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CRANIAL CRUCIATE LIGAMENT DISEASE IN THE DOG: CONTRIBUTIONS TO ETIOLOGY, DIAGNOSIS AND TREATMENT

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“Those who study the cruciate ligaments
and the methods of repair when injured,
are descendants of the discoverer of the wheel
and of those who rediscovered the wheel.
All take great pride in their discoveries.”

Charlie Bild

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LIST OF ABBREVIATIONS

ACL	Anterior Cruciate Ligament
CaCL	Caudal Cruciate Ligament
CCL	Cranial Cruciate Ligament
DJD	Degenerative Joint Disease
ELISA	Enzyme-Linked Immunosorbent Assay
EO	Ethylene Oxide
H&E	Hematoxylin-Eosin Stain
Ig	Immunoglobulin
OA	Osteoarthrosis
OD	Optical Density
TPLO	Tibial Plateau Levelling Osteotomy

GENERAL INTRODUCTION

The stifle joint is one of the most complex joints of the skeletal system. The cruciate ligaments are ligamentous structures in the center of the stifle, upon which various species depend for craniocaudal joint stability.[1,2] The stifle is relatively susceptible to injury. It must transmit forces of a much larger magnitude than other joints.[3]

Hind limb lameness in dogs often is associated with the stifle joint.[4-12] Cruciate rupture has first been recognised as a serious cause of chronic lameness in 1926.[13] All breeds and all sizes of dogs appear to be at risk. The cranial cruciate ligament (CCL) is the most frequently torn ligament of the stifle for it is primarily subjected to excessive forces during extremes of joint motion.[14-16] In contrast, rupture of the caudal cruciate ligament (CaCL) is rarely encountered in the dog.[6,17-19] Meniscal pathology is often seen concurrently with or as a consequence of rupture of the CCL. It is mainly the medial meniscus which shows disease.[20-27]

The dog is an important species both clinically and in studies of comparative pathology. In several studies, the dog is choosen as an experimental animal for human stifle arthropathies.[28-32] An intriguing similarity in the anatomic features is seen between the canine stifle joint and the human knee, considering - of course - their difference in gait being quadrupedal versus bipedal.[18,31,33] The same peri- and intra-articular ligaments are found and their positions in the joint are similar. A different nomenclature is used in dogs and men. The cranial cruciate ligament (CCL) in the canine stifle is the equivalent structure of the anterior cruciate ligament (ACL) in the human knee.[33,34]

Injury to the CCL causes craniocaudal instability of the affected stifle joint. Because of the difference in gait, the greater joint flexion throughout weight bearing, and the steeper slope of the tibial plateau, the dog's stifles are more CCL-dependent for their stability and proper function than the human knees.[35,36] However, a lot of the clinical signs and pathological changes in and around the affected joint following damage to the cruciate ligament are in common. Transsection of the CCL in the dog serves as a standard experimental model of osteoarthritis for human research.[28] As in dogs, insufficiency of the human ACL leads to progressive deterioration of the unstable joint including stretching of secondary restraints, premature degenerative changes, and possible damage to the medial meniscus.[37-40] Only the etiology of cranial cruciate rupture seems to differ between dogs and men. Pure traumatic rupture of the canine CCL is only rarely reported.[41-45] In the dog, most CCL seem to rupture spontaneously under physiological loading as a result of progressive degeneration of the ligament itself.[9,46-48] Such form of nontraumatic ACL lesions is not well documented in the human literature. Men mostly sustain injury to their cruciates during strenuous sport activities.[49-52]

The first bottleneck comprises the diagnosis of CCL rupture in dogs. Damage to the ligament must often be diagnosed based on signs of degenerative changes in and around the affected stifle joint and not by the instability itself. Two clinical tests are well-known to check for the presence of craniocaudal instability in a cranial cruciate-deficient stifle joint, the classical cranial drawer test[13] and the tibial compression test[53]. In both cases, a positive test result is pathognomonic for a torn CCL. Special attention should also be given to the interpretation of the cranial drawer movement in skeletally immature dogs. A certain degree of cranial drawer of the proximal tibia is normal but it comes to an abrupt stop and is not associated with pain or effusion.[54] Unfortunately, false negative results of the manual instability tests are rather common in dogs. Craniocaudal drawer motion might be masked by increased muscle tone[9,54,55] or by tension in the remaining ligament bundle in cases of partial CCL rupture only[56,57]. In those cases surgical intervention is often unnecessarily delayed. Arthrosis will rapidly progress. An extra diagnostic tool with a higher degree of accuracy and sensitivity, applicable in general practice, is badly needed to aid in early detection and prevention of CCL injury.

