which varied from 4 to 79 pounds.

Pathologic Changes

Pathologic changes in the stifle joint following rupture of the cruciate ligaments have been studied in both experimental and clinical cases. Experimentally, the first degenerative changes after sectioning of the anterior cruciate ligament were observed within 25 days and mild to severe osteoarthritis within 51 to 78 days (Paatsama, 1952). In larger and more active breeds, these changes were markedly extensive (Brinker, 1965).

Usually the joint fluid increased in amount and xanthochromia was present due to hemorrhage. The volume of the joint fluid continued to increase in the next several weeks and the fluid became straw colored. The ends of the ruptured ligament appeared rounded and shrunken. The articular cartilage became dull, granular and yellowish white in appearance. Elevated osteoid tissue or fibrocartilage pearls called osteophytes may have been present on each side of the trochlear ridges. The synovial membrane was markedly congested and the menisci may have begun to show evidence of abnormal wear and tear (Brinker, 1965).

After several months without treatment, the joint capsule became thickened. The synovial membrane was markedly congested and sometimes appeared villous. The articular cartilage became more granular, duller, and elevations of fibrocartilagenous osteoid tissue were more extensive and larger. Evidence of abnormal wear was present on the weight bearing surface of the articular cartilage covering the condyles and the menisci. The medial meniscus usually showed more wear than the lateral one (Nilsson, 1949; Brinker, 1965).

After long-standing rupture of the anterior cruciate ligament, chronic proliferative changes of the joint capsule and supporting structures may partially stabilize the joint. The free anterior sliding movement of the tibia may be difficult to demonstrate if stabilization has taken place (Rudy, 1965).

Anatomy of the Cruciate Ligaments

The anatomy of the cruciate ligaments is of great surgical importance for their repair by substitution. As their name implies, they cross each other on both the frontal and sagittal planes (Figure 1). In their

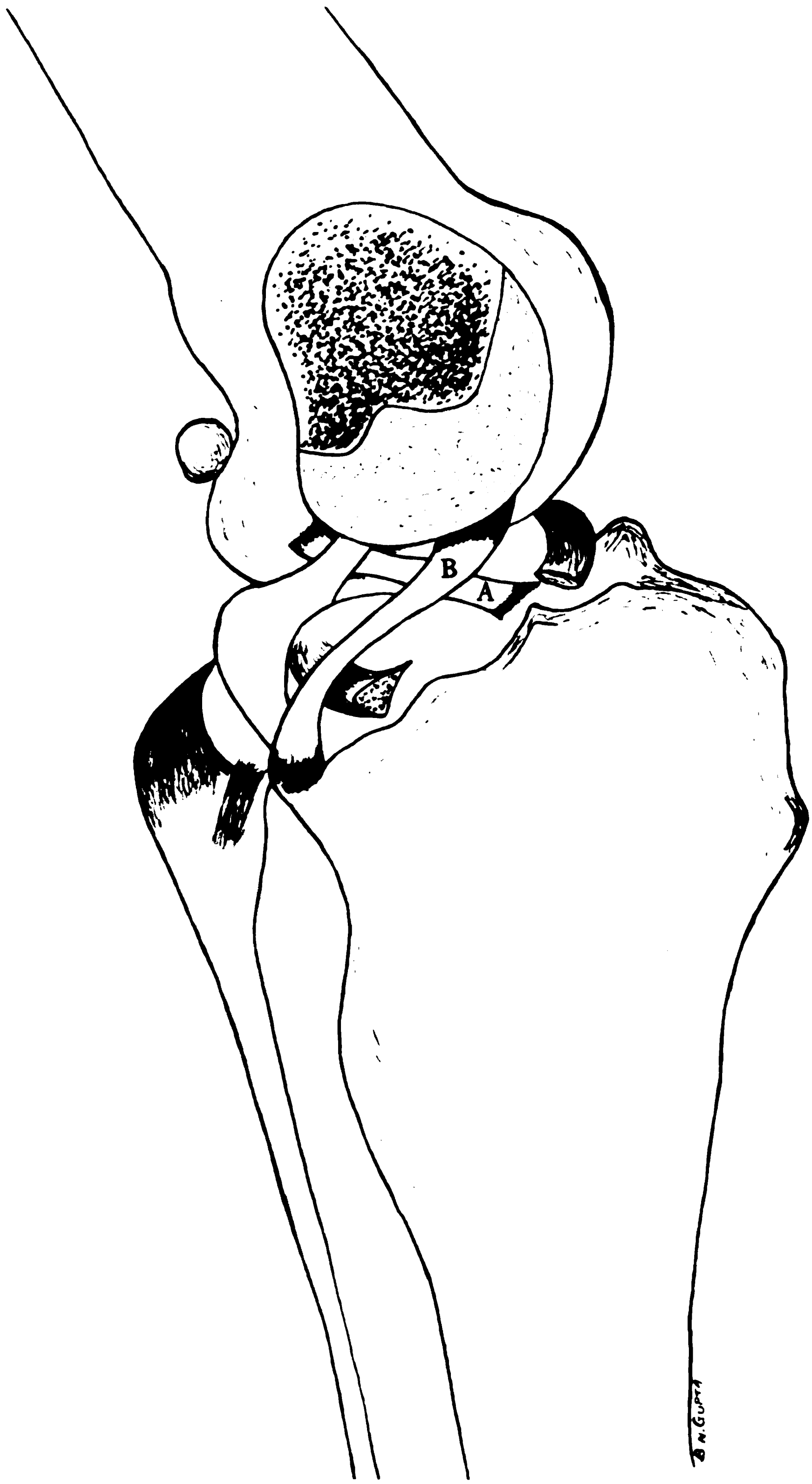

Figure 1. Sagittal section of the stifle joint, showing the attachments of the anterior (A) and posterior (B) cruciate ligaments.

passage from origin to insertion, the ligaments wind around one another by slight twisting, a phenomenon which is more distinct in large than in small breeds (Paatsama, 1952).

The anterior (cranial or lateral) cruciate ligament. This ligament arises by a broad origin from the anterior intercondyloid fossa of the tibia, anterior to the tibial spine and between the anterior horns of the menisci. It passes obliquely and finds insertion on the medial surface of the lateral condyle of the femur. It is crossed by the posterior cruciate ligament medially (Dyce et al., 1952; Rudy, 1965).

The posterior (caudal or medial) cruciate ligament. The posterior cruciate ligament is slightly heavier, stronger and definitely longer than the anterior cruciate ligament. It arises from the medial surface of the popliteal notch of the tibia and is inserted on the lateral surface of the medial femoral condyle. It lies medial to the anterior cruciate ligament (Miller *et al.*, 1964).

These ligaments are 2 powerful intra-articular bands serving to connect the femur with the tibia and thus acting as a central fixation apparatus (Titkemeyer and Brinker, 1958). In flexion, the forward displacement of the tibia is inhibited by the anterior cruciate ligament and bakcward displacement is inhibited by the posterior cruciate ligament (Dyce *et al.*, 1952).

The fact that the cruciate ligaments are set in the joint in both an antero-posterior and a medio-lateral oblique plane accounts for their importance in stabilizing the joint, not only in an antero-posterior plane but also against forces affecting rotation (Paatsama, 1952).

MATERIALS AND METHODS

The 10 dogs used as surgical subjects for this study were of mixed breeds as recorded in TABLE 1. Since they were obtained from a pound, each was kept in isolation for 15 days prior to transfer to the experimental ward. All surgical patients were subjected to a complete physical examination, including general appearance, integumentary, musculoskeletal, circulatory, respiratory, digestive tract, genito-urinary tract, eyes, ears, lymph nodes, tonsils, and mucous membrane. The stifle joint was examined for abnormal movement or evidence of previous injury.

Using a qualitative sugar concentration method (Modified Sheather's Sugar Flotation Technique, Benbrook and Sloss, 1961), fecal samples were examined for parasite ova. Those dogs harboring hookworms, ascarids or whipworms were treated with disophenol,* piperzine citrate,** and phthalofyne*** according to the recommended dosage. Examinations for internal parasites were performed at regular intervals during the study.

Commercial dog food# was fed once a day and water was provided at all times. Each dog was kept in a separate cage, but was permitted to exercise for half an hour every morning and evening in separate indoor runs.

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*D.N.P., American Cyanamid Company, Princeton, N.J.

**Pipcide, Haver-Lockhart Loaboratories, Kansas City, Mo.

***Whipcide, Pitman-Moore, Indianapolis.

#Purina Dog Chow, Ralston Purina Company, Checkerboard Square, St. Louis, Mo.

TABLE 1. Breed, sex, estimated age and body weight of experimental dogs used for cruciate ligament surgery.

Serial No.	Case No.	Breed	Sex	Age (yr.)	Body weight (kg.)
1	104854	Cocker Spaniel	F	3	12.7
2	104888	Beagle	M	3	14.5
3	106626	Airedale	F	2.5	8.0
4	106627	Cocker Spaniel	F	2	8.0
5	106629	Mongrel	F	1	9.5
6	106630	Mongrel	F	1	9.5
7	106631	Beagle	F	4	9.0
8	106632	Mongrel	F	1.5	11.0
9	106634	Beagle	M	2	13.0
10	107191	Cocker Spaniel	F	3	6.3

Instruments used in the surgical procedure are shown in Figure 2. All instruments and materials used during the surgical procedure were sterilized in a High-Vac Sterilizer* at 275 F. for 3 minutes with pressure varying from 29 to 32 pounds. The material used for prosthesis consisted of braided dacron coated with silicone rubber, cut in 8- to 10-inch lengths (Figure 3). The outer coating was previously incorporated with 10% barium sulfate to render the prosthesis radiopaque.

Food was withheld from dogs for 12 hours prior to the surgical operation. The anesthetic was Pentobarbital sodium solution** (1 grain in each ml.) given intravenously in the amount of 1 ml. per 5 pounds of body weight or in amounts sufficient to produce surgical anesthesia. Completeness of anesthesia was judged by eye and toe pinch reflexes.

The surgical site was prepared by clipping (Oster clipper, size 40 blade)*** the hair on the hind leg from the point of hip to the hock joint. The leg was held in an upright position by means of a gauze bandage tied around the phalanges and secured to a transfusion stand. The entire clipped area was scrubbed 4 times with a surgical soap containing an aqueous preparation of high molecular weight alkylaminehydrochlorides composed of benzethonium chloride,# diluted 1:3 with water. Finally the area was left wet with the surgical soap solution. Care was taken to protect the scrotum or vulva from surgical soap contact.

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*Wilmot Castle Company, Rochester, N.Y.

**Halatal solution, Jensen-Salsbery Laboratories, Kansas City, Mo.

***John Oster Manufacturing Company, Milwaukee, Wisconsin.

#Liquid Germicidal Detergent, Parke, Davis & Company, Detroit, Michigan.

Figure 2. Surgical instruments used in cruciate ligament prosthesis. (1) Mayo scissors; (2) Halstead mosquito hemostats, curved; (3) Halstead mosquito hemostats, straight; (4) Mayo-Heger needle holder; (5) Thumb forceps; (6) Allis tissue forceps; (7) Backhaus towel forceps; (8), Bard Parker handle #3 with Bard Parker blade #10; (9) Suturator with type 'A' nylon; (10) Kirschner pin chuck with key; (11) Steinman stainless steel pin with trocar point; (12) Cruciate drill guide with Steinman pin; (13) Hairpin wire; (14) Half circle cutting needle.

