SURGICAL CORRECTION OF A DEFICIENT TROCHLEAR GROOVE IN DOGS WITH SEVERE CONGENITAL PATELLAR LUXATIONS UTILIZING A CARTILAGE FLAP AND SUBCHONDRAL GROOVING

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ABSTRACT

SURGICAL CORRECTION OF A DEFICIENT FEMORAL TROCHLEAR GROOVE IN DOGS WITH EXTREME CONGENITAL PATELLAR LUXATIONS UTILIZING A CARTILAGE FLAP AND SUBCHONDRAL GROOVING

by Gretchen Legreid Flo

A surgical technique developed for deepening a deficient or convex femoral trochlea in dogs affected with extreme congenital patellar luxation was studied in 11 normal experimental dogs of various breeds ranging in age from 6 weeks to 10 months, and 10 clinically affected dogs ranging in age from 6 weeks to 4 years.

The surgical procedure used in experimental dogs involved making a lateral approach to the stifle joint. The patella was luxated to allow exposure of the femoral condyles. A rectangular cartilage flap was prepared by making parallel incisions through the articular cartilage along the condylar ridges and a perpendicular incision connecting the parallel incisions at the proximal end of the trochlear groove. The distal end was left attached 0.5 cm. above the intercondyloid fossa. After peeling the flap and "grooving" the subchondral bone, the flap was laid back down. A relatively deeper trochlear groove resulted and yet the articular cartilage was saved.

The objectives of this experiment were: (1) to see if the flap could be prepared in immature dogs of varying ages; (2) to see if the flap would stay in place and remain viable; and (3) to evaluate the gait and usefulness of the rear legs following the procedure.

Gross pathologic, histopathologic, and histochemical examinations of these femoral condyles 13-20 weeks postoperatively proved that the cartilage flaps remained in place and were viable as demonstrated by using toluidine blue O stain on tissue sections. Gait and activity on these rear legs were normal.

Surgical incisions in the cartilage healed somewhat by cartilage regeneration but mainly by granulation tissue which originated from subchondral bone. Fibrous tissue underwent metaplasia to fibrocartilage. The results indicated that the rate of healing depended more on the width of the defect created by the incisions (and subchondral grooving) than on age in which surgery was performed or the interval between surgery and euthanasia.

This cartilage flap procedure was compared to a grooving technique used clinically whereby the articular cartilage was curetted and removed. It was concluded that the cartilage flap procedure was physiologically more sound and would probably result in a longer lasting, less painful, and more useful stifle joint than curettage.

Clinical cases in which this cartilage flap technique was used along with other reconstructive measures were evaluated by the owners; and in most instances, their reports indicated satisfaction with the outcome.

The need for early corrective surgery in patellar ectopia prior to the development of permanent and unalterable changes was emphasized.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In extreme congenital medial patellar luxation, or patellar ectopia, positive and sometimes heroic surgery is necessary in order to obtain a functional joint. One aspect of this pathologic stifle involves a shallow, absent, or even convex femoral trochlea. Even after surgical realignment procedures have been performed to position the patella on the distal anterior femur, a groove or concave trochlea must be made in some cases to maintain its stability. Vierheller (1959), Mackey and McCune (1967) and Young (1957) have advocated a method whereby the cartilage is curetted to create a groove. This paper describes a procedure whereby a groove could be created at the distal femur and yet the articular cartilage preserved in order to maintain its physiological properties. This method was performed in normal experimental dogs to see if a cartilage flap could be peeled and then replaced after "grooving" the underlying bone. The objectives of the experiment were to see if the flap would stay in place and remain viable and to evaluate the use and performance of these legs. Clinical cases of patellar ectopia subjected to the cartilage flap procedure were reviewed.

During a 4-1/2-year period (January 1964 to September 1968) at Michigan State University, 297 patients with patellar luxations involving 474 legs were examined. Eighty-nine of these legs were considered severe, wherein abnormal curvature of the tibia and femur were present as well as other pathologic entities of the stifle. The breeds included in these figures were as follows: Poodles, Pekingeses, Chihuahuas, Papillons, Pomeranians, English Bulldogs, Yorkshire Terriers, Afghans, Toy Manchesters, and mixed terrier types. Poodles were most often affected.

In 39 legs a notation was made on the case record by the clinician describing a shallow, absent, or convex trochlea. In 12 legs it was judged by the attending clinician that the condition was so severe that surgery would not benefit the dog.

LITERATURE REVIEW

Review of the literature concerning severe congenital patellar luxation is scanty, to say the least. It might be well to review the pertinent structural and functional anatomy of the normal stifle joint in order to understand the pathologic stifle and the various surgeries that have been used for correction.

Structural and Functional Anatomy

Dyce (1952) has done an excellent job in reviewing the stifle joint from a clinical standpoint. By palpation, the most prominent bony landmark, the tibial crest, is located on the anterior aspect of the proximal tibia. Proceeding proximally, the tough middle straight patellar tendon may be felt inserting into the tibial tubercle of the tibial crest while its proximal end lies in the trochlear groove of the femur and merges with the patella. The patella serves as the attachment of the quadriceps group of muscles which form the muscle mass anterior to the femur. The patella, then, is a sesamoid bone which ensures a smooth gliding movement between the quadriceps tendon and its eventual attachment on the tibial tubercle. By ensuring this gliding action, the full leverage of the 2 long bones is maintained by the action of the quadriceps.

The anterior cruciate ligament (clinically more important than the posterior) passes from the medial aspect of the lateral femoral condyle to a position anterior and medial to the tibial spine just ahead of the menisci. The medial and lateral collateral ligaments are short ligaments on each respective side of the joint lying in the center or just caudal to an arc formed by the femoral condylar articular surfaces.

While overflexion of the stifle is prevented by the quadriceps group, overextension is prevented entirely by ligamentous structures (cruciates, collaterals). Medial and lateral movement of the tibia is controlled by the cruciates, collaterals, joint capsule, the fascia of the thigh muscles, and the gracilis tendon medially. The medial and lateral patellar ligaments are weak and relatively insignificant in the dog.

The menisci are 2 fibrocartilaginous crescent-shaped bodies which lie between the incongruent surfaces of the femur and tibia. Their function is to buffer points of greatest pressure on the tibia and femur during flexion and extension.

Kodituwakku (1962) added that in the normal joint the direction of force of the quadriceps muscle's contraction, the femoral trochlea, and the tibial tubercle are practically in alignment; and this, as well as the prominent nature of the lateral and medial ridges of the femoral trochlea, helps to confine the patella to the femoral trochlea in its upward movements during extension of the joint.

Rudy (1965) added that the stability of the patella in the femoral trochlea increases the efficiency of the quadriceps tendon in preventing axial rotation of the tibia.

Gross Pathology of the Deformed Stifle and Related Structures

The pathology of congenital patellar luxation in dogs is well presented by Kodituwakku (1962). Although each case may not possess all of these entities, the following were his observations: (1) the condition was unilateral or bilateral, (2) the patella was permanently medial, or if the patella could be replaced manually, it resumed its abnormal medial position after digital pressure was released, (3) usually there was inability to fully extend the stifle manually due to soft tissue contraction, (4) the quadriceps were atrophied, (5) the distal femur showed outward bending or bowing, (6) occasionally coxofemoral dislocations were present, (7) shallow, absent, or convex trochlea were present, (8) the medial ridge of the femoral trochlea failed to develop, (9) some remodeling of the menisci to accommodate the twisted femur and tibia occurred, (10) the tibial tubercle was twisted as much as 90° (Figs. 1 and 22).

Fig. 1. Left rear limb of a dog affected with patellar ectopia. Note curved femur (A), medial tibial tubercle (B), and medial quadriceps muscles (C).

To this list of pathologic entities, Brinker and Keller (1962) added other complicating factors, such as aseptic necrosis of the femoral head, partial ankylosis of the hock joint and contraction of the flexor muscle and tendons, and alterations in the plane of the articular surfaces between the femur and tibia.

Rudy (1965) described the gait of a dog affected unilaterally as moving on 3 legs while carrying the affected leg in a flexed position with the stifle adducted (medially), the hock abducted (laterally) and the toes pointing medially. If bilaterally affected, this dog would have had a pigeon-toed appearance; or if both stifle and hock were abducted, it would have been bowlegged.

Pathogenesis and Etiology

Although the exact pathogenesis and etiology of this stifle problem are unknown, Kodituwakku (1962) suggested that medial displacement of the patella was initiated by a deformity of the femoral trochlea. This luxation in turn altered the direction of the quadriceps force, bringing a gradual medial torsional stress upon the anterior tibial tuberosity. In the remodeling stages of young pups, this stress caused the tibia to rotate as much as 90°. If luxation occurred in 6- to 8-week-old pups, this rotation of the tibia occurred in only 3 to 4 weeks' time. The quadriceps became more medial. Hence, during extension of the stifle, the medial side of the joint underwent greater than normal pressure. In rapidly growing animals this imbalance of pressure caused a decrease in the diaphyseal and metaphyseal growth on the medial aspect of the femur and an increase in growth on the lateral aspect. Consequently, the femur "bowed" laterally. If the patella did not luxate until the dog was 5 to 6 months old, the severe deformities took longer to develop; and if the luxation began after the growing period (12 months of age), the developmental deformities were minimal.

On the other hand, Shuttleworth (1935) thought that bowing of the femur preceded the patellar dislocation, allowing the quadriceps muscle to pull the patella out of the trochlea medially. Without the physiological function of the patella lying in the groove, the trochlear lips remained immature for life.

Pearson (1963) believed the primary cause of patellar luxations was absence or poor development of the lateral and medial femoral condyles.

Singleton (1960) thought that a combination of the lack of a medial lip of the trochlea with the tibia rotated on the femur and twisting of the tibial tubercle predisposed patellar luxation.

Leonard (1960) took a broader stance as to etiology by stating "congenital luxation is frequently seen in the toy breeds, and is usually caused by the absence of a trochlea or some other congenital malformation".

It is interesting to note that 2 human orthopedic surgeons (Bowker and Thompson, 1964) stated "of the predisposing anatomical [human] findings of patellar dislocation, in 47 limbs, 16 of them were due to deficient patellar trochleas".

Surgical Procedures Used in Extreme Medial Patellar Luxation

Surgical intervention is the only method whereby a functional stifle joint may be obtained in extreme congenital patellar luxation. The procedures used may involve correcting one or more of the pathologic features in each patient. Rudy (1965) summarized these surgical steps as follows: (1) realignment of quadriceps axis by rotating the tibia, (2) reinforcement of lateral femoropatellar support to aid seating in the trochlea, (3) rotation of the tibial tubercle to a more normal position, (4) osteotomy of the curved distal femur, (5) releasing medial femoropatellar fascial and muscular adhesions, (6) creation of a medial barrier to prevent quadriceps migration, (7) tibial osteotomy to correct bowing and torsion, (8) femoral trochlear grooving.