The second sore subject we try to deal with in this study is how to manage a rupture of the CCL in the dog. The questions whether and how to optimally reconstruct the CCL have stimulated lively and endless debate among veterinary surgeons. The described surgical interventions can be grossly divided into extra-articular or intra-articular procedures. In excess of 100 methods of surgical repair for cranial cruciate rupture in dogs have been reported.[58-60] All reconstruction techniques published so far only provide temporary stability to the operated stifle joint. Furthermore, surgical intervention does not seem to be able to stop any further formation of osteoarthrosis (OA), but slows down the degenerative process at most.[25,61,62] On the other hand, there does not seem to be a direct relation between the clinical outcome of a surgical procedure and the degree of postoperative OA. It has been postulated that intra-articular reconstruction using a strong synthetic prosthesis would decrease surgical morbidity and increase stability in the immediate postoperative period.

A third problem concerns the etiopathogenesis of CCL rupture in dogs. Known causes are severe trauma or relatively minor trauma to a previously weakened ligament. In contrast to human beings,[63] most of the injuries in dogs are a result of degeneration of the CCL itself.[6,9,46-48] Degenerative changes within the microstructure of the ligaments might be due to a loss of elasticity because of increasing age[46-48] or due to chronic abnormal loading because of skeletal abnormalities or patellar luxation.[9,15,64-70] Immune-mediated inflammation of the canine CCL as a cause of ligament weakening and destruction has been reported by Niebauer and Menzel.[71] A better knowledge of the disease mechanisms in canine CCL rupture would enable us to accurately alter the degenerative processes. Maybe, prophylactic measures could be taken in the future.

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SCIENTIFIC AIMS

The frequency and importance of cranial cruciate ligament (CCL) injury in dogs has become widely known. Although reports have been published on virtually every aspect of the cruciate ligaments in both man and dog, knowledge has not advanced greatly, and still no unanimity of opinion exists as to various conditions with regard to the CCL. More objective diagnostic means with a higher degree of accuracy and sensitivity are needed and the ideal method of dealing with cranial cruciate instability is still far from being established. Furthermore, it is still largely unclear why that many canine CCL rupture without a definite traumatic injury.

The aim of this study is to come as close as possible to the ultimate answers on those challenging questions.

Diagnostic aspect:

1. To develop and evaluate a new, clinically useful diagnostic method for early detection of CCL disease.

If there is damage to the CCL, a cranial displacement of the proximal tibia in respect to the distal femur is expected during clinical laxity testing. The classical instability tests may reveal false negative results, and the impression of relative displacement and rotation during clinical examination is often not very accurate.
Stress radiographs under tibial compression are routinely taken of all dogs suspected of CCL injury.

Therapeutic aspect:

1. To evaluate the suitability of polyester as CCL substitute by its *in vitro* characteristics.

The structural and material properties of braided multifilament polyester used for intra-articular stabilisation of CCL deficient stifle joints in dogs are determined. The suitability of CCL prostheses does not depend solely on tensile behaviour. The recoverable elastic characteristics are equally important.

Load-to-failure tests are used to mimic acute overload of the CCL. Additionally, a cyclic loading test method is designed to match the dynamic loading conditions of the CCL of a walking dog.

2. To evaluate an intra-articular stabilisation method using polyester in canine CCL-deficient patients.

For many years, polyester has been implanted in the canine stifle joint to substitute the ruptured CCL. The clinical value of new stabilisation techniques can only be assessed by longterm follow-ups.

Detailled questionnaires provide data before surgery, at 6 weeks after the operation, and several months postoperatively. Data are collected by telephone interviews and by clinical and radiographic re-examinations.