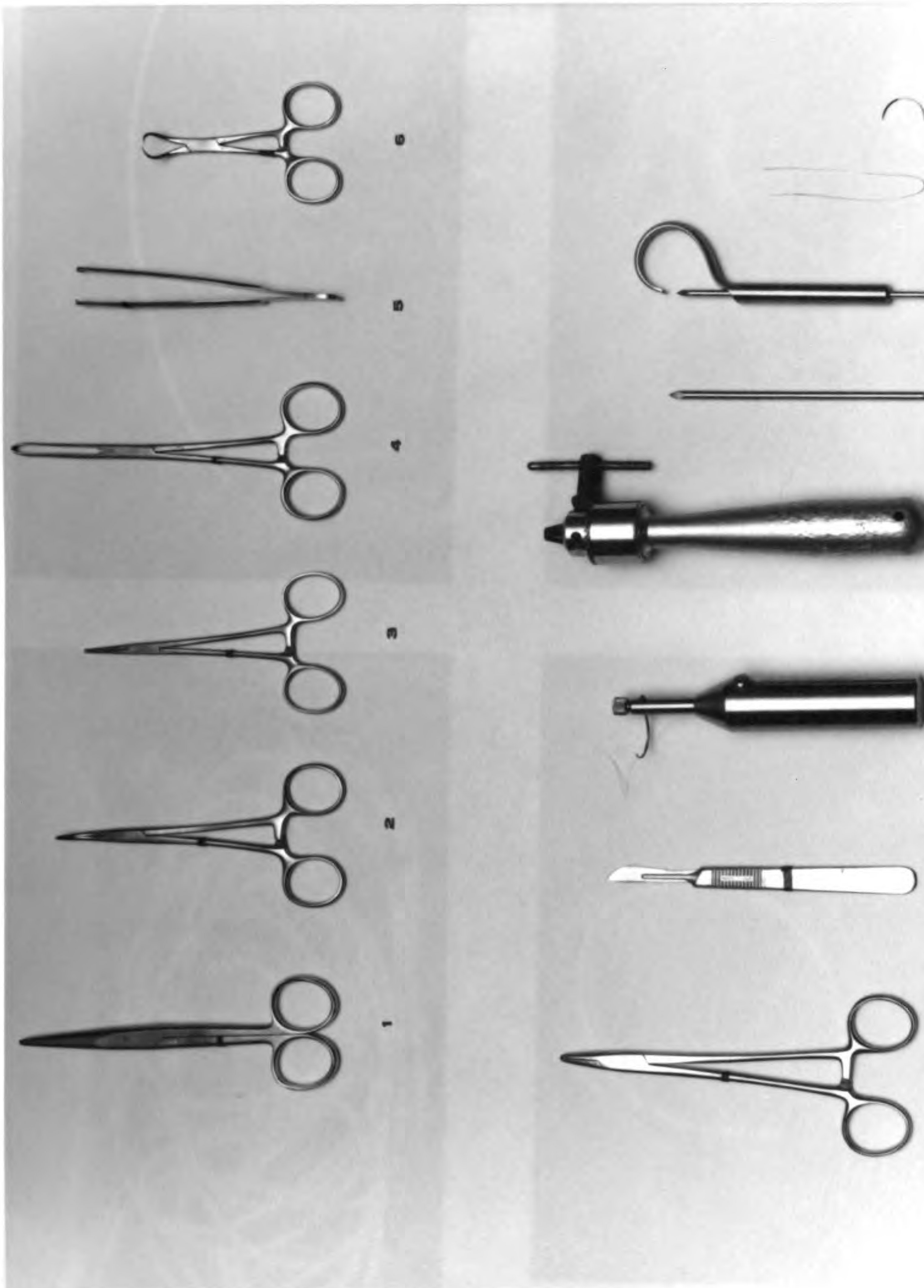

Figure 2

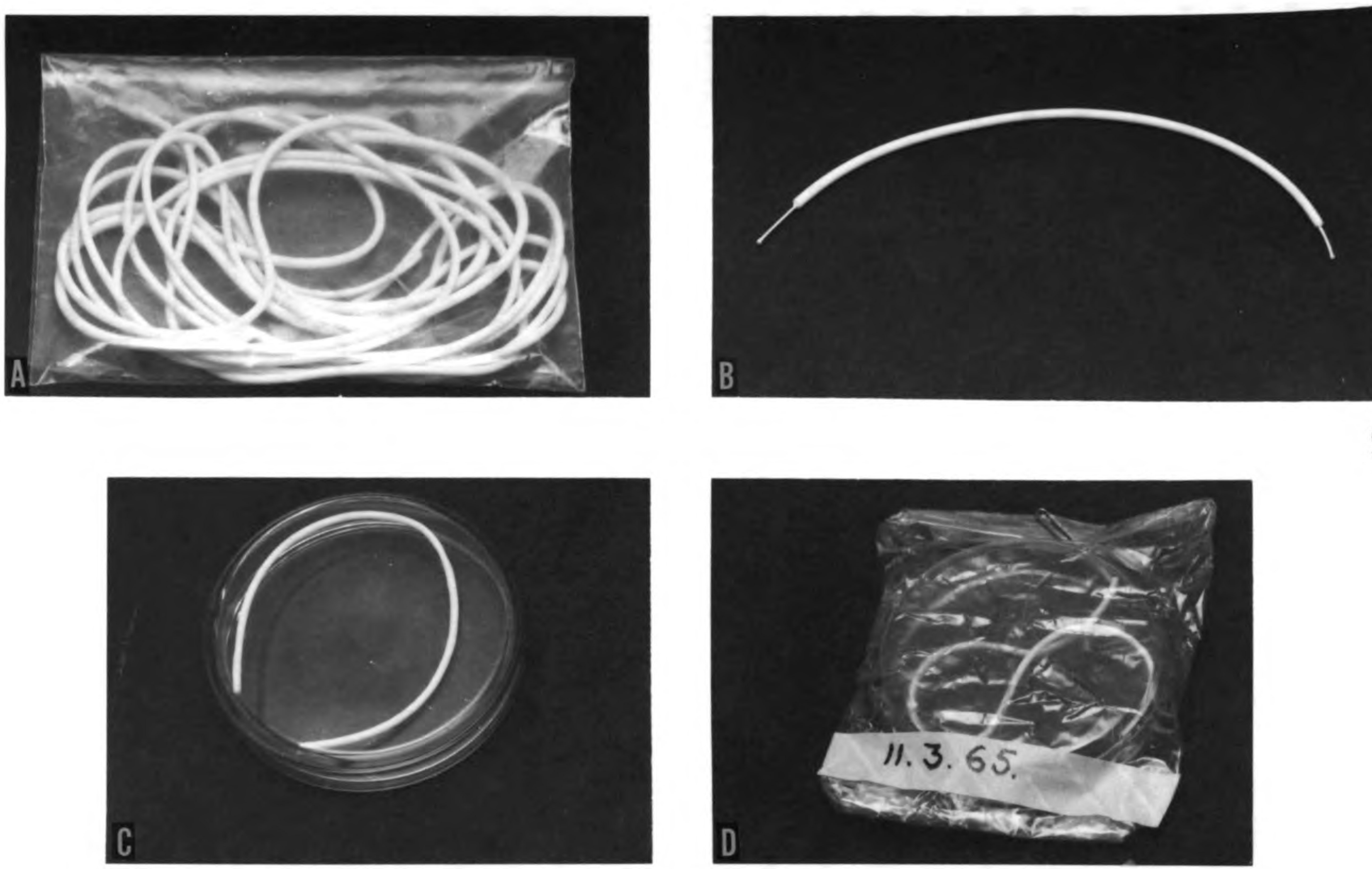

Figure 3. (A) Prosthesis stored in a plastic bag; (B) piece of prosthesis, the outer coating of silicone rubber removed at both ends to show the central dacron cord; (C) the same piece kept in petri dish; and (D) ready for sterilization.

Throughout the surgical procedure strict aseptic precautions were observed. These included the use of caps, masks, surgical gowns and surgeon's hand gloves, and the operative site adequately covered with sterile drapes.

A 4-inch incision was made through the skin extending from the distal fourth of the shaft of the femur to below the tibial crest over the antero-lateral aspect of the femoro-tibial joint (Figure 4). The bleeding vessels were ligated with type "A" nylon. Subcutaneous tissue and fascia were separated with scissors exposing the joint capsule. Another incision was made into the joint capsule from above the lateral condyle of the femur to the tibial crest. The patella was displaced medially and the leg was flexed so that the stifle joint was thoroughly exposed (Figure 5). The limb was flexed so that the shafts of the femur and tibia formed a 60° angle.

A curved mosquito hemostatic forceps was placed under the anterior cruciate ligament and slightly pushed upward. Its proximal attachment was severed taking maximum care not to damage the posterior cruciate ligament. The free end of the ligament was secured with a pair of thumb forceps, and the distal end was also severed at its distal attachment.

For drilling, the curved end of the drill guide, attached to a Kirschner pin chuck, was placed in the small depression of the proximal attachment of the anterior cruciate ligament on the medial surface of the lateral condyle with the trocar pointed pin positioned just above the lateral condyle of the femur (Figure 6). The pin was directed ventromedially and a guide hole was drilled through the femur. Following this, the hole was enlarged with another Steinman pin (Figure 7) with a diameter large enough to accommodate the prosthesis used as the substitute for the anterior cruciate ligament. A hairpin wire was passed through one end of the prosthesis and a loop was made out of this wire. Then the prosthesis was pulled through the femoral tunnel with the help of the wire loop (Figure 8).

Next, the point of the drill guide was located at the anterior intercondyloid fossa of the tibia (the distal attachment of the anterior cruciate ligament) and the trocar pointed pin was positioned below the tibial crest antero-medially (Figure 9). A guide hole made through the tibia was enlarged with a pin, and the other end of the prosthesis was passed through it as described above. A 3rd hole was then drilled transversely through the tibial crest and the prosthesis was likewise passed through it.

The leg was extended and the patella was brought back to its normal position. The silicone rubber coating of the prosthesis was removed from both ends to facilitate tying a square knot. With the femoro-tibial joint simulating the standing position, the prosthesis was drawn taut. One-half square knot was tied. The stifle joint was examined for anterior drawer movement by grasping femur with one hand and tibia with the other, placing one thumb on the posterior aspect of the distal femur and one thumb on the posterior aspect of the tibia. The stifle joint was also tested for easy movement or unusual tightness of the prothesis by moving the tibia back and forth. When the prosthesis was adjusted so that there was easy and free normal movement of the joint and an absence of anterior drawer movement, it was fixed in place with another square knot reinforced with Vetafil* to prevent slipping.

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*Vetafil, Bengen and Company, Hannover, West Germany.

After again testing for normal movement of the stifle joint, the joint capsule was closed with simple interrupted nonabsorbable synthetic sutures.* Sutures were placed outside the synovial lining of the joint capsule to prevent irritation of the lateral femoral condyle. The subcutaneous tissue was sutured with type "A" nylon. The skin was closed with "split-thickness" interrupted sutures using type "A" nylon.

Using an elastic gauze bandage, a protective covering was placed around the stifle joint from the middle of the femur to the middle of the tibia. The bandage and adjacent area of skin was then covered with adhesive tape. Ether was applied to the tape to increase its adhesiveness. Recovery from anesthesia was usually in 3 to 4 hours.

After surgery, dogs were kept in their respective cages and were maintained on the same diet as prior to surgical operation. Rectal temperature was taken with a clinical thermometer every morning for one month. The bandage covering the stifle joint was observed regularly and readjusted if too tight or loose. On the 6th postoperative day the bandage was removed. Skin sutures were removed on the 10th day. Clinical observations persisted until dogs were euthanatized (TABLE 2).

Hematologic Study

Blood for hematologic examination was collected from the cephalic vein on the days preceding and following surgery. Subsequent collections were at an interval of one month. Collections were in a vacutainer containing EDTA.** The hemogram consisted of hemoglobin content, packed cell volume, total and differential leukocyte counts.

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*Vetafil, Bengen and Company, Hannover, West Germany.

**Tripotassium salt of Ethylenediaminetetraacetic acid.

TABLE 2. Interval between cruciate ligament surgery and euthanasia.

Serial No.	Case No.	Date of operation	Date of euthanasia	Interval (wk.)
1	104854	April 29, 1965	August 21, 1965	16
2	104888	May 19, 1965	August 19, 1965	13
3	106626	November 11, 1965	April 25, 1966	24
4	106627	November 29, 1965	April 30, 1966	22
5	106629	November 20, 1965	May 27, 1966	27
6	106630	October 28, 1965	December 1, 1966	57
7	106631	October 19, 1965	April 22, 1966	27
8	106632	November 20, 1965	May 27, 1966	27
9	106634	October 25, 1965	April 30, 1966	27
10	107191	November 30, 1965	August 28, 1966	39

Figure 4. Skin incision over the antero-lateral aspect of the stifle joint.

Figure 5. The patella displaced medially to expose the stifle joint.

Figure 6. Application of the drill guide to the femur. The attachment of the anterior cruciate ligament on the medial surface of the lateral condyle is usually depicted by a small depression. The curved end of the drill guide is located at this point.