The primary objective of these procedures was to realign and maintain the quadriceps tendon, patella, patellar tendon and tibial tubercle in a straight plane.

Jones (1935), Stader (1944), and Price (1955) have reported lateral femoropatellar support surgical procedures. These techniques by themselves were used in recurrent luxation; however, in the more severe congenital deformities, they may be used in conjunction with more positive anatomical reconstruction.

Rotation of the tibial tubercle in the dog was first described by Singleton (1957), which was a modification of the Hauser technique used in dorsolateral patellar luxations in man. Singleton's technique, modified further by Vierheller (1959) and Brinker and Keller (1962), was recommended when the tibial tubercle was deviated and especially when other concurrent pathologic entities existed in the stifle.

Low cuneiform femoral osteotomy reported by Shuttleworth (1935) involved complete fracturing of the distal femur at the point of greatest curvature and subsequent pinning with the distal piece redirected in a more normal vertical plane. This technique was especially useful in dogs with extreme medial displacement of the quadriceps muscle.

While Craver (1938) recommended patellectomy for luxation due to congenital absence of a trochlea, Leonard (1960) warned that this procedure does nothing to correct the pull of quadriceps and thereby accomplishes nothing.

Pearson's method (1963) for correcting the primary cause of patellar luxation was to implant a teflon barrier at the distal anterior medial femur. This, in effect, created a lengthened medial condylar ridge and thereby prevented the quadriceps tendon from sliding abnormally medially, which indirectly kept the patella in its proper place. He felt that if the surgery were done in the growing period the deviated tibial tubercle would eventually return to its more normal alignment. However, his experimental results indicated some problems with this technique.

While Hobday (1905) was the first veterinarian to describe a deficient trochlea in the dog, no one reported its reconstruction until Young (1957) treated a "completely convex" trochlea by paring a groove, just wide enough to take the patella and deep enough to hold it securely, as well as rotating the tibial tubercle. This groove was prepared with a small bone saw or scalpel blade. He also recommended the regrooving procedure in cases of severe recurrent luxation in which the medial lip of the trochlea was worn away. Brian Singleton's (1957) reply to this procedure was,

> "It was a bold step to gouge through articular cartilage and down into the bone, although Mr. Young's results obviously justified the procedure."

Vierheller (1959) stated,

> "In a high percentage of cases, palpation of the trochlear portions of the femur reveals an absence of the central groove and trochlear ridges."

His treatment consisted of a combination of tibial tubercle rotation and careful paring of a shallow groove in the articular cartilage approximating the smooth appearance of a normal trochlea. Mackey and McCune (1967) described a similar technique.

Horowitz (1937), a human orthopedic surgeon, used the Albee procedure in 6 out of 20 human patients, where there was a deficiency of the lateral femoral condyle and the intercondylar sulcus [femoral trochlea]. This procedure involved creating a greenstick fracture of the lateral condyle and elevating it to a plane above that of the medial condyle and maintaining it with a wedge bone graft. In effect, a groove was created.

Vierheller later (1967) reemphasized that he grooved only where a trochlea was absent or flattened, and yet it was only one of the several procedures he used to realign the quadriceps, patella, patellar tendon, and tibial crest. Other steps included releasing the reticulum of the medial and lateral fascias, and surgical readjustment of lateral soft tissue for tension. He carried the grooving to cancellous bone if necessary to provide an adequate depth. He stated,

> "There is good evidence that the carved surface undergoes eburnation from the movement of the patella and becomes a nearly normal articular surface covered with tough fibrous tissue. I have observed no arthritic changes as an aftermath of the carving procedures, having observed scores of clinical patients years after receiving the surgery."

This answer as to what happens to this large denuded surface has not been substantiated by any published data. In unpublished work, Flo* has found that in 8 pups, surgically operated at 2 to 8 months of age

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* In preparation

and sacrificed 4 to 8 months postoperatively, showed, indeed, a generally smooth trochlea and lacked arthritic crescents on the femur. Half of the dogs were curetted without invading the subchondral bone, and half were curetted deeply with invasion of the subchondral bone. Most patellar surfaces displayed a linear groove on the cartilage. Most of the condyles were 3 to 4 mm. wider than the control and the patella .5 to 1.5 mm. wider than the opposite control leg. While obvious lameness was not apparent, these dogs seemed to be weak on their rear legs while pivoting and when their front legs were raised. Upon running, they tended to "bunny hop".

It was noted histologically that deeper curettage resulted in the trochlear groove being overlaid primarily with fibrous tissue, with an attempt to form some fibrocartilage. The groove of the trochlea was overlaid with fibrous tissue and fibrocartilage in dogs in which shallower grooves were created, while the ridges were composed of hyaline cartilage.

In 1 dog, the articular cartilage appeared normal and was not overlaid with fibrous tissue; however, the articular cartilage was orthochromatic as determined by its reaction to the toluidine blue O stain. Other changes included vertical splitting and horizontal flaking of the articular cartilage and flattening of chondrocytes in the superficial layers. Similar changes were evident on the patella but were not as extensive.

Articular Cartilage Regeneration

As early as 1743, William Hunter stated,

> "An ulcerated Cartilage is universally allowed to be a very troublesome Disease: that it admits of a Cure with more Difficulty than a carious Bone, and that, when destroyed, it is never recovered."

Review of the more modern literature concerning articular cartilage regeneration is certainly confusing. Bennett and Bauer (1932) listed opinions of how articular cartilage regenerated as follows: (1) independent regeneration of articular cartilage did not occur, (2) articular cartilage regeneration did occur, (3) regeneration occurred through proliferation of fibroblasts with subsequent metaplasia to cartilage. Herron (1967) added a fourth option, saying that regeneration could occur by amitotic division of existing chondrocytes.

These opinions were all substantiated by experimental work; however, these experiments were so markedly different in design that it is no wonder contradictions existed.

Mankin (1962) used immature rabbits, operating on the distal anterior portion of the femur using a superficial scalpel slice, a deep scalpel slice invading subjacent bone, and a 3-mm. core defect into the subjacent bone. Observation time was 1 day to 6 weeks. All wounds healed identically, going through necrosis and short-lived superficial proliferation, and mainly healed by fibrocartilage proliferation from the base of the wound. Since cartilage was avascular, the typical stage of inflammation in healing was skipped unless the osseous endplate was interrupted and then it was only marked at the base of the defect.

Bennett and Bauer (1932), however, used young adult dogs, removing a 4.6 x 3 x .5 mm. strip of superficial cartilage on the weight-bearing femoral condyle and also a 10 x 3 x .5 mm. strip from the patellar groove. They also repeated the process, removing cartilage and subchondral bone. Their observation period was from 4 to 28 weeks. Their confusing report indicated that some form of repair occurred in the superficial defects in the weight-bearing and nonweight-bearing surfaces by 28 weeks, but only a small portion of the defect was filled. Their results were complicated by the fact that no postsurgical splints were applied and patellar luxation occurred, thereby contributing to the changes.

DePalma _et al_. (1966) used immature and mature (1- to 3-year-old) dogs taking partial (4 mm. diameter) and full thickness cores (with subchondral bone) from weight-bearing and nonweight-bearing surfaces of the femur. Their results, using tritiated thymidine as an indicator of DNA synthesis of impending mitoses, indicated that partial defects, regardless of age or weight-bearing and nonweight-bearing surfaces, failed to indicate articular cartilage proliferation, both grossly and histologically, even up to 66 weeks postsurgically. In full thickness weight-bearing defects, regardless of age, material had filled the defect completely by 16 weeks postsurgically and histologically resembled hyaline cartilage. The nonweight-bearing defects took longer (32 weeks) to fill. Observation periods ran weekly for 66 weeks.

DePalma _et al_. (1966), Mankin (1962), and Bennett and Bauer (1932), then, admitted that articular cartilage may have a limited ability of independent regeneration of cartilage, but it was feeble and not always demonstrable. Mankin (1962) concluded further that there was no evidence that this limited regeneration had any material contribution to the eventual healing of the cartilage defect. Mankin (1962) and DePalma _et_ al. (1966) concluded that the new articular cartilage originated from subchondral granulation tissue, which then underwent metaplasia to fibrocartilage and to hyaline cartilage.

On the other hand, Herron (1967) removed 2 cartilage plugs from the proximal caudal humeral condyle of 11- to 13-week-old pups, simulating osteochondritis dissecans. From each pup (except 2 controls) he took the partial thickness plug and implanted it into the full thickness defect to prohibit the subchondral bone from proliferating into the defect. Regeneration of all these full thickness defects with grafts was apparent 16 weeks postoperatively. However, in 3 of the 8 dogs, subchondral tissue infiltrated around the transplant and inhibited the complete closure of the basal layer of the articular cartilage in that area. When the transplant barrier was effective (5 out of 8 dogs) healing of the articular cartilage by surrounding articular cartilage was apparent within 2 weeks' time and appeared to be the preferable method of repair of the complete defects. The partial defects (with no transplant plug) showed some regenerative ability, but was slower and not complete by 16 weeks. Consequently, it appeared that if a deeper portion of the cartilage were violated, regeneration was more complete by the surrounding articular cartilage; but if subchondral granulation tissue invaded the defect, it slowed down the regeneration by articular cartilage and healing therefore took place by metaplasia.

Articular Cartilage

Joints serve the purpose of bearing weight and providing motion. According to Freyberg (1967) articular cartilage is subjected to more vigorous wear and tear than any other tissues of the body except for the integument.

One function of articular cartilage is to provide a smooth gliding surface for bone ends. As shown in Fig. 2, Freyberg (1967) demonstrated the fibers of articular cartilage as arranged in a manner resembling

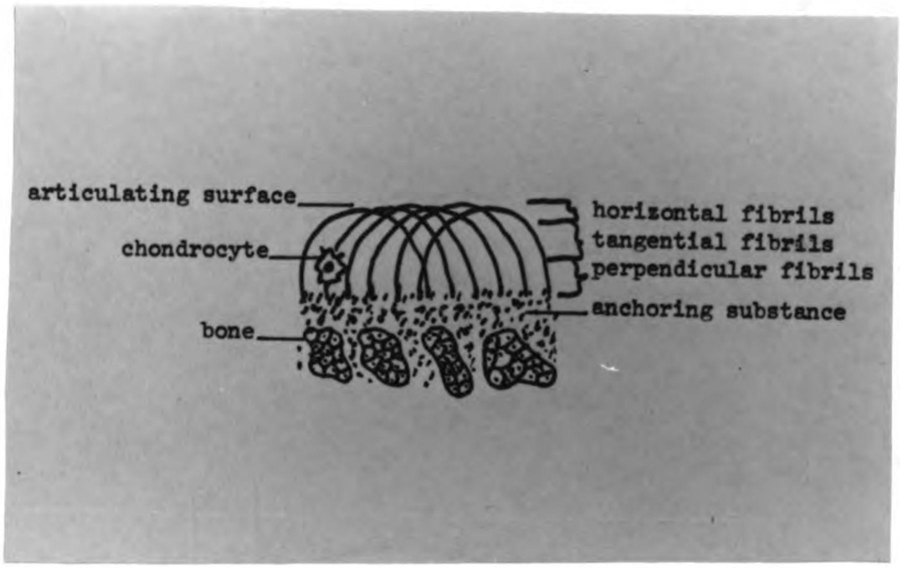

Fig. 2. Sketch showing articular cartilage as revealed by polarized light.

croquet wickets. Gliding action is permitted due to the lubrication by joint fluid and the surface arrangement of the cartilage fibrils, providing a somewhat irregular surface which prevents adhesions of the surfaces. Articular cartilage is avascular and derives most of its nutrition from the joint fluid, with the subchondral bone and subsynovial vessels at the cartilage-synovial membrane junction serving as minor nutritional sources.