Etiopathogenetic aspect:

1. To evaluate immune-mediated phenomena as a possible contribution to CCL rupture in dogs.

Synovial fluid from cruciate-deficient stifles and from joints in which the osteoarthritis was unrelated to cruciate disease is screened for antibodies against collagen. The menisci as well as the intra-articular cruciate ligaments are mainly composed of collagen type I. Collagen type II is the major constituent of articular cartilage.

If anti-collagen antibodies can be detected, it has to be examined whether these auto-antibodies to collagen play an active role in the initiation of CCL disease in dogs or not.

CHAPTER 1

REVIEW OF THE LITERATURE

1.1. Basic science of the cruciate ligaments

1.1.1. INTRODUCTION

The cruciate ligaments are both morphologically and functionally complex, dynamical structures, strongly connecting the femur to the tibia. They run intra-articularly but extrasynovially in the stifle joint of all terrestrial mammals species.[1,2] In the early literature, the cruciate ligaments were referred to as crucial ligaments merely because of their crossed arrangement.[3] Only later on, the crucial role of the cruciate ligaments to the well-being of the physiological kinematics of the stifle joint, has been appreciated.[4] The cruciate ligaments function as major constrains of stifle joint motion although they are only one facet of the restraining system of the stifle joint. By their anatomy and spatial arrangement, the two crossing cruciate ligaments provide the primary ligamentous support of craniocaudal and axial stability of the stifle through the functional range of motion. The importance of the cruciate ligaments to provide primary ligamentous support of craniocaudal stability of the stifle has been generally recognised for a long while.[5] Roughly, the cranial cruciate ligament (CCL) controls the cranial drawer motion, whereas the caudal cruciate ligament (CaCL) acts as major stabiliser against caudal drawer motion. Furthermore, the CCL can be looked at as fine-tuner of proper stifle joint kinematics.[6]

Data appearing in the literature have been focused merely on the CCL particularly for it is the most vulnerable and most important ligament of the stifle joint.[7-9] It has been studied extensively with regard to its morphological appearance and its relationship to other joint structures. Several comparative studies on CCL characteristics in mammals have been published and reinforce the importance of this structure. It may be assumed that only minimal differences between different species do exist anatomically, physiologically and biomechanically.[10,13] Over the past decades, the clinical importance of the CCL became more and more obvious, for the different species themselves but even so for further development of animal models to compare with human circumstances.

A correct understanding of normal anatomy of the stifle joint, and in particular normal cruciate anatomy, is essential to both diagnosis and rational treatment for CCL damage.

1.1.2. INSERTION POINTS

The intercondylar notch between the femoral condyles is almost completely filled by the two cruciate ligaments and some fat (Fig 1 A). In dogs, the normal anatomy of the cranial outlet of the intercondylar notch is bell-shaped, obliqued a mean of 7 degrees.[14] The CCL and the CaCL both attach to the intercondyloid area of the tibia.[7,15-17] Although the length of both canine cruciate ligaments is nearly equal, their distal insertion points on the tibia lay almost twice that far apart as their femoral origins.[11] At the attachment sites of the cruciate ligaments, extensive interdigitation of collagen fibres of the ligament with those of the adjacent bone ensures strong anchorage.[18,19]