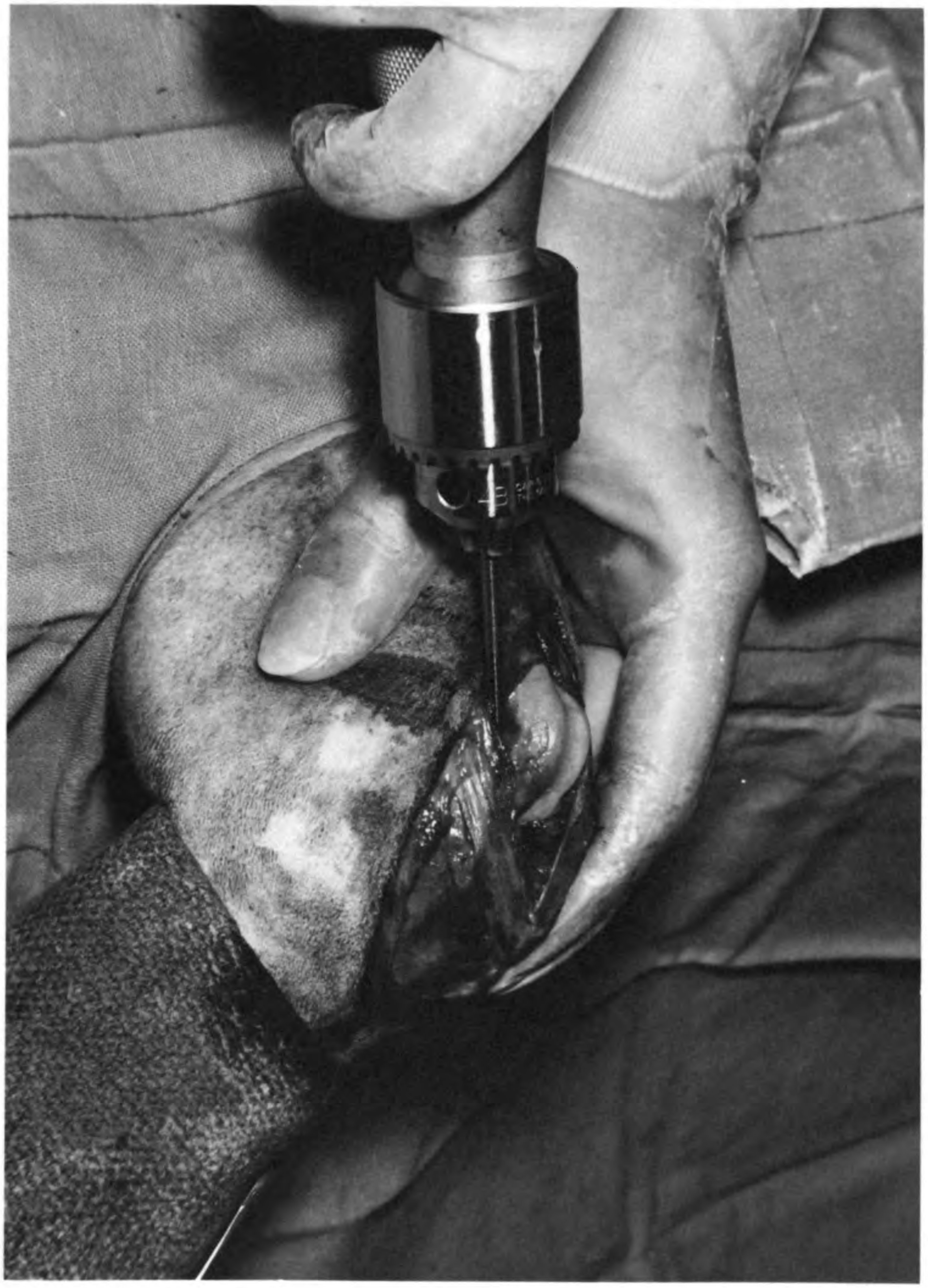

Figure 7. The pilot hole made into the femur is being enlarged to accommodate the prosthesis.

Figure 8. The prosthesis passed through the femoral tunnel.

Figure 9. Application of the drill guide to the tibia.

Radiologic Study

Radiographs of both stifle joints in lateral (Figures 10, 11, and 12) and postero-anterior (Figures 13 and 14) projections were taken after surgery while the dog was still anesthetized. Follow-up radiographs (dog anesthetized with a short-acting drug, Thiamylal sodium*) were also taken once a month.

Post-Mortem Examination

At varying periods of time following surgery (3 months to 13 months, TABLE 2), dogs were euthanatized with pentobarbital sodium solution** intravenously. A longitudinal incision in the parapatellar area was made through the skin, fascia and joint capsule. The insertion of the patellar tendon to the tibial tuberosity was severed and the patella reflected dorsomedially. Both stifle joints (operated and control) were examined for gross pathologic changes.

The color and amount of the synovial fluid was noted. The synovial membrane, fibrous part of the joint capsule, and other adjoining ligaments were examined for inflammatory changes. The articular surfaces of the femoral condyles, trochlea and patella were observed for signs of abnormal wear or erosion. The lateral surfaces of the femoral trochlea were examined for the development of the marginal osteophytes. The lateral and medial menisci were examined for any abnormal wear or splitting.

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*Surital, Parke, Davis & Company, Detroit, Michigan.

**Toxital, Jensen-Salsbery Laboratories, Kansas City, Mo.

Specimens of the medial meniscus and the opposing articular cartilage of the femoral condyle, the regenerated anterior cruciate ligament and the joint capsule were collected from both stifle joints. All specimens were fixed immediately in 10% buffered neutral formalin. Sections of articular cartilage and the adjoining subchondral bone were decalcified* and washed in running water for 3 hours prior to further tissue processing.

Joint capsule and regenerated anterior cruciate ligament were sectioned at a thickness of 6 microns and stained** as follows: (1) Harris' hematoxylin and Eosin Y (H & E); (2) the periodic acid-Schiff (PAS) reaction employing Schiff's leuko-fuchsin solution and counterstained with Harris' hematoxylin; and (3) May-Grünwald-Giemsa. Specimens of the articular cartilage and medial meniscus were cut 6 microns thick and stained with (1) Harris' hematoxylin and Eosin Y (H & E) and (2) toluidin blue O.

Determination of Breaking Strength of Cruciate Ligaments

Dogs for this part of the study were received from the student surgery laboratory in the Department of Veterinary Surgery and Medicine. They were euthanatized with pentobarbital sodium solution administered intravenously. The breed, sex, body weight and approximate age of each dog was noted.

A tensile testing instrument*** (Figure 15) was used to determine the breaking load of the cruciate ligaments. Both the anterior and posterior

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*Decal, Omega Chemical Company, Garden City, N.Y.

**Armed Forces Institute of Pathology: Manual of Histologic and Special Staining Technics, AFIP, Washington, D.C., 1960.

***Instron, Instron Engineering Corp., Canton, Massachusetts.

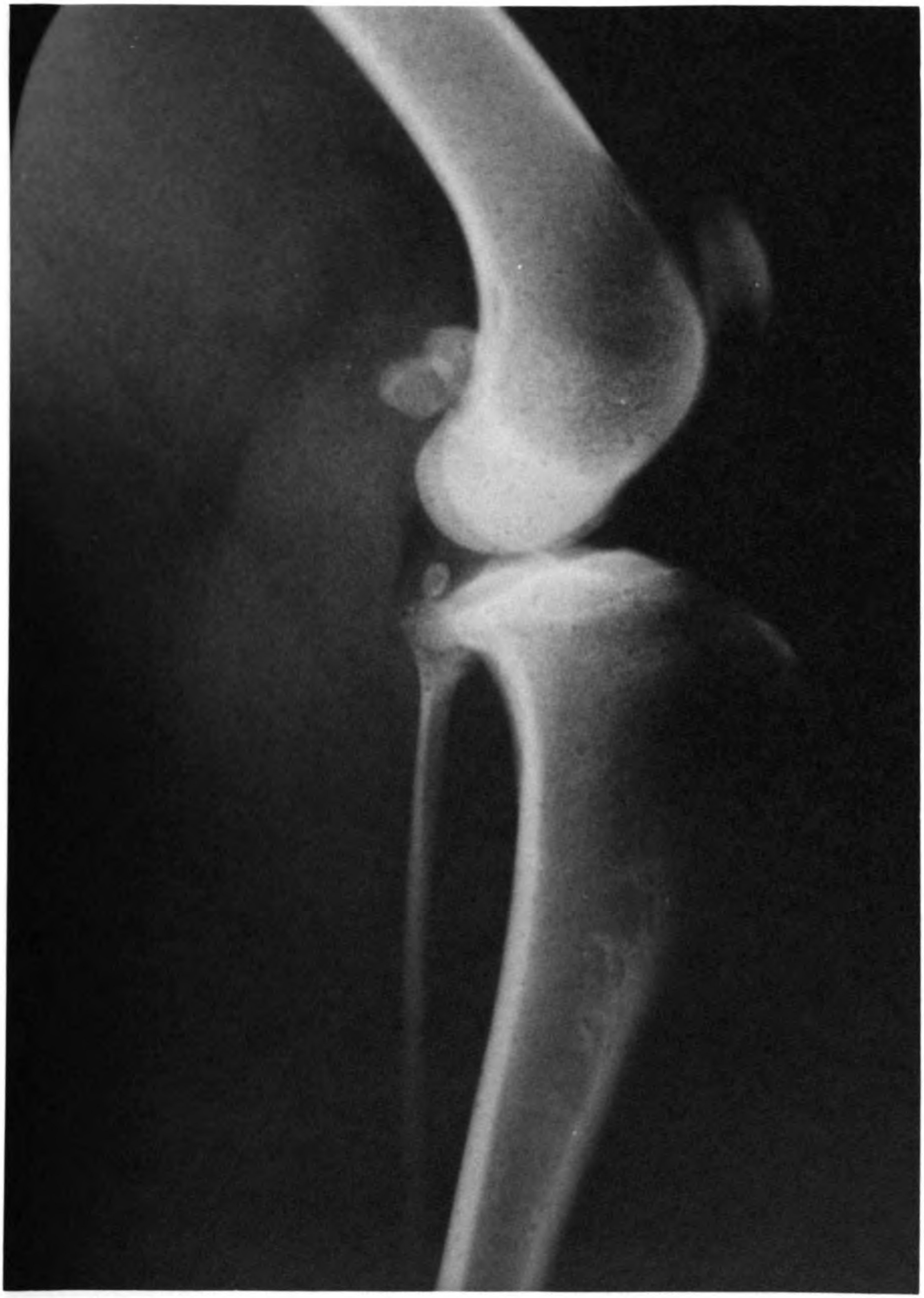

Figure 10. Lateral radiograph of normal stifle joint (case #104854).

Figure 11. Case #106630. Lateral radiograph of the right stifle immediately after surgery. Prosthesis _in_ _situ_.

Figure 12. Radiograph of the right stifle (postero-anterior view) immediately after surgery. Prosthesis <u>in situ</u> (case #106630).

Figure 13. Case #107191. Lateral radiograph of the right stifle taken postoperatively. Prosthesis in situ.

Figure 14. Case #107191. Radiograph, postero-anterior view, of the right stifle after surgery, showing the prosthesis in place.

Figure 15. The tensile testing instrument, "Instron", incorporates a highly sensitive electronic weighing system employing bonded wire strain gauges for detecting and recording the tensile load applied to the sample under test. The chart of the recorder is driven synchronously at a wide variety of speed ratios and a stress-strain curve is plotted. By the use of readily interchangeable "load cells", full scale sensitivity may be obtained extending from 2 Gm. up to 10,000 pounds. The accuracy is independent of the range in use and is better than ± 0.5%.*

*Operating Instructions for the Instron: Tensile Testing Instruments Manual #10-29-1. Instron Engineering Corporation, Canton, Mass.

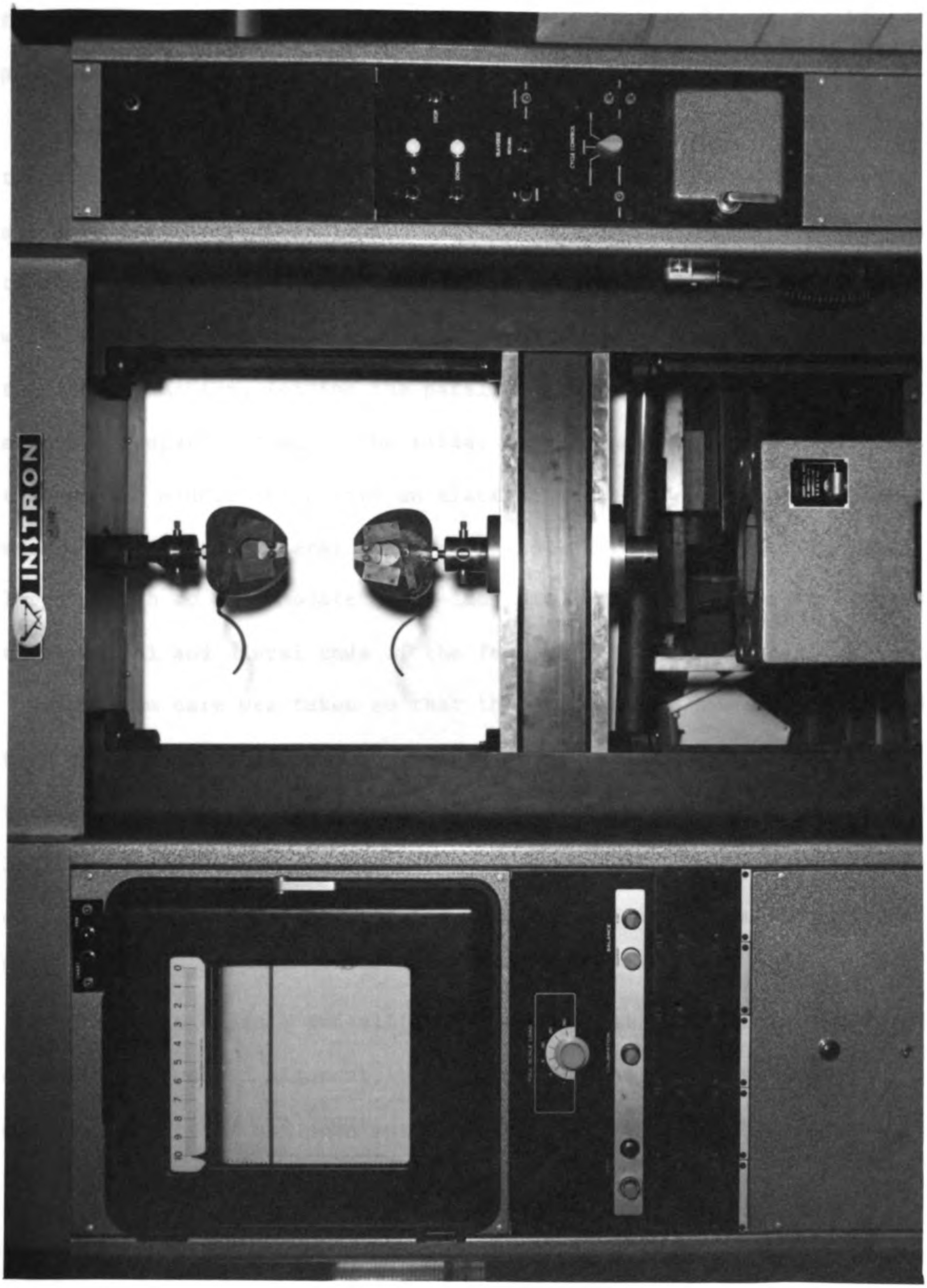

Figure 15

cruciate ligaments were tested separately and, in some instances, simultaneously. Strips of fascia lata, skin, and braided dacron for ligament prosthesis were also tested in the same manner.