Articular cartilage's second important function, according to Freyberg (1967), is to buffer blows and jolts to the body. When pressure is exerted on articular cartilage the "wickets" expand laterally and the thickness of the cartilage decreases. This cushions the blow, thereby protecting the subchondral bone. When this pressure is released, the "wickets" (or fibrils) rebound due to their elasticity.

Johnson (1962) elaborated on the functions in the anatomical layers of articular cartilage, stating that the superficial layer resists shear in joint motion while the broad intermediate layer of cartilage has great shock-absorbing capacity due to its high content of bound water.

Barnett et al. (1961) pointed out that if irregularities of joint surfaces were inelastic they would score grooves upon the opposing surfaces. However, elastic projections will bend and not damage articular surfaces. Herron (1967) detected defects on the scapular glenoid fossa opposite the defects he created surgically on the humerus. These disappeared when the humeral defects healed.

Lewis and McCutchen (1959) proposed the "sponge-weep" theory of articular cartilage. They thought the cartilage (sponge) soaked up fluid, thereby ensuring its adhesiveness to the bearing surfaces, as well as permitting the joint fluid to be squeezed out, thus ensuring an instantaneous formation of lubricant fluid.

According to Curtiss and Klein (1963) the intercellular matrix of articular cartilage is a protein mucopolysaccharide, consisting of mainly chondroitin sulfate-A, with smaller amounts of chondroitin sulfate-C with keratosulfate in combination with a noncollagenous protein.

Sylvan (1947) stated that since chondroitin sulfate is so highly metachromatic, its quantity and quality may be estimated with toluidine blue O stain. Metachromasia, according to Thompson (1966), is a characteristic color change which certain pure dyes exhibit when bound to certain substances (chromotropes) either in tissue section or aqueous solution. Chromotropes are high molecular weight substances with free anionic groups.

Walton and Ricketts (1954) suggested that a decrease in metachromasia with toluidine blue O may mean any of the following: a decrease in the concentration of acid polysaccharides, loss of anionic groups by protein and/or disruption of the molecular structure or at least degradation of acid polysaccharides to diffusable fractions.

Waine (1961) stated that the earliest structural defects of degenerating cartilage took place within the intercellular matrix. Loss of metachromasia was characteristic of degenerating cartilage according to Collins and McElligott (1962). Van Pelt* reiterated this statement, saying that toluidine blue O is one of the simplest tests for cartilage viability.

Synovial fluid, Van Pelt (1962) reported, is composed of a plasma dialysate to which has been added a high concentration of hyaluronic acid, secreted by the synovial cells, in a highly polymerized state. In another article, Van Pelt (1967) stated that the quantity and quality of the hyaluronic acid may be evaluated using a PAS reaction in order to detect degenerative changes in the synovial membrane which in turn may alter the quality of the nutrition and lubrication of the joint.

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* Van Pelt, R. W. - personal communication, Michigan State University, East Lansing, Michigan, 1969.

MATERIALS AND METHODS

Eleven apparently normal and healthy dogs, of various breeding, ranging from 6 weeks to 10 months of age, were subjected to experimental surgery. These dogs were donated for experimental purposes to the Michigan State University Veterinary Clinic from private homes. All puppies were vaccinated for distemper and hepatitis* and wormed upon admission with trichlorvos.**

The smaller dogs were housed in individual cages at the Michigan State University Veterinary Clinic and allowed exercise twice daily in indoor runs. Larger dogs were kept in indoor runs. These dogs were fed once or twice daily with a commercial dry cereal*** with a small amount of canned meat† added. Water was available at all times.

The breed, weight, identification number, and ages at surgery time and sacrifice time may be found in Table 1.

In addition, clinical cases of patellar ectopia were subjected to various combinations of surgery and a follow-up attempted.

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* "Distemperoid," "Hepoid" T.C., Fromm Laboratories, Inc., Grafton, Wisconsin.

** "Task", Shell Chemical Co., New York, N.Y.

*** "Kennel Ration Meal", Quaker Oats Company, Chicago, Ill.

† "Watkins Beef", Watkins Bros., Ferndale, Michigan

Table 1. Experimental operative and euthanasia timetable

Dog	Sex	Breed	Age at Surgery (wks.)	Age at Euthanasia (wks.)	Time on Experiment (wks.)	Weight at Surgery (lb.)	Weight at Euthanasia (lb.)	Grade for gross appearance of trochlear groove (at end of experiment)*
E-1	M	German Shep.	23	36	13	45	70	C
E-2	M	Beagle cross	6	19	13	5	22	A
E-3	F	Springer cross	10	24	14	12	23	A
E-4	M	Boxer cross	10	30	20	18	45	B
E-5	F	Brittany cross	40	60	20	35	35	C
E-6	M	Boxer cross	21	38	17	28	35	A
E-7	M	Boxer cross	32	46	14	40	40	B
E-8	F	Poodle	35	48	13	12	12	A
E-9	M	Boxer cross	14	33	19	18	40	A
E-10	F	German Shep.	20	38	18	40	63	C
E-11	M	Springer cross	15	43 arthrotomy	28	15	40 arthrotomy	A

* See page 32, paragraph 2, for interpretation of grading system.

Preoperative Preparation

Solid foods were withheld from experimental animals 24 hours prior to surgery. Each dog was given a basal anesthetic with thiamylal Na,* intubated, and surgical anesthesia was maintained with methoxyflurane** in a closed system.***

The hair of the leg on which surgery was to be performed was completely clipped from the hock to the dorsal midline of the back. The leg was scrubbed 5 or more times with a germicidal detergent† and strict aseptic procedures were carried out from that point until the completion of surgery. The animal was placed in dorsal recumbency using a V-trough for support with the stifle slightly flexed. Surgical lights, instrument trays and special instruments were placed in proper positions.

All surgical instruments, drapes, gloves, suture material, towels, and gowns were sterilized in a steam autoclave. A surgical cap and mask were donned by the surgeon. Surgical preparation of the hands and arms of the surgeon was accomplished using a germicidal detergent,† scrubbing with a brush for 10 minutes. Sterile gown and gloves were worn while carrying out the operative procedure. The opening of the surgical drape was placed over the anterior surface of the stifle so that the tibial tubercle and patella were exposed (Fig. 3).

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

** "Metafane", Pitman and Moore Co., Indianapolis, Indiana

*** Ohio Heidbrink, Model 960, Madison, Wisconsin

† "Germicidal detergent", Parke, Davis & Company, Detroit, Michigan

Surgical Procedure

The surgical approach to enter the stifle joint with a lateral incision is described by Piermattei and Greeley (1966). A curved parapatellar skin incision extended from the lateral aspect of the tibial tubercle to the distal fourth of the femur (Fig. 4). Skin bleeders were clamped and ligated with a nonabsorbable suture material.* Subcutaneous fascia was incised longitudinally, exposing the joint capsule. With the limb flexed, a careful stab incision just medial to the patellar tendon initiated the arthrotomy, which was continued distally and proximally along the patellar tendon and patella with Mayo dissecting scissors, leaving enough fascia along the patella to pass a suture through upon closing the joint. With the stifle extended, the patella was luxated laterally (Fig. 5). The stifle was then flexed slightly in order to keep the patella luxated. Joint capsule bleeders were clamped but not ligated so that no suture material would be left within the joint.

Parallel incisions in the articular cartilage just inside the trochlear ridges were started at a level .25-.5 cm. from the intercondyloid fossa (Fig. 6) and carried proximally to the periosteum of the distal femur. The incisions penetrated the entire thickness of the avascular articular cartilage until the subchondral bone offered greater resistance to the scalpel and bleeding was observed. A perpendicular incision connecting the parallel incisions was made just proximal to the trochlea in the perichondrium.

A rectangular cartilage flap was peeled distally beginning at the proximal end of the trochlea (Fig. 7) with a sharp 1/8 inch osteotome and continued distally the entire length of the parallel incisions.

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* "Tasalon", Coats and Clark, New York, N.Y.

Care was taken to avoid injuring the articular cartilage. The cartilage flap was left attached distally but had to be bent outwards in order to allow subchondral grooving with a #15 scalpel blade or small rongeurs* (Fig. 8). The grooving in these normal experimental dogs was carried to a depth such that when the cartilage flap was replaced a visible deepening of the trochlea was discerned (Fig. 9).

Subchondral bone was grooved deeper at the proximal end of the trochlea where the patella normally lies in a standing dog. Distally, subchondral bone was grooved less deeply to allow a gentle transition between the cartilage just above the intercondyloid fossa and the deepened trochlea.

An attempt was made to create a smooth and uniform groove in the bone. Subchondral bleeding was controlled by blotting until the grooving was complete. At this time the cartilage flap was carefully pushed down into the groove until the cohesiveness of the subchondral bone kept the flap in position. No attempt to suture the flap was made, since it was unnecessary. The subchondral hemorrhage seemingly stopped after the flap was in position.

The patella was repositioned over the cartilage flap and the fibrous joint capsule was sutured with nonabsorbable sutures** in a simple interrupted pattern. Subcutaneous and skin sutures were placed in an interrupted pattern with a nonabsorbable suture material.***

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* "Lempert Rongeur", Richards Mfg. Co., Memphis, Tennessee

** "Vetafil Bengen", Dr. S. Jackson, 7801 Woodmont Avenue, Washington, D.C.

*** "Tasalon", Coats and Clark, New York, N.Y.

Fig. 3. Surgical patient in dorsal recumbency with patella and tibial tubercle exposed.

Fig. 4. Skin and subcutaneous tissue incision lateral to the patella followed by an incision into the joint capsule.

Fig. 5. Luxation of the patella to permit exposure of the femoral condyles.