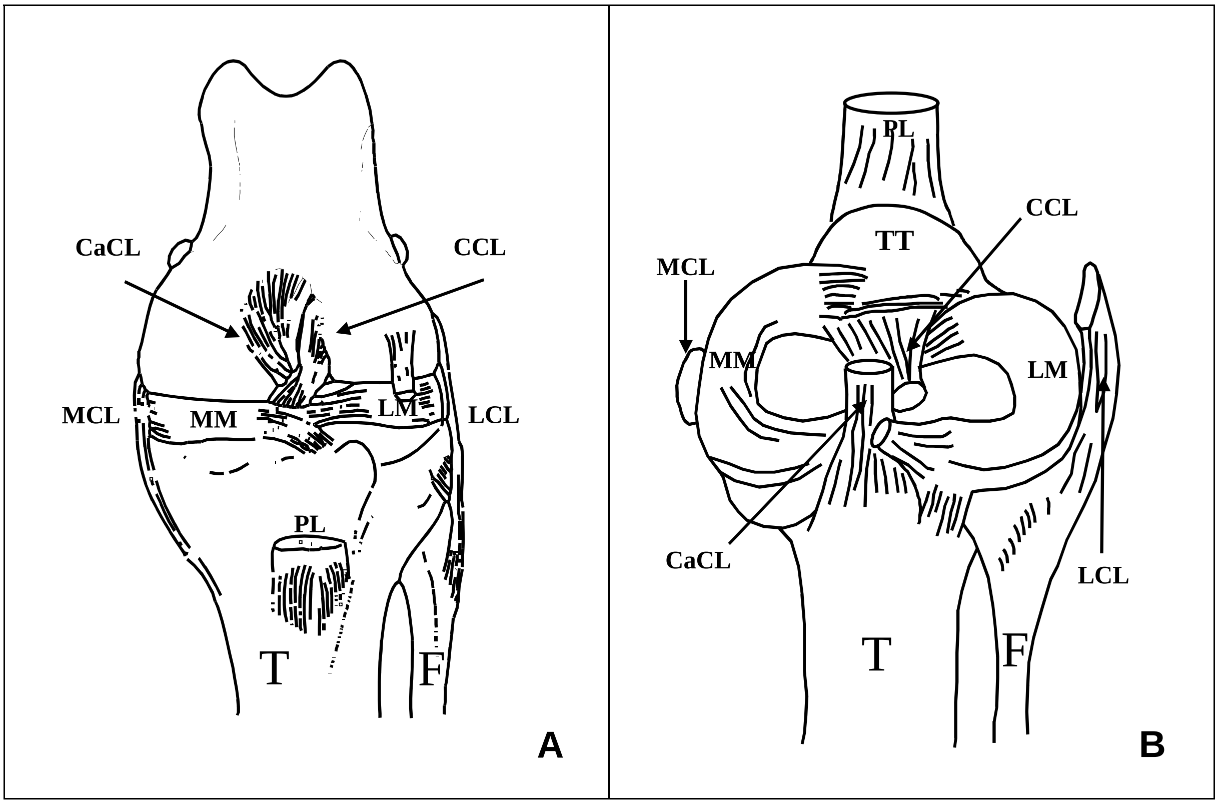

Fig 1. Ligaments and structures associated with the stifle joint in the dog
A. Cranial view
B. View on the tibial plateau after removal of the femur

CaCL Caudal cruciate ligament, CCL Cranial cruciate ligament, F Fibula, LCL Lateral collateral ligament, LM Lateral meniscus, MCL Medial collateral ligament, MM Medial meniscus, PL Patellar ligament, T Tibia, TT Tibial tubercle

Within the centre of the stifle joint, the cruciate ligaments form a cross from caudal to cranial, and also from outside to inside, connecting the femur with the tibia.[20] The entire CCL and CaCL begin to wrap around each other, checking against each other when the stifle flexes.[7] Meanwhile, the fibres of both ligaments begin to twist upon themselves to a varying degree.[16]

The cranial cruciate ligament

The cranial (or lateral) cruciate ligament originates on the axial aspect of the lateral femoral condyle, very close to the articular margin and extends diagonally across the joint space.[16,20] It runs cranially, medially and distally in an outward spiral as it passes from the femur to the tibia.[20,21] The amount of twist can vary in different parts of the CCL and the bundles can spiral up to 180 degrees.[22] The long axis of the CCL is vertical.[16] The tibial attachment is to the cranial intercondyloid area of the tibial plateau.[7,15,16,20] This insertion point is cranially bordered by the cranial meniscotibial ligament of the medial meniscus and caudally by the similar-called ligament of the lateral meniscus (Fig 1 B).[1,15,23] There are no fibres connecting the ligament to one of the menisci.[16] The attachment areas are considered important when considering landmarks for intra-articular techniques of cranial cruciate substitutions.[24]