A longitudinal incision was made through the skin, extending from the trochanter major proximally to the tarsus distally. Using a pair of scissors for blunt dissection, skin was separated from the subcutaneous tissue. Soft tissues around the femur, stifle joint, tibia and fibula were removed. The quadriceps femoris muscle was severed at the musculotendinous junction, leaving the patella with its straight patellar tendon and joint capsule intact. The tibia, fibula and femur were amputated through the middle third with an electric saw. Finally, the fibula was separated from the lateral tibial condyle. With a power drill, holes large enough to accommodate a 3/8-inch pin were made transversely through the proximal and distal ends of the femoral and tibial pieces.

Maximum care was taken so that the stifle joint was not subjected to any unusual strain during preparation of the bones for the tension test. The specimen was wrapped with gauze and kept moist with physiological saline solution until used. From one-half to one hour's time elapsed between the removal of the specimen and actual testing of the breaking strength.

The joint capsule and all the femoro-tibial attachments were divided except the cruciate ligaments before setting the specimens into the machine. A steady and constant pull was applied until the ligament broke (Figure 16).

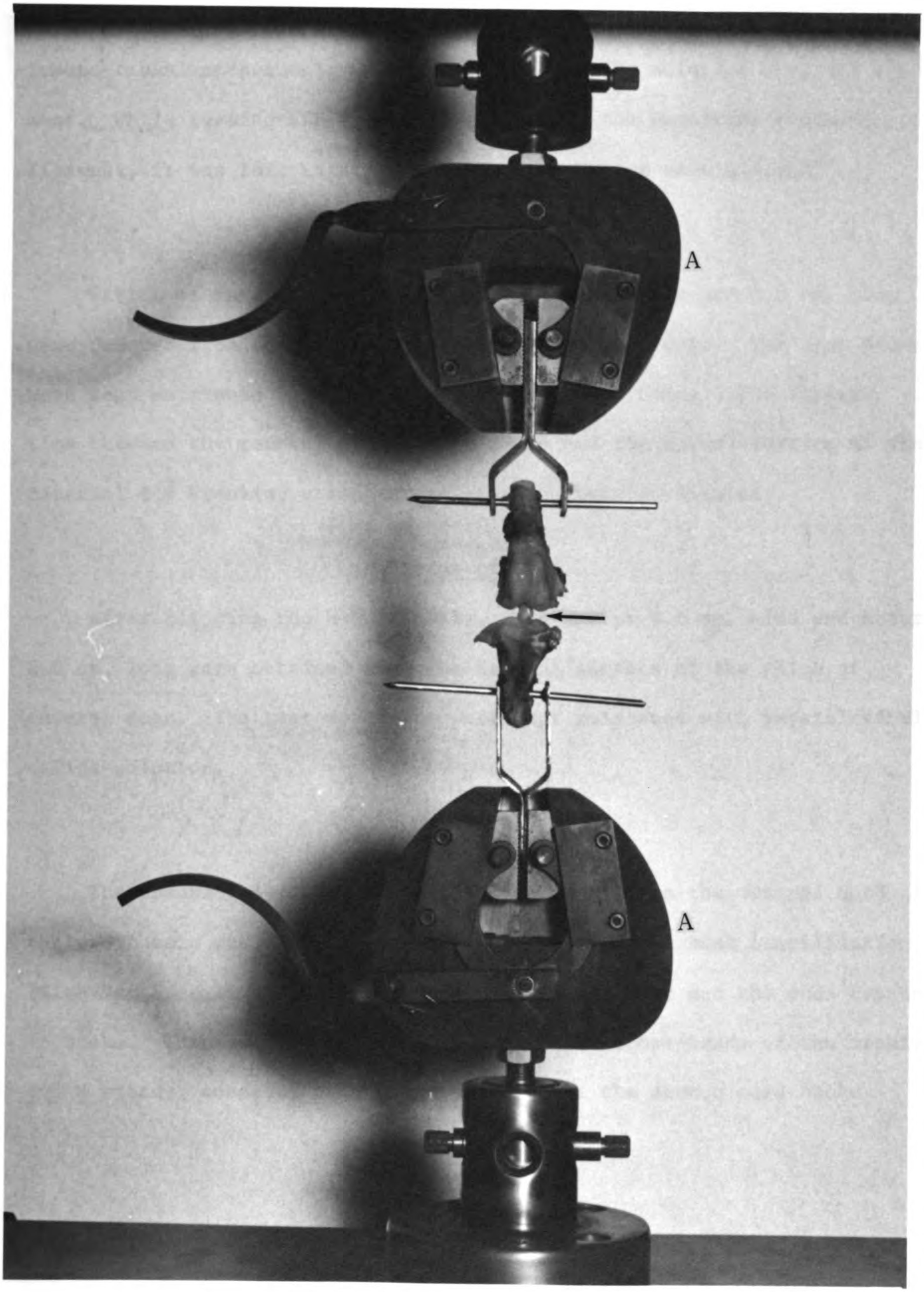

Figure 16. The specimen, showing stretched cruciate ligaments (arrow) under strain while the cross-heads (A) were moving apart.

For breaking strength of the anterior cruciate ligament, all the femoro-tibial attachments were severed except the anterior cruciate ligament. While testing the breaking strength of the posterior cruciate ligament, it was left intact and other attachments were divided.

Strips of Fascia Lata

Strips of fascia lata approximately 1.0 cm. wide and 8.0 cm. long were removed from the parapatellar area of several dogs. The test pieces were kept moistened with physiological saline solution. The elapsed time between the removal of the test piece and the actual testing of the material for breaking strength was approximately 30 minutes.

Strips of Skin

After clipping the hair closely, skin strips 0.6 cm. wide and about 8.0 cm. long were obtained from the lateral surface of the thigh of several dogs. The test specimens were kept moistened with physiological saline solution.

Braided Dacron

The breaking load of the braided dacron used as the central cord of the prosthesis was determined before and after moist heat sterilization (High-Vac Sterilizer). Pieces 8.0 cm. long were cut and the ends fastened to hooks. Then the hooks were attached to the cross-heads of the machine and a steady, constant pull was applied until the dacron cord broke.

RESULTS

A postsurgical rise in rectal temperature of 1 to 2 degrees was noted. Normal body temperature values were attained in 2 to 3 days. In all cases there was first intention healing of the incisional wound. In 2 cases a postoperative swelling around the stifle joint was noticed which subsided within 10 days. All dogs evinced pain on palpation of the operated stifle joint during the 1st and 2nd week. No swelling or tenderness of the joint was noticed in any case after 3 weeks (TABLE 3). Eight dogs attained complete recovery, and the other 2 showed signs of lameness after strenuous exercise.

There was no significant change in hemoglobin values or in packed cell volume after surgery. However, there was a significant rise in the total leukocyte count with a shift to the left in all cases. Leukocyte counts returned to normal within 3 to 4 days. Marked lymphocytic depression was noticed 24 hours after surgery in 8 cases. There was no significant change in relative or absolute monocyte values. Eosinophils either disappeared completely from the peripheral circulation or decreased in number for 2 to 3 days, following which their numbers returned to normal. During the later period of observation, no abnormality was detected in the individual hemograms.

Gait

All dogs walked with a marked lameness during the first postoperative week. They refused to bear weight on the limb with a prosthesis and held

TABLE 3. Duration of postoperative swelling and tenderness of the stifle joint.

Serial No.	Case No.	1st week		2nd week		3rd week		4th week	
		Swelling	Tenderness	Swelling	Tenderness	Swelling	Tenderness	Swelling	Tenderness
1	104854	-	+++	-	+	-	-	-	-
2	104888	-	+++	-	-	-	-	-	-
3	106626	-	++	-	-	-	-	-	-
4	106627	-	+	-	-	-	-	-	-
5	106629	-	++	-	++	-	+	-	-
6	106630	++	+++	+	+	-	-	-	-
7	106631	-	++	-	+	-	-	-	-
8	106632	-	+	-	-	-	-	-	-
9	106634	++	+++	-	+	-	-	-	-
10	107191	-	++	-	+	-	+	-	-

None = -
Slight = +
Moderate = ++
Marked = +++

it up during walking. By the end of the 4th week all dogs attained a normal gait (TABLE 4).

Thirty minutes of strenuous exercise, such as running and jumping, occasionally elicited pain, evidenced by failure to use the limb for as long as the 4th postsurgical week. In 8 dogs no lameness was detected after exercise by the end of the 2nd month. Two dogs occasionally limped after exercise, but there was no detectable lameness or disability when walking. In neither of the rear limbs was there disuse atrophy of muscles in any of the dogs.

Drawer Sign and Range of Movement

Very slight to moderate anterior drawer movement (Figure 17) was noticed in all dogs. No posterior drawer sign was detected in any dog, nor were there any crepitation or clicking sounds in the stifle joint. There was free movement in the joint, and the leg could be completely extended. The extent of flexion was also normal. The only physical abnormality detected was a slight to moderate anterior drawer sign of the tibia.

Radiographic Observations

The outer coating of the dacron prosthesis (silicone rubber), which was made radiopaque by incorporating barium sulfate, was clearly visible in radiographs (Figures 18 through 23). During the 2nd month, the prostheses were found broken in 3 dogs and by the end of the 4th month, 4 additional dogs had broken their prostheses (TABLE 5).

TABLE 4. Postoperative functional recovery evaluated during a slow walk.

Serial No.	Case No.	1st week	2nd week	3rd week	4th week
1	104854	lame	lame	normal gait	normal gait
2	104888	lame	lame	normal gait	normal gait
3	106626	lame	normal gait	normal gait	normal gait
4	106627	lame	normal gait	normal gait	normal gait
5	106629	lame	lame	lame	normal gait
6	106630	lame	normal gait	normal gait	normal gait
7	106631	lame	lame	normal gait	normal gait
8	106632	lame	normal gait	normal gait	normal gait
9	106634	lame	lame	normal gait	normal gait
10	107191	lame	lame	lame	normal gait

Figure 17. Position for testing for anterior drawer movement of the tibia.

TABLE 5. The condition of the silicone covering of the prosthesis as observed by radiography.

Serial No.	Case No.	Surgery	Radiographs taken after: 1st month	2nd month	3rd month	4th month	5th month	6th month	9th month	12th month
1	104854	---	---	---	intact	intact	---	---	---	---
2	104888	---	---	---	intact	---	---	---	---	---
3	106626	intact	intact	intact	intact	broken	broken	---	---	---
4	106627	intact	intact	intact	intact	---	broken	---	---	---
5	106629	intact	intact	broken	broken	broken	---	broken	---	---
6	106630	intact	intact	broken	broken	broken	---	broken	---	broken
7	106631	intact	intact	intact	broken	broken	---	broken	---	---
8	106632	intact	intact	broken	broken	broken	---	broken	---	---
9	106634	intact	intact	intact	intact	broken	---	broken	---	---
10	107191	intact	intact	intact	intact	---	---	intact	broken*	---

*The outer silicone covering was found broken but the central dacron cord was intact, as noticed at post-mortem examination.

The prostheses of 2 dogs, 3 and 4 months postoperatively, were found intact. This observations was confirmed at necropsy. The prosthesis of one dog, case #107191, showed evidence of fraying at 9 months (Figure 24). However, at necropsy, the central dacron cord was still intact but the outer covering of the silicone rubber was frayed.