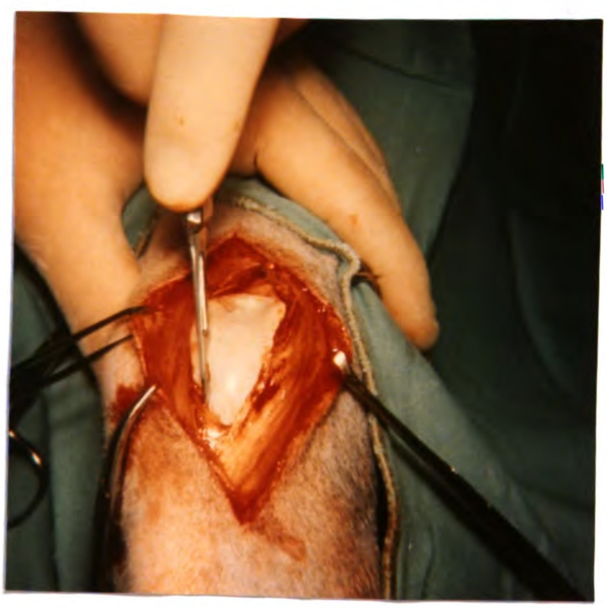

Fig. 6. Parallel incisions along the condylar ridges, followed by a perpendicular incision at the proximal end of the ridges.

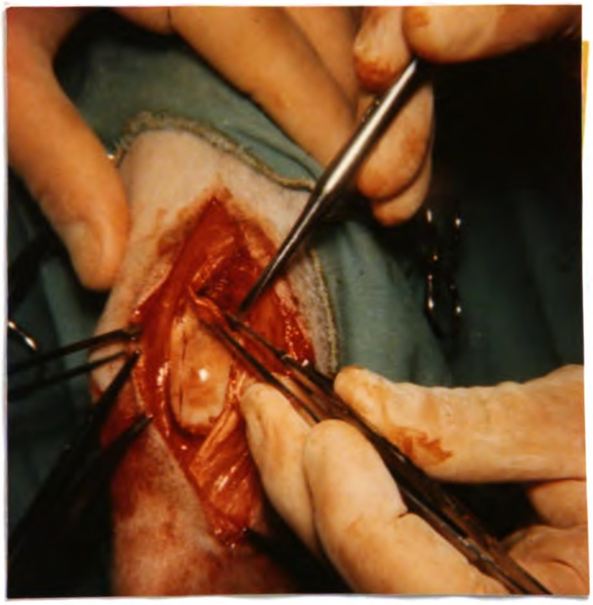

Fig. 7. Peeling the articular cartilage flap.

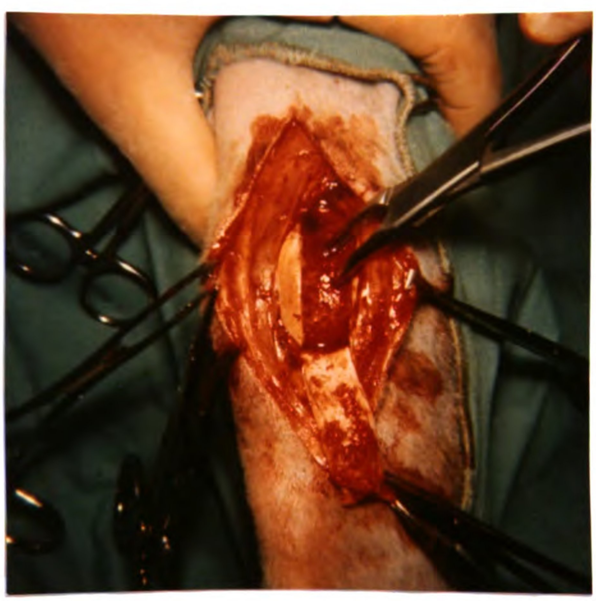

Fig. 8. "Grooving" the subchondral bone with the flap reflected.

Fig. 9. The cartilage flap repositioned over the subchondral bone followed by replacing the patella and closing the joint capsule, subcutaneous tissues, and skin as separate layers.

Postoperative Care

Benzathine penicillin (10,000 U/lb.)* I.M. was given prophylactically as well as a distemper hepatitis booster.** A modified Thomas splint was applied, which remained in place 7 to 14 days, depending on the age of the dog.

Antemortem Examination

At various indefinite intervals, and prior to euthanasia, the dogs were exercised and evaluated for lameness. Palpation of the stifle joints was carried out.

In order to keep 2 experimental dogs for longer periods of time, exploratory arthrotomies were performed on E-4 and E-11 at 4 weeks and 28 weeks (postoperatively), respectively, at which time the trochleas were photographed. Long term studies were planned for E-11. Consequently, this dog was not euthanatized.

Postmortem Examination

Each dog (except E-11) was euthanatized with pentobarbital sodium*** at the rate of 36 mg./lb. I.V. As quickly as possible the stifle joints of both legs were opened, the joint fluids aspirated, and the surrounding muscles stripped from the distal femur and proximal tibia. A double action bone cutter was used to remove the distal femur, patella and proximal tibia (in one piece), which were immediately photographed and then immersed in a mixture of 1 part formalin, 3 parts alcohol, 1 part

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* "Bicillin Fortified", Wyeth Labs, Inc., Philadelphia, Pennsylvania

** "Distemperoid," "Hepoid" T.C., Fromm Laboratories, Inc., Grafton, Wisconsin

*** "Toxital", Jensen-Salsbury Labs, Kansas City, Missouri acetic acid, 5 parts water (FAA), as recommended by Quartuccio.*

Histopathologic Studies

After the tissues were preserved in FAA for 48 hours, cross sections were taken from 3 levels of the femoral trochlea and 1 level of the patella (Fig. 10). These bony sections were then decalcified in 1.5%

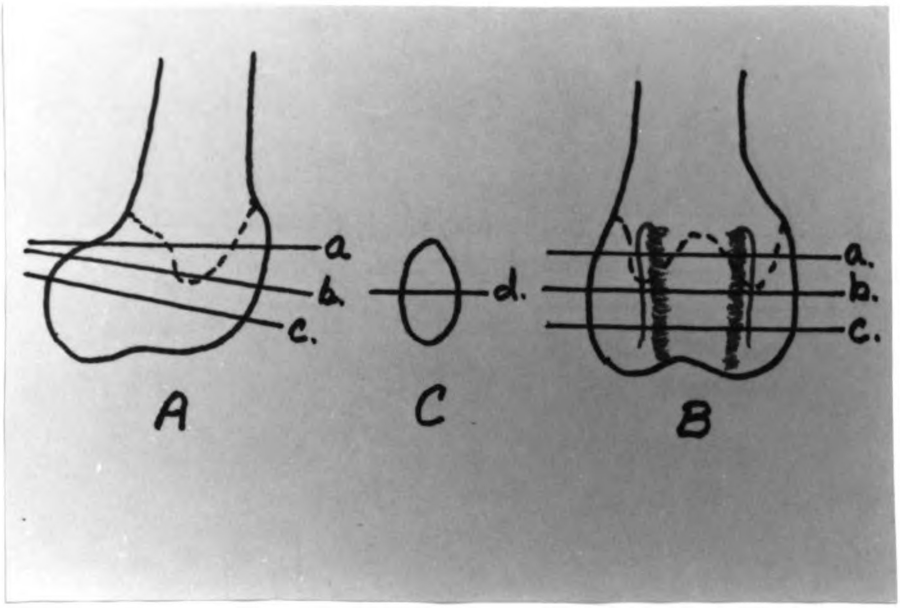

Fig. 10. Histologic sectioning of experimental dog. (A) lateral view of distal femur, (B) anterior view of distal femur, (C) anterior view of patella, (a) proximal femoral trochlea, (b) midfemoral trochlea, (c) distal femoral trochlea, (d) mid patella. Note: the dotted lines represent the epiphysis.

nitric acid in 10% formalin for 1 to 3 weeks, as advocated by Quartuccio.* The end point of decalcification was determined by testing for the calcium ion in the decalcifying solution after a change as described in

* Quartuccio, Nicholaus - personal communication, Anatomy Department, University of Wisconsin, Madison, Wisconsin, 1968

The Preparation of Decalcified Sections, by Brain (1964).

After washing, dehydrating, and clearing, these bony tissues were embedded in paraffin.* Sections were cut at 7 to 8 microns. All tissues were stained as follows: hematoxylin and eosin using Galigher's method (1964) described in Essentials of Practical Microtechnique but modified using Walter Lipp's eosin formula;** periodic-acid-Schiff (PAS) as described in the Manual of Histologic and Special Staining Technics of the Armed Forces Institute of Pathology, Washington, D.C. (1957); and toluidine blue O as described in McClung's Handbook of Microscopical Technique (1950).

All sections were mounted in Permount*** and examination was accomplished by light microscopy.

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* "Paraplast", Aloe Scientific Division of Brunswick, St. Louis, Missouri

** Lipp, Walter - personal communication, Anatomy Department, Wayne State University, Detroit, Michigan, 1968

*** Fisher Chemical Specialty, Fairlawn, New Jersey

RESULTS

Experimental Surgical Observations

The younger the puppies were, the relatively thicker the cartilages were on the distal femur. A 6-week-old puppy (E-2) had a cartilage flap thickness of approximately 3 mm., while a larger, 20-week-old puppy (E-10) had a 2 mm. thick cartilage flap and a 32-week-old puppy (E-7) had a flap approximately 1.5 mm. thick. The cartilage-subchondral bone junction was much easier to separate (in the peeling process) in young pups, whereas the older puppies' (48-60 weeks) junctions were much more adherent.

Performance

When lameness was detected it was most apparent immediately after removal of Thomas splints. Lameness persisted only a few days, with the exception of E-7, which had mutilated its splint on the 7th postoperative day, resulting in development of an excessive joint effusion. On the 12th postoperative day, 15 cc. of serosanguineous synovial fluid was aspirated from the stifle, and lameness disappeared the following day. Bacteriologic cultures of the synovial effusion were negative.

This same dog (E-7), as well as E-11, were observed repeatedly leaping 2 to 3 feet in the air while "exercising" in indoor runs. The heaviest dogs on experiment, E-1 and E-10, often "bounced" off their cages or runs when excited, and used their rear legs for thrust. Obviously, these dogs were not hesitant in using their rear limbs.

All experimental dogs walked, trotted, and ran normally using full strides with no tendency to "bunny hop".

Response to pain could not be elicited on palpation of the stifles of experimental dogs. The relatively higher trochlear ridges could be discerned as well as the nonabsorbable suture material on the medial aspect of the joint capsule. In only 1 dog (E-10) was an abnormality detected. This was denoted by a slight click when the patella was pushed against the medial trochlear ridge while the stifle was flexed.

Gross Examination of the Femoral Condyle and Patella

An arthrotomy was performed on the 1st experimental dog (E-3) to check the healing process 4 weeks postoperatively. The flap was adhered to the subchondral bone and the cartilage incisions were beginning to fill in (Fig. 11).

An arthrotomy, 28 weeks postoperatively on E-11 (used for long term study), indicated that the incisions were healing with no abnormalities present on the femur or patella.

Joint fluid aspirated from both control and operated stifle joints was normal in color, quantity, and viscousness.

Cartilage flaps in general had the appearance of normal, viable articular cartilage (Fig. 12).