The caudal cruciate ligament

The fibres of the femoral attachements of the caudal (or medial) cruciate ligament originate as a broad fanlike band along the fossa on the ventral aspect of the axial side of the medial femoral condyle.[16,20] The ligament transverses caudodistally across the femorotibial joint with only a slight inward helical angle, and attaches to the medial aspect of the popliteal notch of the tibia.[16,20,25] This insertion point is cranially bordered by the caudal meniscotibial ligament of the medial meniscus and caudolaterally by the similar-called ligament of the lateral meniscus.[23]

Both sites of attachment of the CaCL lay behind the axis of flexion of the stifle joint, and the ligament lies medial to and crosses the CCL.[16] The band is slightly longer but also broader than the CCL.[7,15-17,26,27] In more than half of the dogs, fibres of the femoral ligament to the lateral meniscus are found within the CaCL.[16]

1.1.3. FIBRE BUNDLE ANATOMY

The cruciate ligaments have not just a single strand configuration of longitudinally orientated collagen fibres.[16] They contain twisted collagenous fascicles and fiber bundles subdivided into fascicles, subfascicular units, fibres and fibrils.[19,28-30] In the dog, the CCL as well as the CaCL can be divided in two functional components because they adhere to individual attachment zones.[16]

The cranial cruciate ligament

The canine CCL is the narrowest in its middle portion and fans out proximally and distally.[1,22] The shape of the entire CCL changes through the normal range of motion of the stifle joint.[1,16] The decrease of the cross-sectional area is also greatest at the midportion of the CCL when forces are acting.[31] The length of the canine CCL is positively correlated with the body weight of the dog. A mean of 13.5 to 18.7mm has been calculated.[32-35]

In man, the ACL wrinkles into three fibre components as the stifle flexes.[36,37] The human ACL was first anatomically subdivided as a two-part ligament in a so-called craniomedial and a caudolateral bundle, based on reference to their relative tibial insertion sites.[38,39] Later on a third, smaller bulk was identified, and got the name of intermediate bundle.[36] The separate parts are the most demonstrable within the region of the intercondylar notch in a fully flexed stifle.[36,40] The appearance of three discrete fibre bundles can not always be confirmed, especially not in specimens derived from younger individuals because of thicker envelopment of the ACL in the synovial covering.[40] Some workers even failed to identify a separable interface between portions of the ACL in cadaver knees from some human adults.[41,42] There is general agreement regarding functional subdivision of the ACL, although there is not neccesarily macroscopic evidence of separate entities.

The spiral in the canine CCL gives the gross appearance of distinct anatomic bands. Apparent are two demonstrably separate bundles in the dog (Fig 2).[1,16] The bands are designated as craniomedial and caudolateral, based upon their relative insertional points onto the tibial plateau as their human counterparts. The craniomedial subdivision is the most spiral, the longest but the smallest component of the two.[1] It arises more proximally from the femur and also inserts more cranially on the tibial insertion area, as compared to the remainder caudolateral band of the CCL.[1,16] The fibres of the latter component originate from the most lateral and distal part of the insertion area of the lateral femoral condyle, have a more straight path, and insert on the most caudal part of the tibial area.