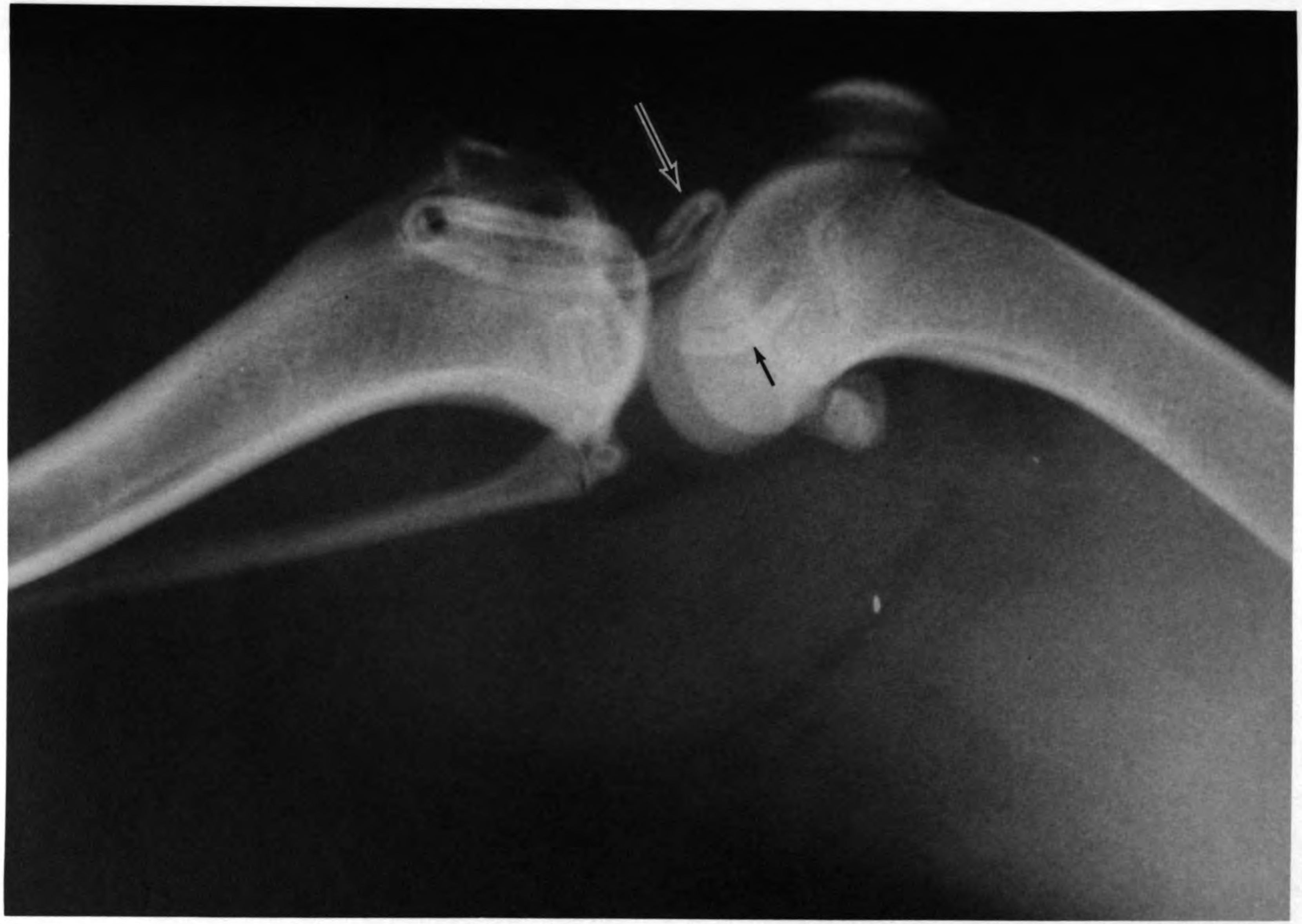

Figure 18. Case #106630. Lateral radiograph of the right stifle, 2 months postoperatively. Note the broken prosthesis (arrows).

Figure 19. Radiograph, postero-anterior view, of the right stifle, 2 months after surgery, showing the broken prosthesis (arrows).

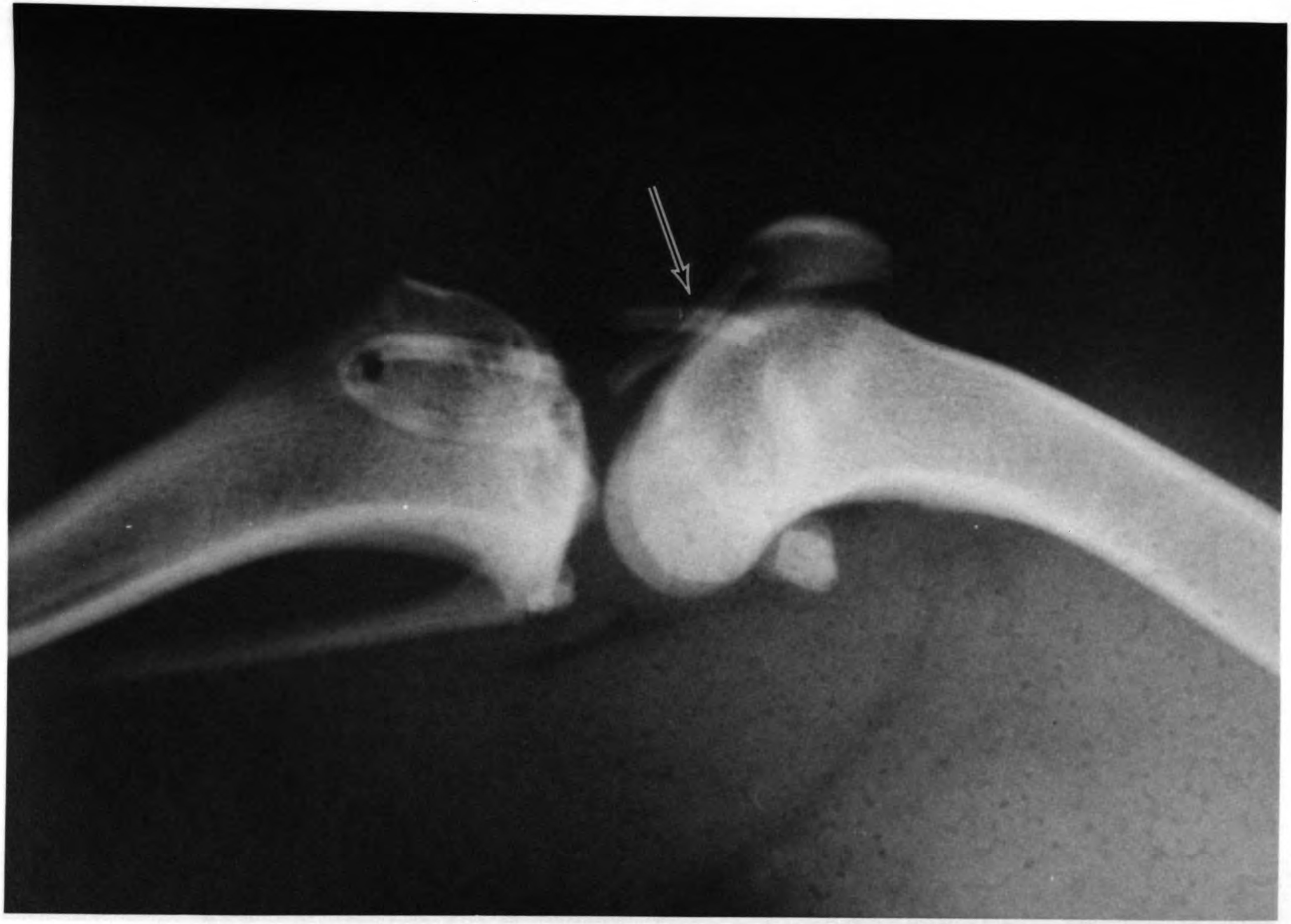

Figure 20. Lateral radiograph of the right stifle (case #106630) taken after 7 months of surgery. Note the pieces of silicone rubber within the joint (arrow).

Figure 21. Radiograph, postero-anterior view, of the right stifle (case #106630), 7 months post-operatively. Note the broken prosthesis (arrows).

Figure 22. Case #106630. Lateral radiograph of the right stifle 12 months after surgery. Two pieces of silicone rubber within the joint (arrow).

Figure 23. Radiograph, postero-anterior view, of the stifle joint (case #107191) 6 months after surgery.

Figure 24. Case #107191. Radiograph, postero-anterior view, of the right stifle, 9 months post-operatively. Note the separation of the radiopaque silicone rubber (arrow) within the joint.

Gross Pathologic Observations

A thickening of the joint capsule of the operated limb was evident at post-mortem examination. The joint capsule of the control stifle joint was normal. In 7 cases the joint fluid was clear; in 3 cases it was cloudy (TABLE 6). The femoro-patellar synovial sac appeared slightly edematous and ranged in color from brown to reddish brown. Wear or tear was not seen grossly on the lateral or medial menisci. The articular surfaces of the femoral condyles were bluish white, smooth and glistening except for 2 joints which were slightly congested. There was no evidence of the development of marginal osteoarthritic pearls along the edges of the femoral trochlea. The lateral and medial collateral ligaments were normal and intact.

The prosthesis was found broken in all but 3 dogs (TABLE 6). The outer covering of the silicone rubber was ripped longitudinally and transversely and, in a few cases, fragments of it were found inside the joint (Figure 25). The central dacron cord broke in the middle of the joint. The broken ends appeared to be either pulled inside the femoral or tibial tunnels or hanging inside the joint (Figure 26). The knot in the dacron cord on the lateral side of the joint was completely intact and tight and encapsulated with fibrous tissue. The intact prostheses were not as taut as when they were originally inserted. The points of origin and insertion of the anterior cruciate ligament were joined with a white, flat fibrous band in 3 cases (Figure 27). This newly formed ligament was not as taut or tough as the original (normal) anterior cruciate ligament. There was no gross pathologic change in the corresponding normal stifle joint.

TABLE 6. Gross examination of the stifle joints with prostheses after euthanasia.

Serial No.	Case No.	Synovial fluid Color	Synovial fluid Amount	Joint capsule	Prosthesis
1	104854	Clear	Scant*	Thickened	Intact
2	104888	Clear	Scant	Slightly thickened	Intact
3	106626	Yellow	0.5 ml.	Slightly thickened	Broken
4	106627	Cloudy	0.8 ml.	Thickened	Broken
5	106629	Clear	0.75 ml.	Thickened	Broken
6	106630	Clear	0.9 ml.	Thickened	Broken
7	106631	Clear	Scant	Thickened	Broken
8	106632	Clear	0.5 ml.	Thickened	Broken
9	106634	Cloudy	0.75 ml.	Thickened	Broken
10	107191	Clear	0.6 ml.	Thickened	Intact

* Scant = insufficient amount to measure.

Figure 25. Two pieces of silicone rubber (outer covering of the prosthesis) found inside the stifle joint at post-mortem examination. Case #106630.

Figure 26. One end of the broken dacron cord inside the stifle joint noticed at post-mortem examination. Case #106630.

Figure 27. Regenerated anterior cruciate ligament (arrow) noticed at post-mortem examination. Case #106630. (l) Thickened joint capsule, (m) patella, (n) femoral trochlea.

Figure 25

Figure 26

Figure 27

Histopathologic Observations

Articular cartilage. While the articular cartilage appeared to be normal grossly, there were, in some cases, a microscopic horizontal flaking (Figures 28 and 29) of its superficial layers (stratum superficialis). Vertical splitting was also present in a few cases. In such cases, clusters of chondrocytes in the stratum radialis and in the stratum calcificatum were noticed. In one dog (case #106630), there was early cartilagenous fibrillation with hydropic degeneration of chondrocytes. Pitting of the stratum superficialis (Figure 30) was also noticed. The articular cartilages of control stifle joints were comparatively normal, although some early horizontal flaking and fibrillation (absence of superficial layer of chondrocytes) were noticed in a few cases.

Medial meniscus. There was vertical splitting of the medial meniscus in one case (Figure 31). Transverse flaking and folding of superficial layers were noticed. There was some evidence of clustering of chondrocytes near the areas of flaking. The collagen fibers in superficial layers were arranged parallel to the articular surfaces. In the center of the meniscus, collagen fiber bundles were interwoven. The menisci of the control stifle joints were comparatively normal (Figure 32).

Joint capsule. The stratum synoviale was composed of 2 to 3 layers of cells with small folds at certain places in the control stifle joints (Figure 33). Synovial cells were pleomorphic, and they varied from round or spindle shaped to polygonal and epithelioid. Synovial intimal cells were PAS positive due to the presence of nonsulfated mucopolysaccharides. Moderate to strong PAS-positive granules were present in intimal and sub-intimal layers.

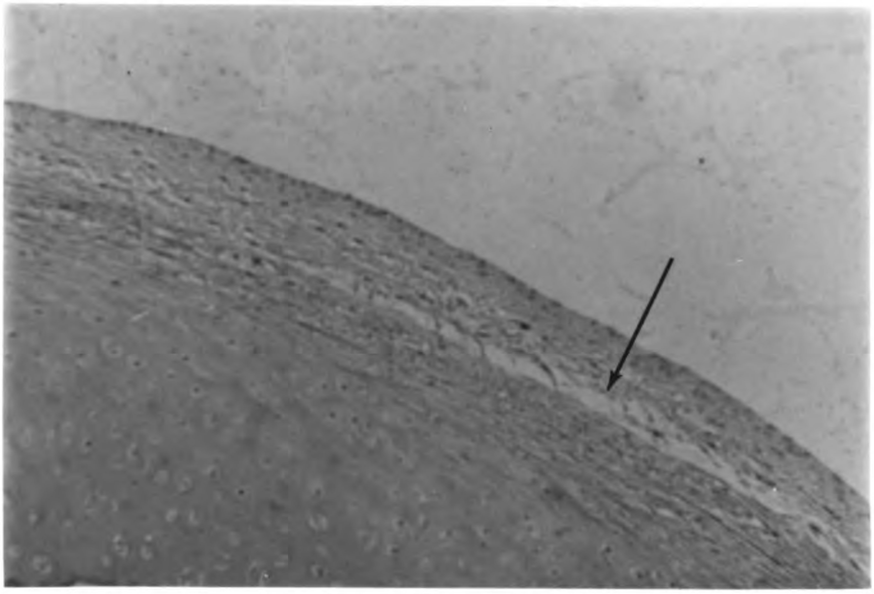

Figure 28. Horizontal flaking (arrow) of the articular cartilage of the femur. Case #107191. Hematoxylin and eosin. x 375.