The incisions could still be seen; however, distally in the joint they were less distinct (Fig. 13). The gap (created by an incision in the articular cartilage) between the cartilage flap and the condylar ridge of the femur was widest at the proximal third of the trochlea. By passing a hemostatic forcep over this gap, a slight depression was evident.

Usually no grinding was detected, indicating some type of tissue was covering the subchondral bone underneath the incisions. In small areas (1-6 mm.) in 5 dogs (E-1, E-4, E-5, E-7 and E-10) subchondral bone was palpated. Therefore, in order to compare stifles, a grading system was devised, the results of which are tabulated in Table 1.

Grade "A" was assigned to those condyles wherein only the incisions were visible; grade "B" denoted incisions with small areas (1-3 mm.) of exposed subchondral bone; and grade "C" was applied to those dogs in which the proximal incisions were rough and larger areas (3-6 mm. in length) of subchondral bone were exposed.

The flap of E-5 at the time of original surgery was peeled with great difficulty, resulting in several tears and cracks. Its distal attachment had been inadvertently severed, except for 1/4 of its width. Postmortem examination revealed an oblique midtrochlear depression located in the same position where the flap had been torn at the time of peeling. However, distally, where the attachment had torn, only a faint line was visible. Although this stifle was graded "C", the outcome was surprisingly good (Fig. 14).

In 3 dogs (E-1, E-10, E-7) a white cartilage-like projection (2 x 2 x 1 mm.) grew out of the incisions (Fig. 15). Only in E-10 did the overhang project towards the trochlea and cause mechanical interference. It was only when the patella was pushed in a slightly abnormal medial position and the stifle flexed that a slight "catch" was noticed.

Two other femoral abnormalities were detected: an elongated and distorted intercondyloid fossa on E-2 and a bony enlargement (exostosis) above the trochlea on E-10, which did not interfere with patellar movement.

Fig. 11. Femoral condyle of dog E-3 with the cartilage flap adhesed in place 4 weeks postoperatively.

Fig. 12. Healed cartilage flap of dog E-6 17 weeks postoperatively. Notice smooth and hyaline appearance of the cartilage flap.

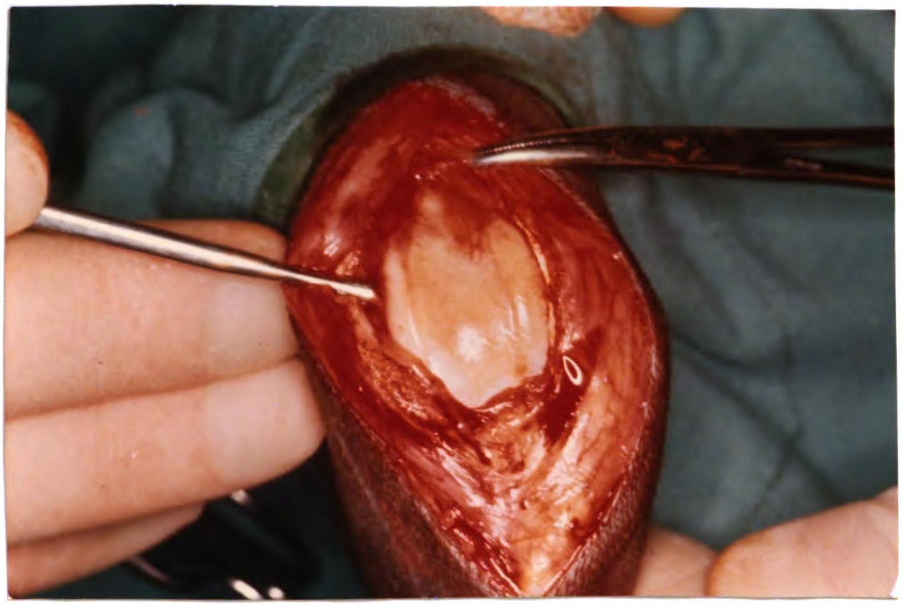

Fig. 11

Fig. 12

Fig. 13. Control and operated (on right) femoral condyles and patellas of dog E-9 19 weeks postoperatively. Notice disappearance of distal incisions.

Fig. 14. Femoral condyle of dog E-5 20 weeks postoperatively. Notice hyaline appearance of flap, rough proximal incision (A), midtrochlear defect (B), and faint line above intercondyloid fossa (C) where the attachment had been torn.

Fig. 13

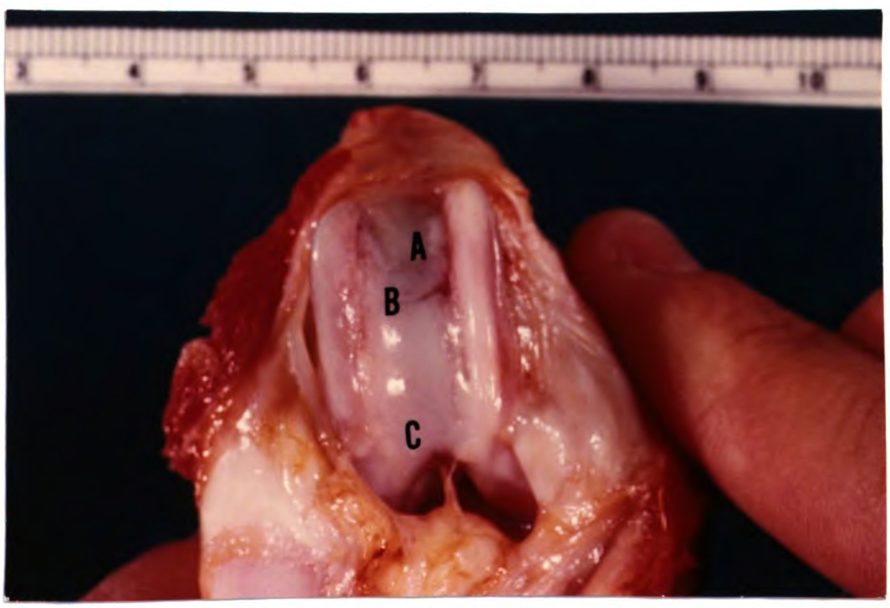

Fig. 14

Fig. 15. Femoral condyle of dog E-1 13 weeks postoperatively. Notice groove on patella (A), rough proximal medial incision (B), and cartilage-like projection on condylar ridge (C).

Fig. 16. Cross section of the femoral condyle of dog E-3. Notice smooth cartilage flap adhered to the subchondral bone (A) and incision sites (B). Toluidine blue O stain; low magnification.

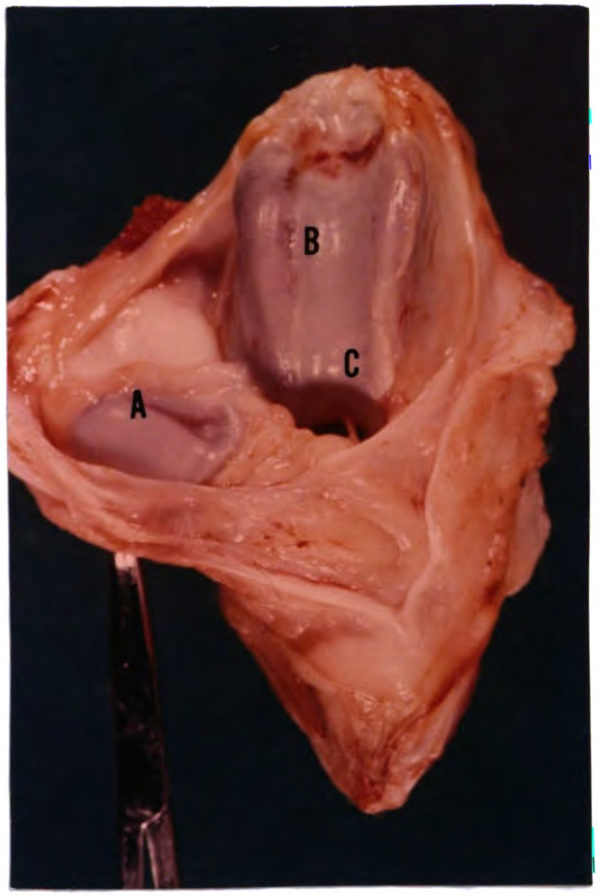

Fig. 15

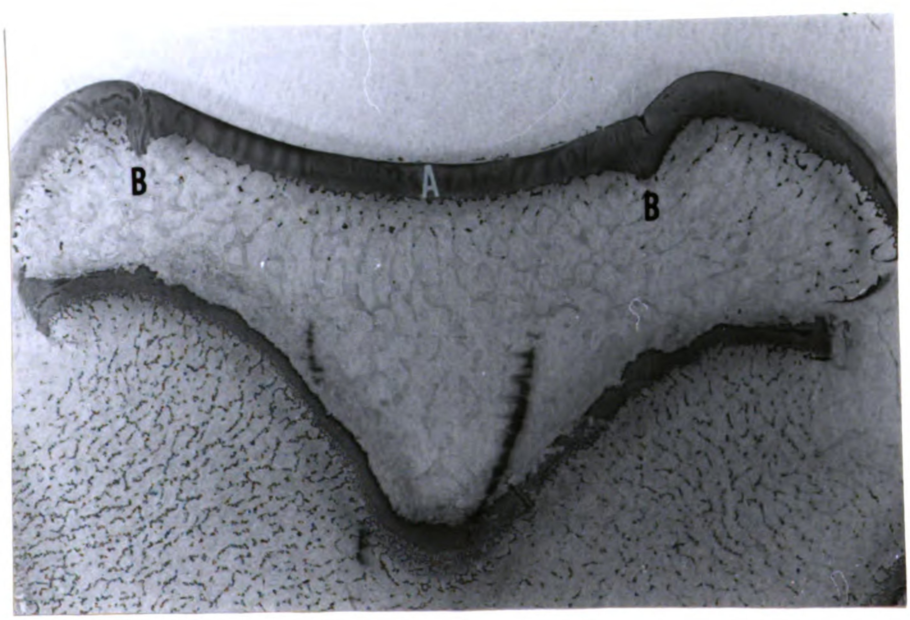

Fig. 16

Patellas in most instances appeared normal. However, patellas in the operated stifle joints of E-7 and E-10 were 1 mm. longer than the patellas in control stifle joints. Obvious grooving of the articular cartilage of the patella was present in E-1 opposite a rough proximal medial condylar incision (Fig. 15).

In general, dogs showing the most gross pathology were German Shepherds (E-1 and E-10), which were extremely active on their rear legs and were the heaviest dogs in the experiment.

Histopathologic Examination of the Femoral Condyle and Patella

Histologically and histochemically the control stifles were normal. Cross sections taken at the proximal level (Fig. 10, level a) were unreliable as to the healing of cartilage incisions, since this area represented the junction between the cartilage and perichondrium. Consequently, on both control and operated joints fibrous tissue and cartilage were present.

Distal sections (Fig. 10, level c) were similar to midsections (Fig. 10, level b).

The following gross observations were made on specimens stained with toluidine blue O (Fig. 16): the cartilage flaps were adherent to the subchondral bone and articular surfaces were smooth, the area of both incisions was visible, the cartilage flap was approximately 1-1/2 to 2 times the thickness of the corresponding area in the control joint, and the distribution of subchondral bony trabeculae was normal.

Upon closer examination, the most significant reaction to the toluidine blue O stain was that the cartilage was metachromatic. Some of the incisions were healed (Fig. 17), while others were only partially filled at the base of the incision (Fig. 18). It was not unusual to find one side healed while the other was still gapped, probably due to the greater distance created at the time of surgery between the cartilage flap and the femoral condyle. Some of this repair tissue reacted metachromatically, indicative of a more mature and viable fibrocartilage (Fig. 19), while other incisions were filled with fibrous tissue or immature fibrocartilage which was orthochromatic in reaction.

Repair tissue filling the gaps created by the incision and grooving seemed to come from the subchondral bone (Fig. 18). However, numerous clusters of chondrocytes (clones) lined these defects (Figs. 20 and 21). This finding was considered indicative of attempts to repair the articular cartilage. Histologically and histochemically the patella appeared normal. Focal areas of wear were rarely present. When present, foci of erosion were characterized by pitting or fragmentation of the articular surfaces.

Histologically and histochemically the synovial membranes were normal in both control and operated stifle joints. Synovial intimal cells lining joint cavities revealed the presence of cytoplasmic PAS-positive material, indicative of normal hyaluronic acid synthesis.

Clinical Cases and Results

Since patients where the cartilage flap technique used had different deformities, surgical procedures, gaits, and outcomes, a review of these cases will be given. Table 2 summarizes some of the data. A postoperative follow-up was attempted in all cases; but, due to the distances owners had to travel, a phone conversation was all that could be obtained in most instances.

Table 2. Clinical case timetable

Dog	Sex	Breed	Age at Surgery (wks.)	Age at Follow-up Time (wks.)	Follow-up Interval (wks.)	Weight at Surgery (lb.)
C-1	F	Yorkshire T.	16	46	30	1-1/2
C-2	F	Min. Poodle	21	29	8	9
C-3	M	Rat Terrier	33	54	21	10
C-4	F	Afghan	12	21	9	13
C-5	M	Min. Poodle	52	64	12	18
C-6	F	Min. Poodle	208	236	28	6
C-7	F	Min. Poodle	6	17	11	1
C-8	M	Chihuahua	12	died	--	1/2
C-9	M	Chihuahua	12	18	6	3/4
C-10	F	Min. Poodle	9	10	1	1

Case 1 (C-1) involved unilateral medial patellar ectopia with the tibial tubercle deviated medially. A convex trochlea was present, as well as slight twisting of the distal femur. The salient features of the surgery were as follows: The medial contracted tissues and joint capsule were incised and the medial quadriceps muscle border was freed longitudinally. A lateral joint capsulotomy was performed over the convex femoral trochlea to allow exposure for preparing the cartilage flap and grooving the subchondral bone. Although the intended area for the trochlea was visualized, the surgically created trochlea was made at a different angle to take into account the surgical realignment of the muscles and tubercle (Fig. 22). The tibial tubercle was dissected from the tibia as described by Brinker and Keller (1962) and transplanted as far over as the fibula and pinned in place with a small pin. Sutures, using a nonabsorbable suture material in an interrupted pattern, were placed in the lateral joint capsule for support, while the fibrous parts of the medial joint capsule were left open to avoid luxating the patella medially again. However, loose subcutaneous tissue was pulled over the open medial joint capsule and sutured to the tissue surrounding the patella. Skin closure was followed by an application of a Thomas splint which remained in place for 3 weeks.

This pup was able to move around well but limped often and carried the leg intermittently before surgery. The owner reported that after the Thomas splint came off the dog showed an immediate improvement over the preoperative condition and now used the leg normally. Eight months later the owner reported the dog was active, had no impairment and, in fact, "you would never know anything was ever wrong with her".

Case 2 (C-2) had unilateral patellar ectopia with the tibial tubercle twisted to a medial posterior position. Contracture of the flexor muscles and quadriceps markedly limited extension of the stifle, and bowing of the femur and tibia was present. The quadriceps muscles were acting as flexors instead of extensors, and the femoral trochlea was convex.

The surgery was essentially the same as in C-1, except that after the tibial tuberosity was freed, the patella placed in the groove, and the quadriceps placed on the anterior surface of the femur, the tibial tubercle was thereby pulled into an abnormal position midway between the femur and proximal tibia (i.e., midway in the joint). Consequently, in order to allow the tubercle to be pinned to the tibia, a lengthening procedure had to be performed. This consisted of cutting the patellar tendon, anchoring the tibial tubercle with a pin and resuturing the patellar tendon with a nonabsorbable suture material in a Bunnell (Z) pattern as described in Piermattei and Greeley's book (1966), leaving about a 3/8 inch gap. The stretched lateral joint capsule (already incised) was pulled under and over the elongated patellar tendon and sutured on itself at the lateral side. This served 3 purposes: it protected the underlying femoral trochlea from the suture material; it provided a tunnel and guide for proliferating fibrosis; and it aided lateral support of the patella and the patellar tendon. The closure was the same as described in C-1, and a Thomas splint was applied which remained in place for 3 weeks.

Preoperatively, this dog's left leg was practically useless. She could not extend the stifle and did not use the leg unless very excited. Two months postoperatively the dog was about the same. The owners were just beginning a program whereby they were tying up the good leg to make her walk on the operated leg. The referring veterinarian thought the patella was still in its proper place. No crepitation of the stifle was palpated.

Case 3 (C-3) showed recurrent medial luxation of the left leg and patellar ectopia of the right leg with concurrent curvature of the femur, medial deviation of the tibial tubercle and a convex trochlea.

Surgery on the left leg consisted of tibial tubercle rotation, while the right leg was operated on similarly to C-1. Two Thomas splints were used for 2-1/2 weeks.

This dog had carried its left leg most of the time. Six months post-operatively the owners reported the dog used the leg much better and would only hold the leg up occasionally. He had become much more active and did not seem hampered at all. His activities included jumping, standing on his rear legs only, and running.

Case 4 (C-4) had a healed proximal tibial fracture (which may have caused the patellar luxation) of 7 weeks' duration. The patella was now adherent to the medial side of the femoral condyle. Curvature of the tibia was apparent (from fracture?) as well as a convex femoral trochlea.

The surgery was similar to C-1, except that 2 pins were used to stabilize the tibial tubercle. A secondary "trochlea" could be seen on the side of the medial condyle where the malpositioned patella had eroded the bone.

This Afghan pup had been in a splint from 5 weeks of age to 12 weeks of age due to a tibial fracture. When the referring veterinarian removed the splint, medial luxation of the patella was apparent, and the dog limped. After the cartilage flap procedure, another splint was in place for 2-1/2 weeks. The owner reported that the stifle turned in slightly after the splint was removed, and 9 weeks postoperatively the leg was in near normal angulation and the limp was diminishing as its leg grew stronger.

Case 5 (C-5) had bilateral medial patellar ectopia with bowing of the femurs and tibias present, with marked medial deviation of the tibial tubercles. Both trochleas were nonexistent. Surgery was essentially the same on both legs as that performed in C-1. Two Thomas splints remained in place for 2-1/2 weeks.

Before surgery this 1-year-old Poodle walked "pigeon-toed", bearing weight on the sides of his feet rather than the toe pads. He had learned to bear most of his weight on his front legs. The owner reported that both legs were so improved that he would walk on all 4 feet and had "forgotten how to do handstands". Three months later the dog could even stand on his hind legs and place his paws up on the furniture.

Case 6 (C-6), a 4-year-old Poodle, was donated to the MSU Clinic for research. Bilateral medial luxating patellas were present, along with medial rotation of the tibial tubercles and a shallow trochlea on the right side and a nonexistent trochlea on the left side. The left leg was operated on, while the right leg served as a control.

Surgery was essentially the same as in C-1. A Thomas splint was applied and remained for 2 weeks.

One week after the Thomas splint removal, it was noticed that the patella was again luxating. A second surgical procedure was later performed in an attempt to reattach the tibial tubercle, which had evidently slipped off the stabilizing pin. This time a nonabsorbable suture was placed through the patellar tendon just above the tubercle, and it was then attached to the lateral side of the proximal tibia. The joint capsule lateral to the patella was opened to view the cartilage flap. The trochlear groove was still deep, and the cartilage flap appeared healthy and was adhered to the subchondral bone. The joint capsule, subcutaneous tissue and skin were sutured. A Thomas splint remained in place for 3 weeks.

Since this was a kennel dog, no report of "home" performance was available. Observation revealed a bowlegged dog. When the forequarters were elevated, the rear legs would collapse. After surgery on one leg, it was noted that the animal, when prancing in its cage, would hold up its unoperated leg (control leg) as if in pain. However, the gait and performance of the two legs was not significantly different 6 months postoperatively.

At the time of euthanasia the patella was riding in the deepened femoral trochlea. No crepitation was palpated. The groove was especially deep in the proximal area, and the incisions appeared healed with no rough spots.

Case 7 (C-7) had been obviously lame 3 weeks (it was 6 weeks old). The left patella would pop into place upon flexion but would luxate on extension. The tubercle was deviated medially slightly. The femoral trochlea was convex.

Surgery in this case was minimal. An arthrotomy was performed, and a cartilage flap and groove were made. During flexion and extension the patella now stayed in its proper place. Lateral interrupted support sutures were placed in the joint capsule. A Thomas splint was applied and remained in place for one week.

The owner said that prior to surgery this 6-week-old pup was extremely active, except that its affected leg would slip out from under it often and it had some trouble maneuvering. After the splint came off the dog had been entirely normal and still was normal 2 months later.

Case 8 (C-8) had been diagnosed 2 weeks prior to surgery as having Von Gierke's syndrome (hypoglycemia with 40 mg.% sugar). The puppy was undersized, and the owner desired to have the pup undergo the surgical risk, since the other alternative was euthanasia. The patella was luxated medially and could not be moved toward the nonexistent femoral trochlea. Slight curvation of the femur and tibia were present, while the tibial tubercle was only slightly medial.

The surgical procedures were essentially the same as for C-7. When the patella was placed in the proper place the entire tibia twisted on its long axis, positioning the tubercle in its proper place, thereby obviating tibial tubercle rotation. Halfway through the procedure the dog died.

Case 9 (C-9) was a littermate to C-8. Although this was a much more robust puppy (3/4 pound), the stifle deformities were more marked, in that the tubercle was deviated more medially and the patella was more firmly adherent medially. Again, there was a convex trochlea.

Surgical procedures were identical to that of its littermate (C-8), except that when the patella was placed in the new groove the tibial rotation on its long axis was not sufficient to bring the tubercle into a normal position. Consequently, it was rotated and pinned. No external fixation was used, and the dog was confined in a carrier crate for 10 days.