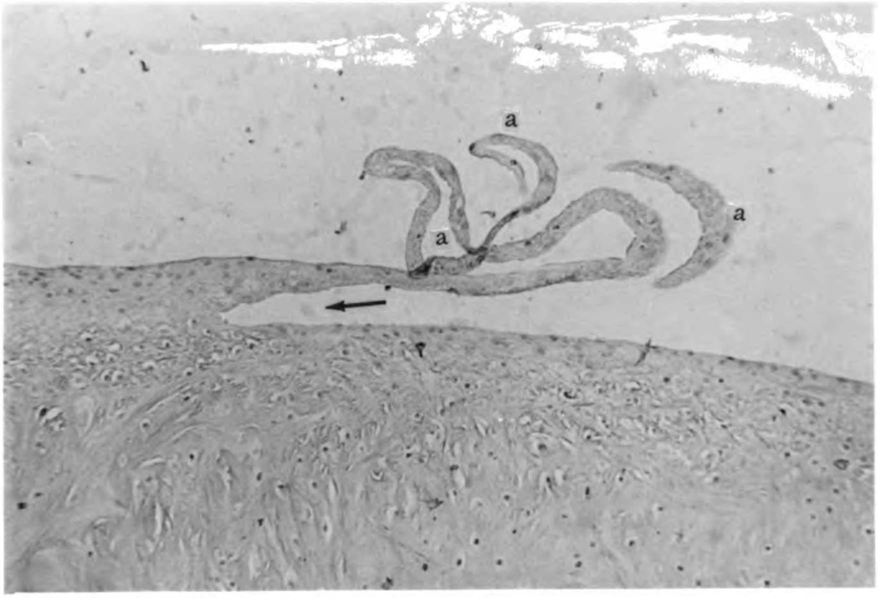

Figure 29. Horizontal flaking (arrow) and shredding (a) of the articular cartilage of the femur. Case #107191. Hematoxylin and eosin. x 375.

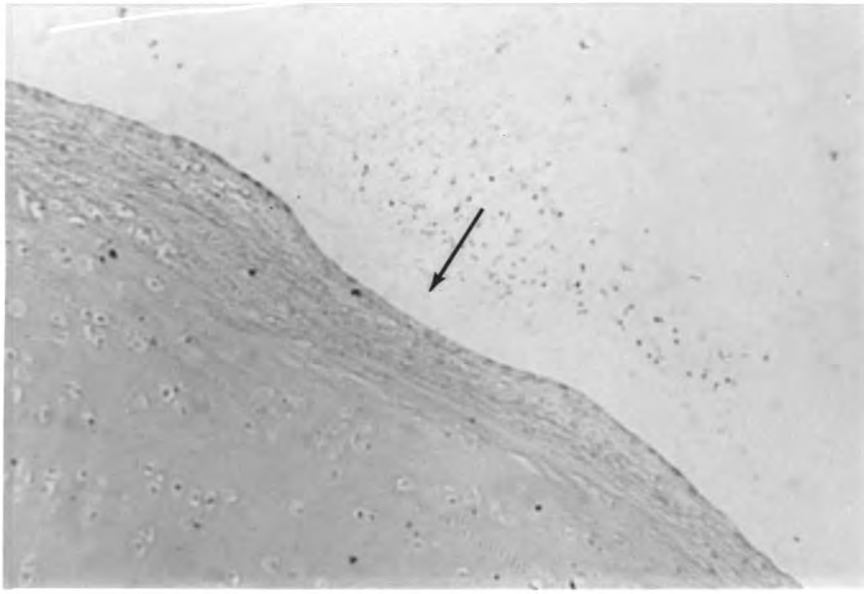

Figure 30. Pitting (arrow) in the stratum superficialis of articular cartilage of the femur. Case #107191. Hematoxylin and eosin. x 375.

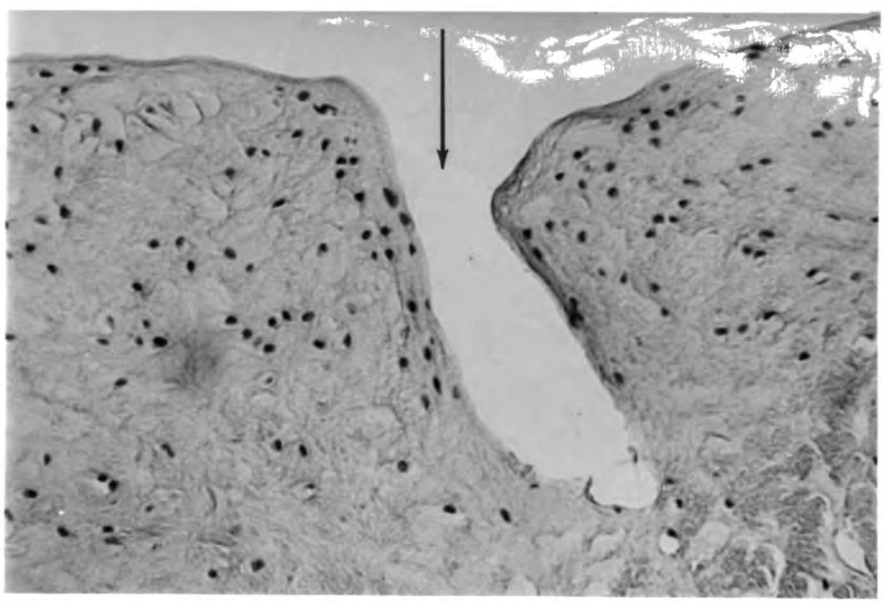

Figure 31. Vertical splitting (arrow) in the medial meniscus. Case #106630. Hematoxylin and eosin. x 375.

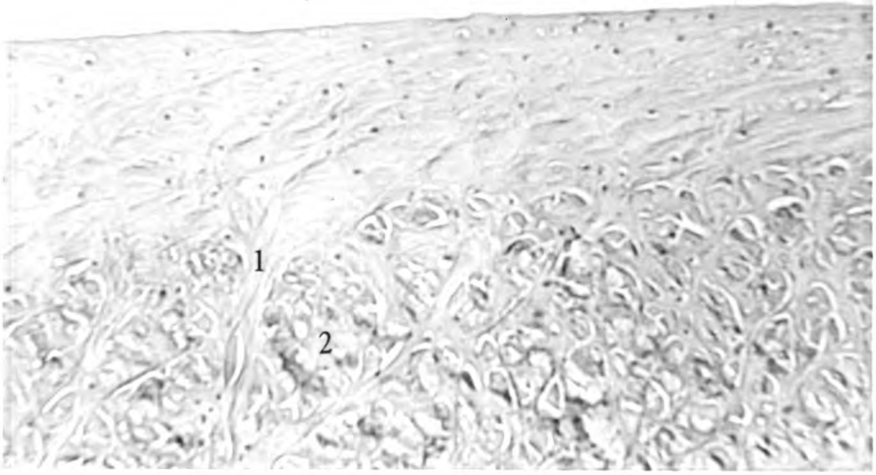

Figure 32. Normal medial meniscus. Note the interwoven collagen fiber bundles. Longitudinal section (1) and transverse section (2) of collagen fiber bundles. Hematoxylin and eosin. x 375.

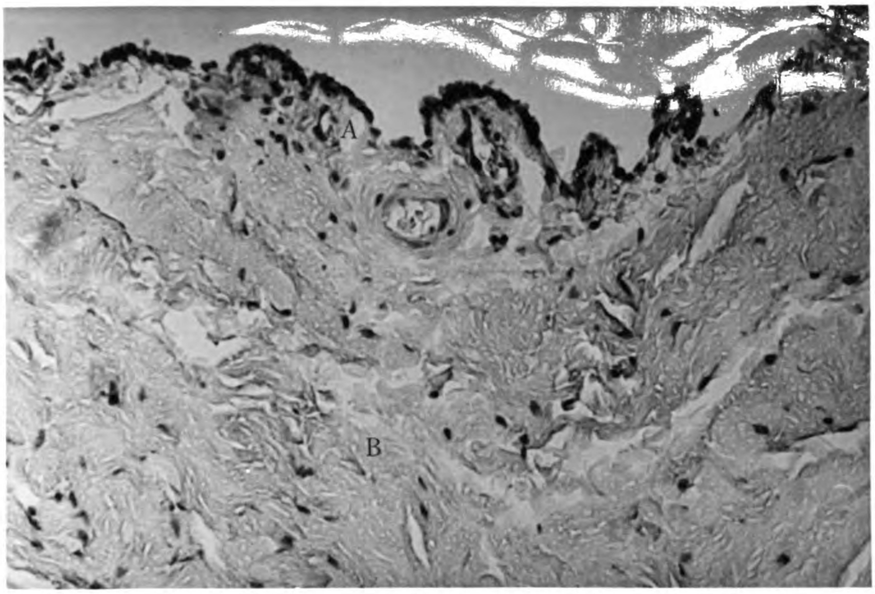

Figure 33. Normal joint capsule. Stratum synoviale (A) and stratum fibrosum (B). Hematoxylin and eosin. x 375.

In the stifle joints bearing the prosthesis there was minimal to moderate villus hypertrophy (Figure 34). Large numbers of Langhans' type giant cells and foreign body giant cells were observed in both intimal and subintimal layers (Figures 35 through 37). The cytoplasm of giant cells contained fragmented dacron and PAS-positive granules. There was moderate edema of the stratum fibrosum and the subintimal layer of the synovial membrane. Plasma cells and a few mast cells were noticed.

Regenerated cruciate ligament. In the regenerated ligaments, collagen fibers were loosely infiltrated with fibroblasts. Synovial fibroblasts and synovial fringes were noticed in several places. Numerous synovial villi had formed around regenerated cruciate ligaments, with a proliferation of synovial intimal cells and numerous blood vessels at the perimeter (Figures 38 and 39). Large numbers of Langhans' type giant cells with phagocytized foreign material (fragmented dacron) were seen primarily in the superficial layers (Figure 40). These giant cells contained PAS-positive granules. Plasma cells and mast cells were scattered throughout regenerated tissue. The cellular structure appeared to be identical with normal cruciate ligament (Figure 41); however, the cells and fiber bundles were loosely arranged. The broken dacron cord inside the stifle joint was infiltrated with fibroblasts and collagen fibers (Figures 42 and 43).

Breaking Strength of the Combined Anterior and Posterior Cruciate Ligaments

Of the 30 specimens tested for breaking strength of the combined anterior and posterior cruciate ligaments, 12 separated from the epiphyseal line of either the femur or tibia without breaking the ligaments (TABLE 7). When this happened, it was always in dogs under 2 years of age. The total load to break both the anterior and posterior cruciate ligaments

Figure 34. Joint capsule from the stifle joint (case #106626). Note the edema of the stratum fibrosum and numerous villi in the stratum synoviale. Hematoxylin and eosin. x 94.

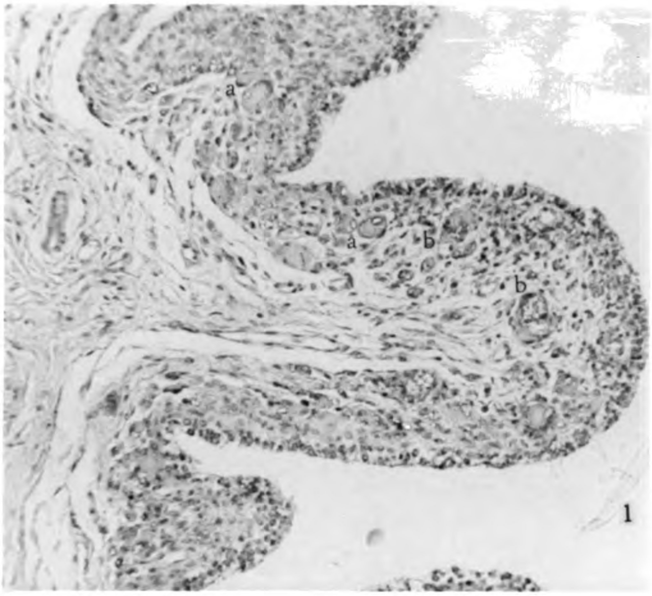

Figure 35. A higher magnification of synovial villi and fragmented dacron fiber (1) shown in Figure 34. Note the Langhans' type giant cells (a) and foreign body giant cells (b). Hematoxylin and eosin. x 375.