Prior to surgery, this dog could walk on its affected leg; however, it was weak and would collapse occasionally. The dog was examined 5 weeks postoperatively. The owners were very pleased with the puppy's progress. The dog walked and ran normally. Palpation revealed the operated leg to be stable, without crepitation or pain, and a deepened trochlea was defined.

Case 10 (C-10) was presented with patellar ectopia, medial tibial rotation, slightly bowed femur and contracted medial tissues. A convex trochlea was present.

Surgical steps were similar to that of C-7. It was very obvious that when the patella was placed in the new groove the entire tibia rotated laterally on its long axis, bringing the tibial tubercle into its normal anterior position. A Thomas splint was applied and stayed in place for 7 days.

Prior to surgery the dog could move his legs, but most of the weight was borne on his good leg, using the bad one in a paddling motion. Seven days later, when the Thomas splint was removed, the patella was stable. However, abnormal medial-lateral movement was palpated.

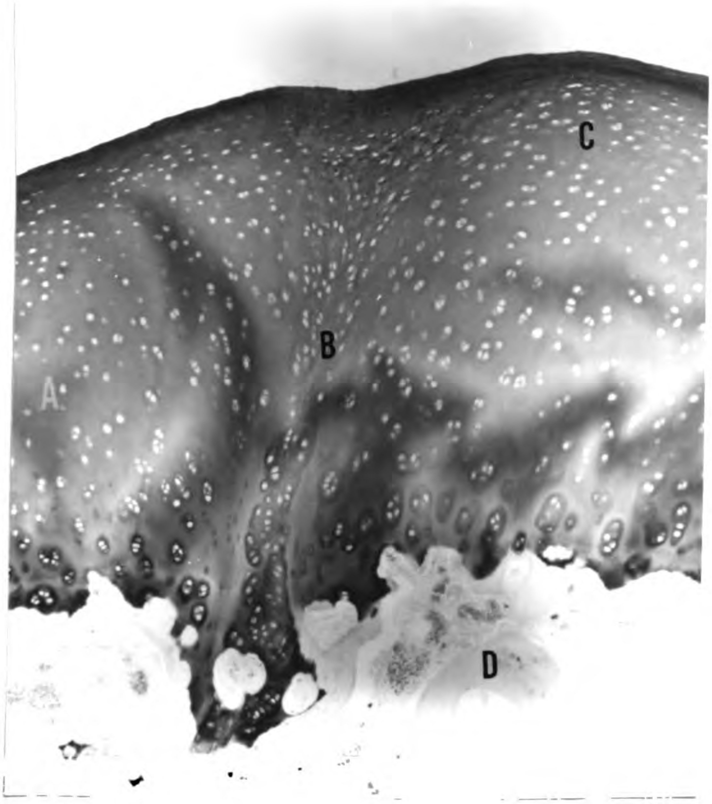

Fig. 17. Completely healed incision in the articular cartilage of dog E-6. Notice metachromasia of flap (A), incision (B), condylar ridge (C), and normal nonmetachromatic bone (D). Toluidine blue O stain; x68.

Fig. 18. Partially filled incision in the articular cartilage of dog E-5. Notice fibrocartilage adjacent to bony trabeculae (A). Toluidine blue O stain; x68.

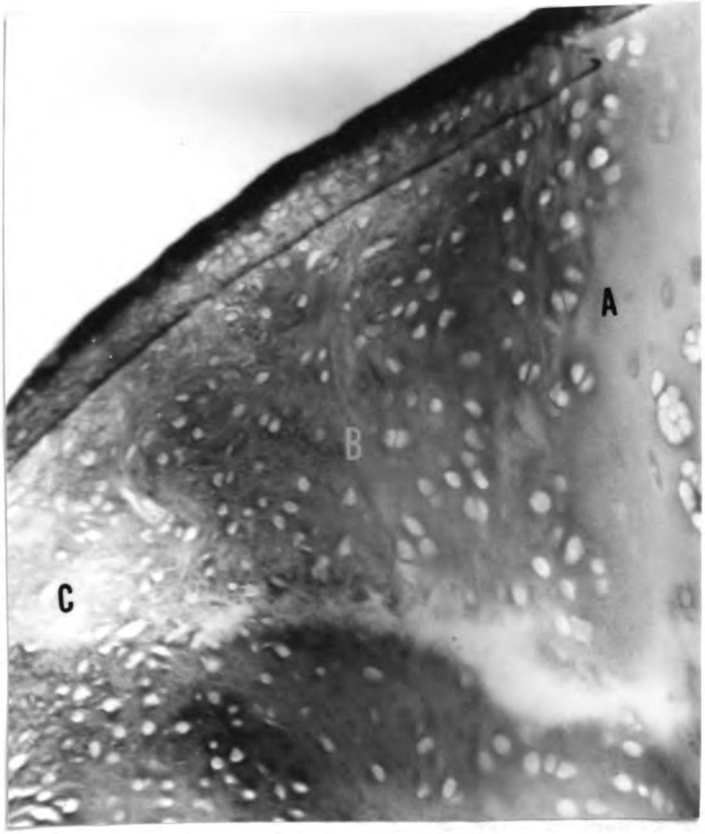

Fig. 19. Healed incision in the articular cartilage of dog E-9. Notice normal metachromatic cartilage (A), metaplastic fibrocartilage which reacted metachromatically (B), and fibrous tissue which did not react metachromatically (C). Toluidine blue O stain; x170.

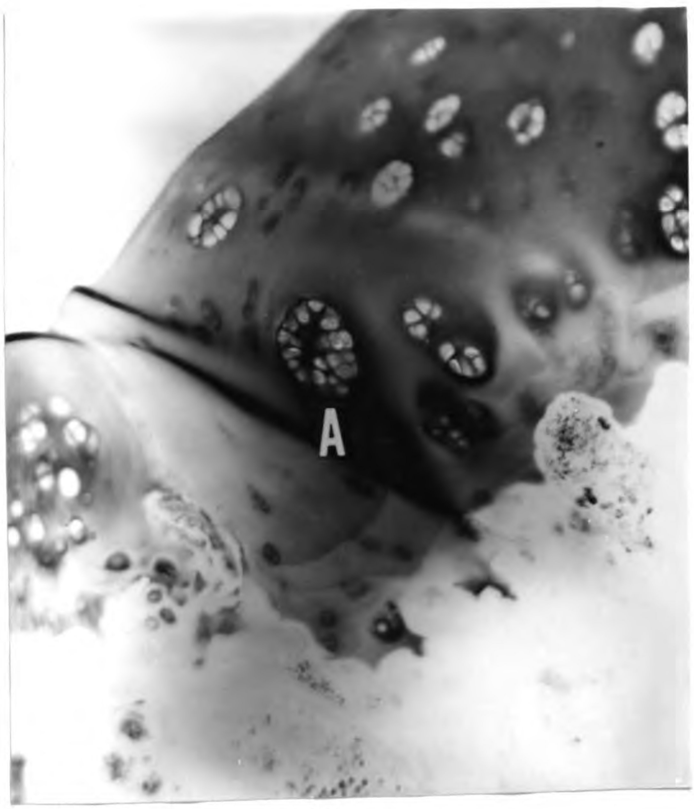

Fig. 20. Incision in the articular cartilage of dog E-6. Notice the large cluster of chondrocytes (clone) (A) indicative of attempts by articular cartilage to regenerate. Toluidine blue O stain; x170.

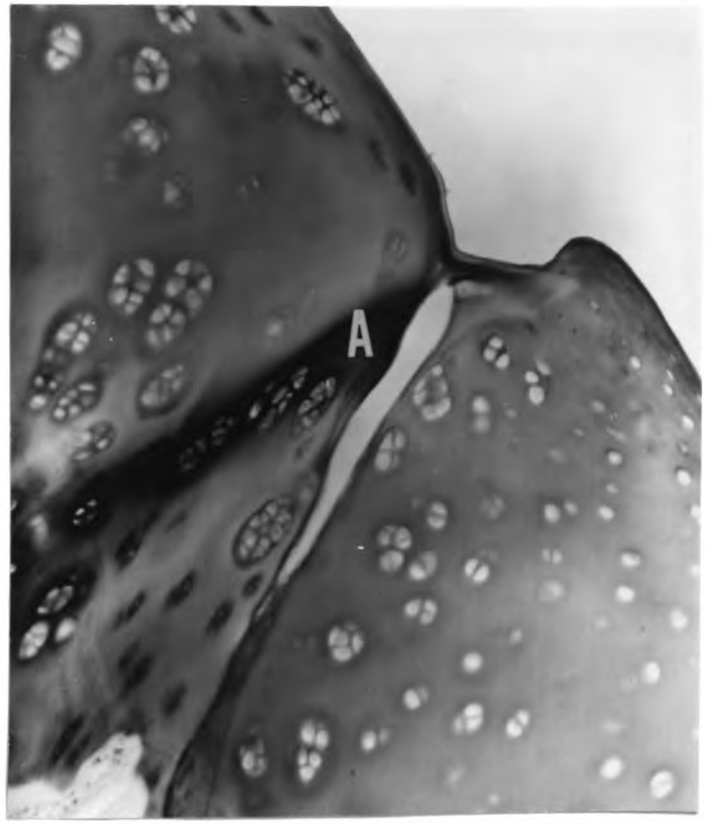

Fig. 21. Opposite incision in articular cartilage of dog E-6. Notice the numerous clones lining the defect (A). Toluidine blue O stain; x170.

DISCUSSION

Experimental Procedure

Dogs subjected to the grooving procedure as described by Vierheller (1967) were devoid of healthy viable trochlear hyaline cartilage. By removing this articular cartilage in the grooving procedure, the "croquet wicket" theory as explained by Freyberg (1967) is no longer functioning to cushion jolts and blows to the stifle joint. According to Flo (1969) inelastic fibrous tissue and immature fibrocartilage supplied the only protection to the subchondral bone in most instances. As Barnett et al. (1961) explained, loss of this cartilaginous elasticity would result in scoring grooves upon opposing surfaces. Flo mentioned that several dogs had midsaggital grooves on the patella. Probably this was a result of this inelastic femoral trochlear surface. Herron's work (1967) on humeral defects also described mirror image grooves on the glenoid cavity of the scapula.

While Herron (1967), DePalma et al. (1966), Mankin (1962), and Bennett and Bauer (1932) were creating defects of small dimensions which apparently healed, they were not creating large lesions such as the trochlear grooving procedure as described by Vierheller (1959). Since Flo (1969) did not have any long term studies it was impossible to state positively that viable cartilage would never return. However, assuming only inelastic tissue covered the patella and large areas of the femoral trochlea, it could be conjectured that the subchondral bone would be subjected to excessive wear and tear, possibly ending up in a painful degeneration of the femur and patella.