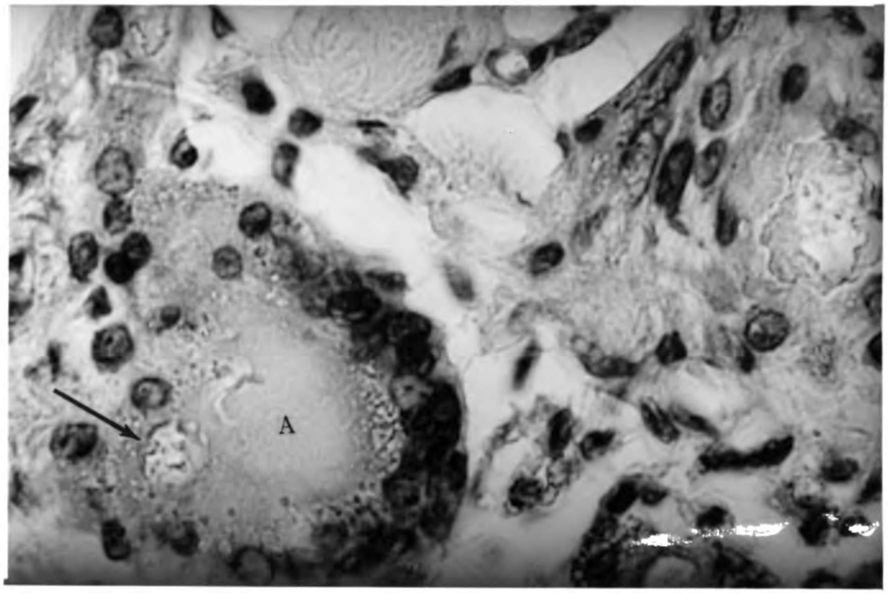

Figure 36. A higher magnification of synovial membrane from the stifle joint (case #106631). Note the Langhans' type giant cell (A) with fragmented dacron (arrow). Hematoxylin and eosin. x 1500.

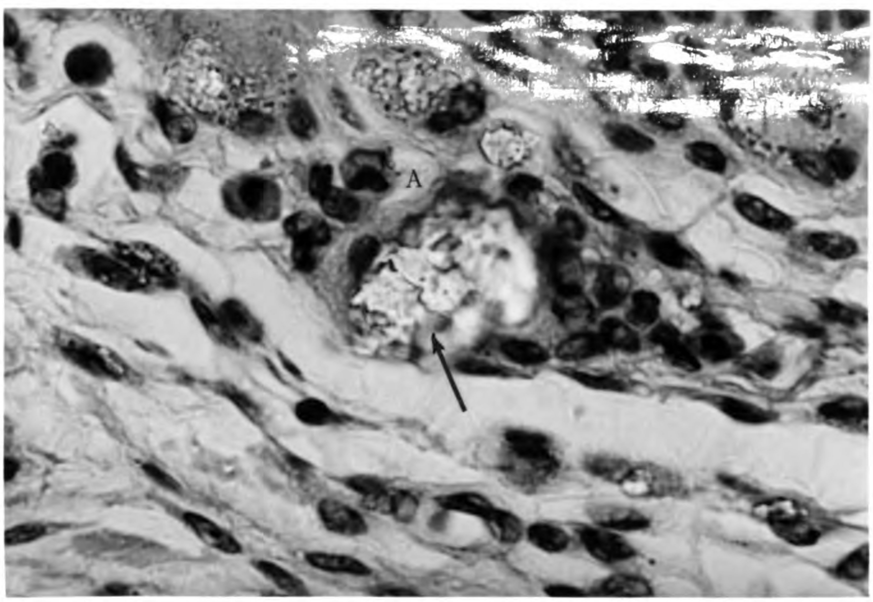

Figure 37. A higher magnification of foreign body type giant cell (A) in the stratum synoviale (case #106626). Note the phagocytized fragmented dacron fibers (arrow). Hematoxylin and eosin. x 1500.

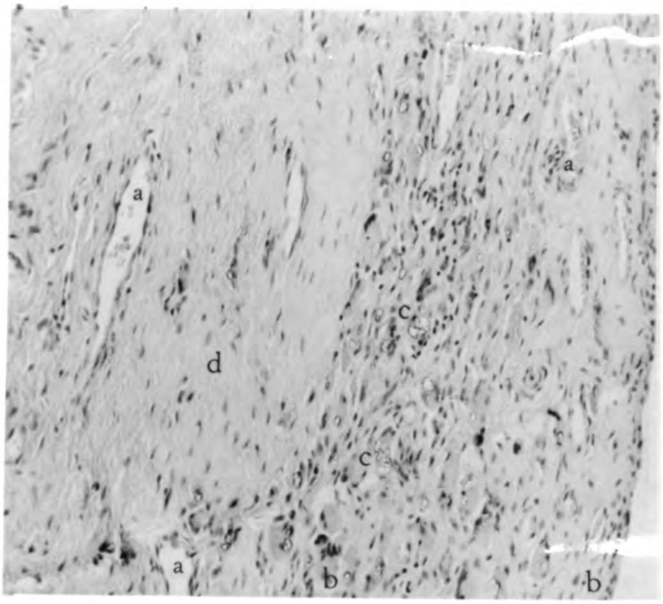

Figure 38. Regenerated anterior cruciate ligament (case #106630). Note the numerous blood vessels (a), proliferated synovial intimal cells (b) at the perimeter, phagocytized dacron fibers (c), and collagen fibers and fibroblasts (d). Hematoxylin and eosin. x 375.

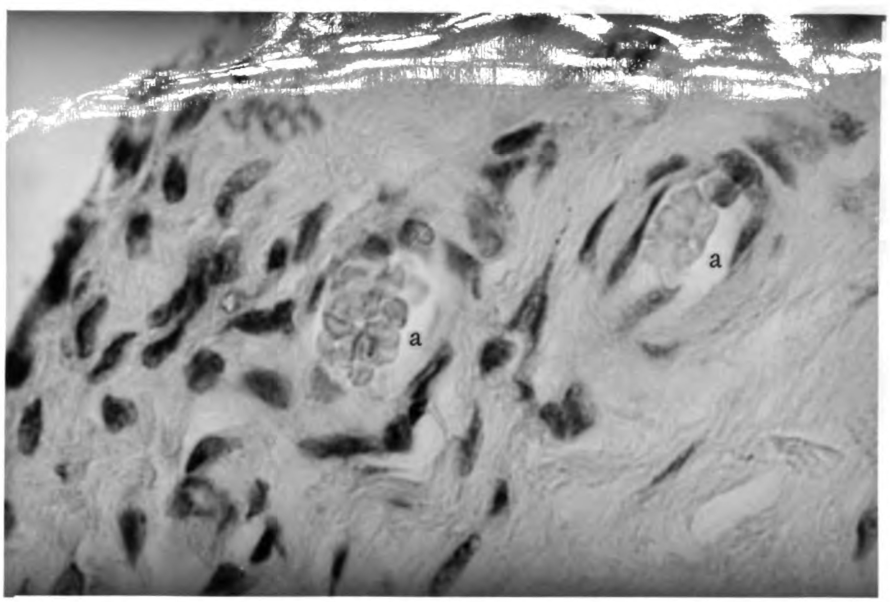

Figure 39. A higher magnificiation of regenerated anterior cruciate ligament shown in Figure 38. Note the blood vessels (a). Hematoxylin and eosin. x 1500.

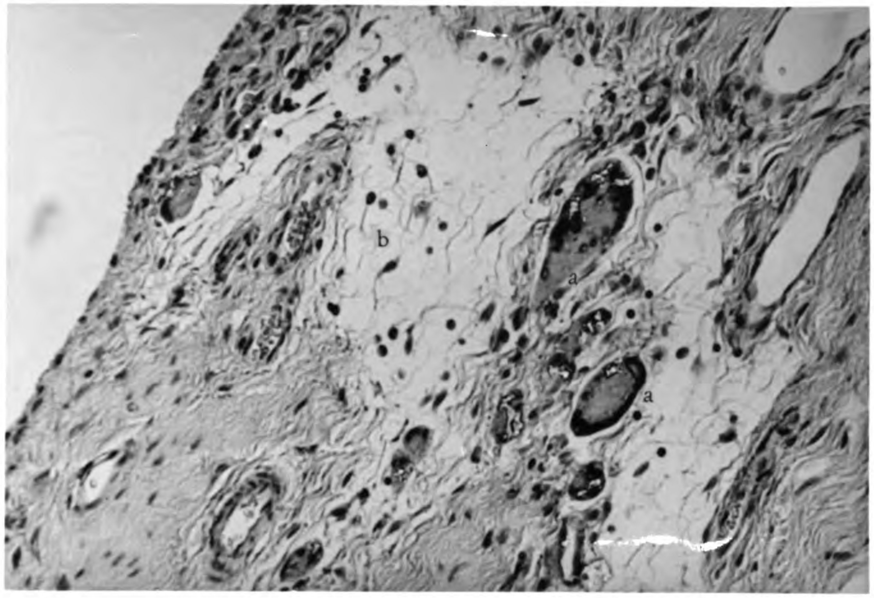

Figure 40. Regenerated anterior cruciate ligament (case #106630). Note the Langhans' type giant cells (a) with phagocytized dacron fibers, loosely arranged collagen fibers and fibroblasts (b). Hematoxylin and eosin. x 375.

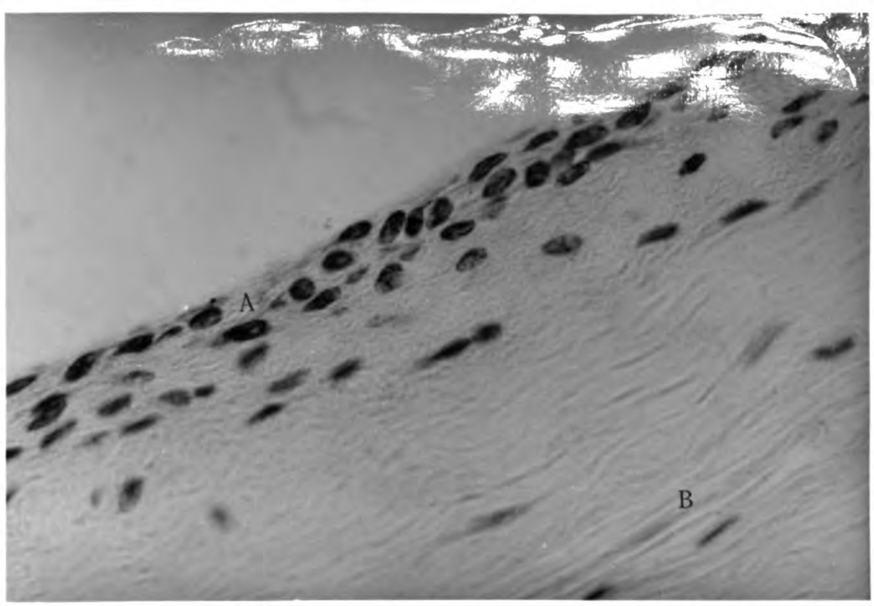

Figure 41. Normal anterior cruciate ligament. Synovial fibroblasts (A); fibroblasts and collagen fibers (B). Hematoxylin and eosin. x 1500.

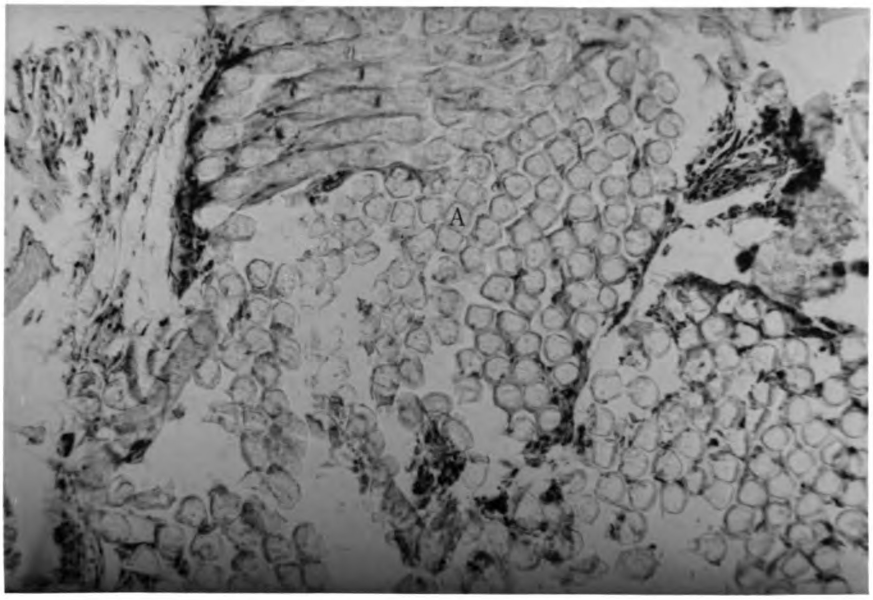

Figure 42. Transverse section of the dacron cord from the stifle joint (case #106630). Note the infiltration of fibroblasts and collagen fibers in between the dacron fibers (A). Hematoxylin and eosin. x 375.