Therefore, a technique where the articular cartilage could be preserved while accomplishing the objective of deepening the trochlear groove would seemingly be a preferable method to this curetting procedure. As Singleton (1957) said, "gouging away articular cartilage is a bold step".

Upon comparing the performance and gait of these 2 grooving techniques, a significant difference was found. In Flo's (1969) experimental curetting procedure, lameness was not discerned at a walk. Weakness upon pivoting and standing on the rear legs was noted, as well as a tendency to "bunny hop" while running. "Bunny hopping" could be interpreted as reluctance to use the full range of movement of the stifle due to pain. The fact that at least 4 of the cartilage flap dogs were voluntarily leaping or thrusting powerfully with their hind legs indicated a lack of concern about their operated legs.

While large dogs are usually not clinically afflicted with the problem of patellar ectopia, 2 German Shepherds were used in order to magnify the results of the surgical reconstruction by using the cartilage flap technique. These heavy dogs would subject this procedure to a more strenuous trial than smaller dogs. As it turned out, these dogs' condyles were the poorest in appearance (Fig. 15). However, the surgical technique could have been at fault, since nicking of the flap occurred at the time of surgery (Fig. 9). Nonetheless, these flaps healed and lived.

It appeared that the proximal portion of the incisions was "slower" to heal than the distal. The subchondral grooving was shallower under the distal end of the flap in order to avoid an abrupt dip as the cartilage flap laid down on the deepened groove. Thus, a deeper groove at the proximal area where the patella is normally situated resulted in a greater gap between the condyles and the flap, requiring more filling tissue, and hence a longer healing period.

In comparing the gross appearance of the femoral trochlea and the condyles at postmortem, dogs whose flaps were nicked and gouged at the time of surgery (E-1, E-10, E-5) resulted in rougher areas at the proximal incision sites at the time of euthanasia (Figs. 14 and 15). Therefore, it would seem that care should be taken in preparing the flap.

According to DePalma et al. (1966), cartilage defects of mature dogs (1-3 years) healed just as well as immature dogs. The healing of cartilage flaps in which surgery was done at a young age (6-15 weeks old) did not seem different from those in which surgery was done at an older age (20-40 weeks). Therefore, age (i.e., the very young vs. the young adult) may not be a factor as far as healing is concerned. However, the cartilage flap of E-5, a 10-month-old dog, was more adherent to the subchondral bone, which made the peeling procedure much more difficult. Splitting and gouging of the articular flap resulted. The distal attachment of this flap had been almost completely severed inadvertently, and yet the flap healed (Fig. 14). Therefore, it is questionable if an attachment is necessary to maintain the viability of the flap. Certainly this attachment is useful in maintaining the position of the flap.

The question of why the cartilage flap lives is worthy of discussion. As Freyberg (1967) pointed out, the main nutrition of articular cartilage is provided mainly by the synovial fluid. According to the "sponge-weep" theory of Lewis and McCutchen (1959), synovia is stored in the superficial layers of the articular cartilage. Therefore, after the surgical procedure was performed, the bathing synovia would already be there to nourish the flap. Secondly, the flap adhered readily to the bleeding subchondral bone. It was assumed this vasculature resumed its function of delivering nourishment to the articular cartilage flap by osmosis.

If this flap were dying, the first area to undergo this degeneration would be in the intercellular matrix, according to Waine (1961). This acid polymucosaccharide matrix is metachromatic (Sylvan, 1947), and its degradation (Walton and Ricketts, 1954) would lead to a loss of metachromasia. Understandably, then, the use of toluidine blue O stain was a valuable adjunct to this project in evaluating the viability of the cartilage flap histochemically.

Although long term studies are not yet available, it seems unlikely that the cartilage would later degenerate unless rough areas on the articulating surfaces were present to chisel away larger areas of articular cartilage.

Clinical Cases

Although this thesis project does not directly concern itself with the pathogenesis or etiology of patellar ectopia, the opportunity to study a limited number of young puppies has pointed out a few things. In 4 puppies examined at 4-8 weeks of age, the main findings were: medial displacement of the patella, an absent or convex trochlea, stretching of the lateral parapatellar soft tissues, medial pull of the quadriceps muscles, contracture of the medial parapatellar tissues, and medial rotation of the tibia on its long axis. When the patellas were loosened medially and were transposed to a more normal position, the tibias rotated on their long axes so that the tibial tubercles resumed an anterior position in 3 out of 4 legs. This observation would support Rudy's (1965) statement that the patellar stability in the trochlear groove aids in preventing tibial axial rotation.

Dyce (1952) pointed out that the cruciates, collaterals and joint capsule aid in preventing medial and lateral movement of the tibia. If the tibia twists medially and the femur twists laterally in patellar ectopia, these soft structures must stretch. When the patella was repositioned in the groove of C-10, the tibia rotated on its long axis to a more normal position. Abnormal medial-lateral movement was noted 7 days later. It was conjectured that return of the tibia to an anterior position allowed the stretched ligaments to slacken and thereby diminished medial-lateral support of the tibia.

Gross bending or bowing of the femur or tibia in these 4 cases was not obvious. This limited number of cases would tend to refute Shuttleworth's (1935) theory that bowing of the femur was responsible for the initial patellar luxation, but it does support Singleton (1960), Kodituwakku (1962), and Pearson (1963), who suggest that a lack of a medial condylar ridge or trochlea was responsible for initiating the luxation, which in turn resulted in further exaggeration of the deformity.

Vierheller (1959, 1967), Mackey and McCune (1967), and Young (1957) agreed that in some cases the creation of a trochlear groove was necessary along with other surgical corrective measures on the ectopic patellar syndrome. This necessity was apparent in some clinical cases in which the tibial tubercle was surgically rotated, bringing the patella over the convex trochlea. Upon flexion, the patella still luxated due to the medial pull of the already loosened quadriceps. Creation of a trolley in which the patella may ride then stabilized the patella. It is apparent in this discussion that repositioning the quadriceps over the anterior surface of the femur would help in maintaining stability also. Pearson's (1963) method was to use a teflon barrier wired to the anterior medial femur proximal to the trochlea. However, this method has not been without its shortcomings. In one case, C-7, the creation of the groove using the cartilage flap technique was all that was needed to keep the patella in its normal position. Sutures were placed in the lateral aspect of the joint capsule as an added stabilizer. Most cases, however, would require additional corrective measures.

In clinical cases with a flat or convex trochlea, the area for the intended trochlea was visualized. Due to bending of the distal femur this intended area was at an angle to the normally vertical trochlea (Fig. 22). If the tibial tubercle were rotated surgically to a more normal position and the leg flexed, the new angle of pull is more vertical than the intended trochlear area. Therefore, the cartilage flap was made to parallel this new axis of pull (Fig. 22).

While experimental work showed the flap to heal in older pups, the ease of peeling the flaps was diminished. In older clinical cases of patellar ectopia (1-4 years) the cartilage was not as adherent as the experimental dogs'. This observation was made, however, on small numbers of clinical and experimental dogs.

Pearson (1963) stated that by stabilizing the patella in young animals (using a medial barrier only to the quadriceps) the tubercle could

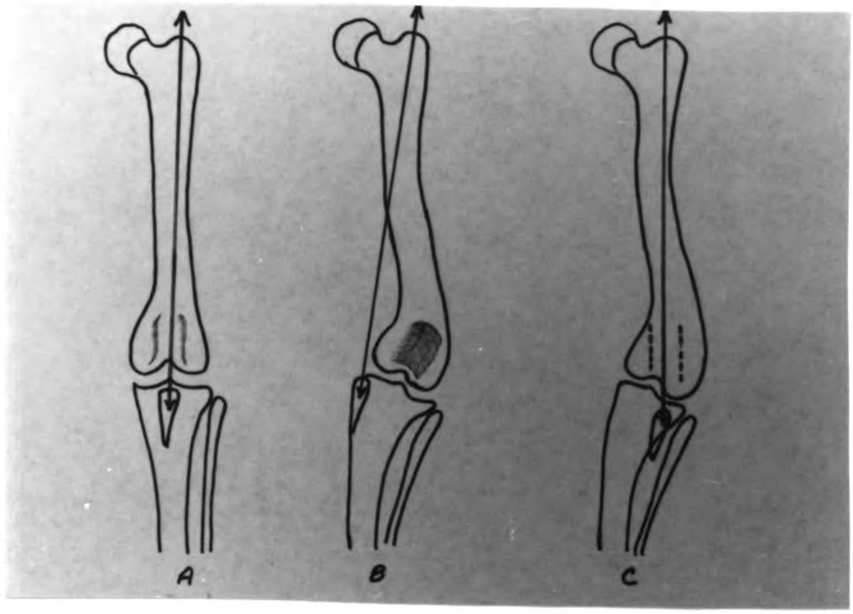

Fig. 22. Schematic drawing of quadriceps muscular pull. (A) normal femur and tibia, (B) "bowed" femur and tibia, angled convex trochlea, and medial tibial tubercle in the patellar ectopia syndrome, (C) surgically corrected quadriceps pull by rotation of the tibial tubercle, and surgical creation of trochlear groove (as indicated by dotted line).

be slowly influenced to grow in a more normal anterior position. As Rudy (1965) and Brinker and Keller (1962) mentioned, contracture of the flexor and extensor muscles is certainly a complicating factor in the more severely crippled animal. This was demonstrated in C-2, where a tendon lengthening procedure had to be carried out. Therefore, surgery should be carried out before these complications become insurmountable and while the dog's bones are still growing, to permit remodeling after surgical reconstruction of these deformities.

SUMMARY AND CONCLUSIONS

A surgical method developed for deepening an absent or convex femoral trochlea in dogs affected with extreme congenital patellar luxation was studied in 11 normal experimental dogs aged 6 weeks to 10 months and 10 clinically affected dogs aged 6 weeks to 4 years.

The technique used in experimental animals involved a lateral approach to the stifle joint. An articular cartilage flap was prepared, subchondral bone was "grooved" and the flap was repositioned over the bone. In effect, a deeper trochlea was created, and yet, the articular cartilage was saved.

Gross, histopathologic, and histochemical examinations of young experimental dogs' femurs 13 to 20 weeks postsurgically proved that the cartilage flaps remained in place and were viable. Viability was demonstrated by using toluidine blue O stain. Gait and activity of these dogs were normal.

The surgical incisions in the cartilage healed somewhat by cartilage regeneration but mainly by granulation tissue which originated from the subchondral bone. Fibrous tissue underwent metaplasia to fibrocartilage. The results tended to indicate that the rate of healing depended on the width of the defect (incision) rather than on age at which surgery was performed or interval between surgery and euthanasia.

This cartilage flap procedure was compared to a technique of grooving whereby the articular cartilage was curetted and not saved. It was concluded that the cartilage flap procedure was physiologically sounder and would probably result in a longer lasting, less painful, more useful stifle than curettage.

The need for early surgical correction, before permanent and unalterable changes arose, was emphasized.

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