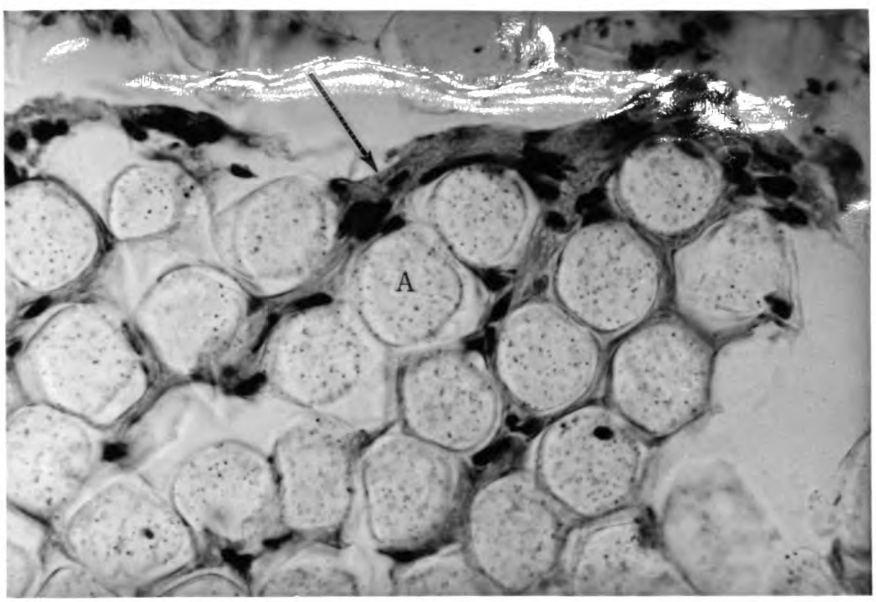

Figure 43. A higher magnification of the dacron cord shown in Figure 42. Note the infiltration of fibroblasts and collagen fibers (arrow) in between the dacron fibers (A). Hematoxylin and eosin. x 1500.

TABLE 7. Breaking load of the combined anterior and posterior cruciate ligaments.

Serial No.	Breed	Sex	Age (yr.)	Body wt. (kg.)	Breaking load (kg.) Right anterior & posterior cruciate lig.	Breaking load (kg.) Left anterior & posterior cruciate lig.
1	Mongrel	F	1	6.8	66.0	81.0
2	Brit. Spaniel	F	4	9.5	98.5	98.2
3	Siberian Husky	M	0.5	9.5	67.0*	77.0*
4	Beagle	M	2	9.0	133.0*	146.0*
5	Beagle	M	1.5	11.3	110.0*	110.0*
6	Beagle	M	7	11.8	107.0	126.0
7	Mongrel	M	1.5	8.0	75.0*	92.0*
8	Cocker Spaniel	M	1.5	6.8	63.0*	69.0*
9	Mongrel	M	1.5	12.7	91.0*	100.0*
10	Mongrel	M	6.5	11.3	111.0	105.0
11	Mongrel	M	2.5	9.5	82.0	68.0
12	Mongrel	F	7	7.7	99.0	69.-
13	Poodle	M	1.5	6.8	80.0	86.0
14	Beagle	F	7	11.3	90.0	76.0
15	Ital. Greyhound	M	7.5	5.5	87.0	96.0
				Average	90.63	93.28

*Separated either from the femoral or tibial epiphyseal line without breaking the cruciate ligaments.

together varied from 66.0 kg. to 126.0 kg. In one case, a 146.0 kg. load was not enough to break both ligaments, but instead they separated from the tibial epiphyseal line.

Breaking Strength of Anterior Cruciate Ligaments

The breaking load varied from 24.5 kg. to 51.0 kg. The breaking load was remarkably similar for the right and left anterior cruciate ligaments from the same dog (TABLE 8). In most cases, the stress train graphs of anterior cruciate ligaments of right and left stifle joints of the same dog were superimposable.

Breaking Strength of Posterior Cruciate Ligaments

The breaking load of posterior cruciate ligaments in different dogs varied from 24.0 kg. to 51.0 kg. The maximum difference in breaking load of the ligaments of right and left stifle joints of the same dog was 4.75 kg. (TABLE 9). Much similarity was found in stress strain graphs of posterior cruciate ligaments of right and left stifle joints of the same dog.

Breaking Loads of Strips of Fascia Lata, Skin and Braided Dacron

The breaking load of the fascia lata strips (1.0 cm. wide and 8.0 cm. long) varied from 16.5 kg. to 24.5 kg., with an average of 20.5 kg. The skin strips (0.6 cm. wide and 8.0 cm. long) broke at loads varying from 25.5 kg. to 31.7 kg., with an average of 28.5 kg. The average breaking load of the braided dacron was found to be 16.84 kg. A marked decrease in the breaking load was observed after moist heat sterilization of the dacron cord (TABLE 10).

TABLE 8. Anterior cruciate ligament breaking loads.

Serial No.	Breed	Sex	Age (yr.)	Body wt. (kg.)	Breaking load (kg.) Right anterior cruciate ligament	Breaking load (kg.) Left anterior cruciate ligament
1	Mongrel	F	1	8.2	35.50	38.00
2	Mongrel	M	4	7.7	33.50	26.75
3	Mongrel	M	2	7.3	43.00	39.75
4	Mongrel	M	1.5	10.0	47.75	51.00
5	Cocker Spaniel	M	2	10.9	24.50	24.50
6	Mongrel	M	6	9.5	40.75	44.75
7	Mongrel	F	9 mo.	6.0	24.75	27.50
				Average	35.68	35.96

TABLE 9. Posterior cruciate ligament breaking loads.

Serial No.	Breed	Sex	Age (yr.)	Body wt. (kg.)	Breaking load (kg.) Right posterior cruciate lig.	Left posterior cruciate lig.
1	Mongrel	M	2	8.2	24.00	24.50
2	Schnauzer	F	2	7.7	31.50	36.25
3	Mongrel	M	2	8.2	51.00	48.00
4	Cocker Spaniel	M	3	11.4	27.75	27.50
5	Cocker Spaniel	M	9	14.5	34.25	35.00
6	Cocker Spaniel	F	2	11.4	47.25	46.00
7	Mongrel	F	1.5	8.2	35.50	32.25
				Average	35.90	35.64

TABLE 10. Breaking load of braided dacron.

Test No.		Breaking load (kg.) before sterilization	Breaking load (kg.) after sterilization
1		16.40	11.60
2		16.30	14.30
3		15.90	15.50
4		17.90	13.90
5		17.70	15.30
	Average	16.84	14.12

DISCUSSION

The main objectives in repair of anterior cruciate ligaments are to eliminate the anterior drawer movement and to stabilize the stifle joint. Anterior sliding movement of the tibia during ambulation causes microtrauma to the articulating cartilage of the femur and menisci, which are the chief articulating weight bearing surfaces. Continuous microtrauma, during a period of time, is responsible for the pathologic changes resulting in osteoarthritis of the stifle joint.

In this experimental study of the replacement of the anterior cruciate ligament, braided dacron coated with silicone rubber was used as the prosthetic material. The coating of simple silicone rubber is not physically modified by soft tissue and is chemically inert (Braley, 1965). It does not cause any inflammatory or foreign body tissue reaction and can be sterilized. It can be molded to the appropriate size and shape of a tendon or ligament. Furthermore, it seems to possess a physiologic bounce that complements soft tissue during motion (Hunter, 1965). This material has many desirable characteristics. However, it does lack strength and is susceptible to tearing.

The idea of coating the dacron cord with silicone rubber was to protect the central piece from coming in contact with the joint fluid. In this way the integrity and strength of the dacron cord should be maintained with only minimal foreign body tissue reaction in the stifle joint.

Due to constant mechanical pressure on the prosthesis and the normal back-and-forth movement of the stifle joint, the silicone rubber broke at several places, permitting the dacron cord to come in direct contact with the joint fluid. The combined effects of the joint fluid, body temperature and mechanical wear after tearing of the silicone rubber might be the contributory factors in fragmentation of the dacron cord.

Two months following surgery, 8 of the 10 dogs had a normal gait and 2 dogs occasionally favored their legs after strenuous exercise. No functional disability was observed, even after the prosthesis broke. Of the 10 prostheses, 7 were found broken after a period varying from 2 to 4 months. Very slight to moderate anterior drawer movement of the tibia could be produced when the dogs were anesthetized.

At post-mortem examination, there was no evidence of osteoarthritis in the stifle joint. But foreign body tissue reaction was clearly observed on histopathologic examination. There was also some wear and tear of articular cartilages and of the menisci of the stifle joint which could be seen microscopically. Probably the foreign body tissue reaction was due to the dacron fibers. The microscopic wear and tear was due to constant microtrauma caused by anterior drawer movement of the tibia.

In this study, the functional recovery, anterior drawer sign, reduction in the breaking strength and fraying of the prostheses, microscopic wear and tear in the articular cartilages and menisci, chronic foreign body inflammatory changes, and the thickening of the joint capsule of the stifle joints appeared to support the results of Harrison and Adler (1956), Rathor (1959), Emery and Rostrup (1960), Leighton (1961), Vaughan (1963), Butler (1964), Ryan and Drompp (1966), Strande (1966a,b) and Childers (1966).

It was interesting to note that there was regeneration of the anterior cruciate ligament in 3 cases. On histopathologic examination the regenerated structure was found to be similar to the normal anterior cruciate ligament. However, there was some chronic inflammatory reaction, as evidenced by the presence of giant and plasma cells. Bassett and Carroll (1963), Ashley (1963) and Hunter (1965) reported similar results. They reported formation of a new sheath around a substitute tendon made of polyester fiber and silicone rubber. During surgical repair of the ruptured anterior cruciate ligament, partially or completely broken stumps should not be removed, as there is a possibility of ligament regeneration and reunion.

The average breaking strength of the combined anterior and posterior cruciate ligaments was found to be 91.9 kg., whereas breaking loads of anterior and posterior cruciate ligaments separately were 35.8 kg. and 35.7 kg., respectively. Breaking strengths of strips of fascia lata (1.0 cm. wide) and skin (0.6 cm. wide) were 20.5 kg. and 28.5 kg., respectively. These are the usual widths of fascia lata and skin strips used for anterior cruciate ligament substitutes in dogs weighing approximately 10.0 kg., even though their breaking strengths are considerably less than that of anterior cruciate ligament. The dacron cord used in this experiment had a breaking strength less than that of fascia or skin strips and approximately only one-half of that of the original anterior cruciate ligament.

SUMMARY

A study of the replacement of anterior cruciate ligaments with synthetic material (braided dacron coated with silicone rubber) was performed on 10 dogs. Breaking strength of the cruciate ligaments, fascia, skin and braided dacron was also determined.

Preoperative procedures consisted of standard routines preparatory to the use of sterile techniques. After making a skin incision in the parapatellar area, the stifle joint was exposed. The prosthesis was passed through oblique tunnels made in the femur and tibia. Finally, it was passed through a 3rd hole made below the tibial crest and the 2 ends were tied on the lateral side of the joint.

Dogs were kept under observation for variable periods of time, ranging from 3 to 13 months. Postoperative recovery was uneventful. Some of the dogs started using their legs as early as 2 weeks after surgery. Postoperative functional recovery was evaluated during a slow walk. All dogs attained normal gait after 4 weeks. After strenuous exercise, 2 dogs occasionally favored the leg with a prosthesis. Very slight to moderate anterior drawer movement could be produced in all cases when examined during anesthetization. Of 10 prostheses, 7 broke after 2 to 4 months. Broken prostheses were visible in radiographs.

Post-mortem examinations of joints bearing prostheses did not reveal osteoarthritic changes. Some wear and tear of the articular surfaces of the femur and the menisci was evident on histopathologic examination. Chronic inflammatory changes with foreign body tissue reaction were

observed in the joint capsule. In 3 cases, the anterior cruciate ligament regenerated.

A tensile testing instrument, "Instron", was used to determine the breaking strength of normal cruciate ligaments. Both the anterior and posterior cruciate ligaments were tested separately and, in some cases, simultaneously. Breaking strength of fascia lata, skin and braided dacron were also tested in the same manner.

CONCLUSIONS

After reviewing all available literature concerning repair of the anterior cruciate ligaments, it appears that all authors claim superiority for their individual techniques. Every claim for superiority is based upon experiments conducted on dogs. There is, however, agreement that the main objective is to stabilize the stifle joint.

In this experiment, the prosthesis broke and a slight to moderate anterior drawer movement was present. Even regenerated anterior cruciate ligaments were not as taut as the original ones. Nevertheless, the dogs were able to walk or run without functional disability. No disuse atrophy of the muscles was evident in any case.

It is concluded that dacron cord coated with silicone rubber when used as a substitute for the anterior cruciate ligament, did give temporary stability to the stifle joint. It appears that during this period of stability there is a compensatory strengthening and thickening of the joint capsule, thus permitting functional recovery of the affected limb. There may be, however, some anterior drawer movement of the tibia following attainment of functional recovery. The dacron used as a prosthetic anterior cruciate ligament does cause chronic inflammatory changes in the joint capsule. When a prosthesis is used as a substitute for a removed anterior cruciate ligament, there is a possibility of its regeneration. The prosthesis made of dacron covered with silicone rubber is unsatisfactory due to loosening of the coating and rupture of the dacron, even though the prosthesis may appear to function in a satisfactory manner initially.

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