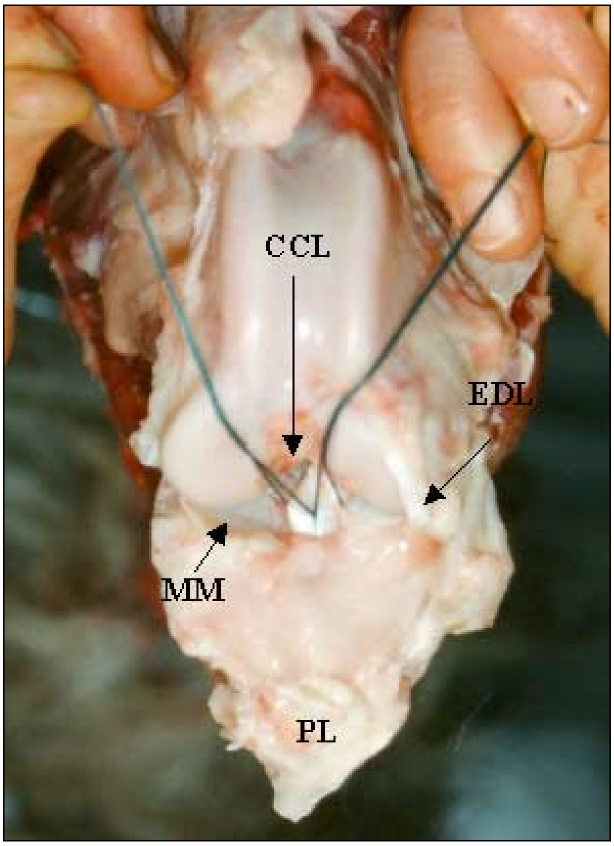

Fig 2. Cranial view of the stifle joint. The cranial cruciate ligament (CCL) in the dog is composed of two separate bundles. A forceps has been pushed bluntly between these bundle parts to insert a double suture, demonstrating the separate components

EDL Tendon of long digital extensor muscle, MM Medial meniscus, PL Patellar ligament

The geometry of the reciproce attachment sites of the component parts of the cruciate ligament is responsible for their slackening and tensioning due to relative rotations of the attachments through the normal functional range of motion of the stifle joint.[16,22,40,42] Different morphological components of the CCL appear to attach to different locations within the insertional area of each bone. Reciprocal tension and thus functional difference does occur because of the arrangement of their individual attachment points.[16] In the extended stifle joint, the long axis of the CCL runs along the axis of the femur, and the femoral attachments of both the craniomedial and the caudolateral fibre bundle are almost perpendicular to the joint surface and both bundle parts are taut.[1,22] In flexion, the craniomedial part of the CCL curves and twists around the remaining caudolateral part, while meanwhile its femoral attachment area moves distally and caudally.[1,16] This reorientation of the femoral attachment sites during flexion of the stifle results in an increased distance between the areas of femoral origin and tibial insertion of the craniomedial bundle. Therefore, this bulk remains tense in flexion. The inverse shift happens to the femoral insertion of the caudolateral component so as to bring the femoral attachment area of the CCL almost horizontal to the joint.[1] Relative relaxation of the fibres of the caudolateral bundle can be explained by the same principles, since the bone attachments move closer together as the stifle is flexed. The caudolateral component is slack in flexion.[1,16]

The caudal cruciate ligament

The canine CaCL is longer and broader than the CCL.[7,15-17,26,27] Even its collagen fibrils are thicker in comparison with the CCL.[43,44] The total diameter of the ligament in its midsection is the smallest as it fans out from the centre making the femoral and to a lesser extent tibial attachments larger.[15]

As its cranial counterpart, the CaCL as well is a two-part ligament[26] although they are not as distinct as those of the CCL and often inseparable.[1] The cranial bulk is heavier than the caudal band.[25,45]

Also here, the restraining effect of both bundles varies with the position of the stifle, and the component parts perform reciprocal functions at different angles of flexion because of the location of their points of attachment.[16,26] In similarity with the CCL, the geometry of the femoral attachment is responsible for tensioning or not.[1] The cranial band is taut in flexion and loose in extension whereas the situation is reversed for the caudal part.[16,26]

1.1.4. FUNCTIONAL ANATOMY AND ASPECTS

The cruciate ligaments have specific functions directly related to their anatomic locations and orientations within the stifle joint. Although the main functions of other intra-articular and peri-articular structures and ligaments differ from those of the cruciate ligaments, they complement them as constraints of stifle joint motion in various planes.[23,46] There is a ranked hierarchy of structures neutralising specific forces acting on the stifle joint and resisting different kinds of joint laxity. Not only the real ligamentous structures but also muscle forces and joint compression contribute to joint stability.[47,48] Stifle joint function is complemented by a static support from a complex (passive) restraining system consisting of bony and musculotendineous structures, menisci and several ligaments. Passive control is largely dependent on the femorotibial ligaments, i.e. the cruciate and collateral ligaments, which interact to prevent excessive motion, in concert with all other anatomical structures.[49,50] The conception of ligaments as passive ropelike structures with purely biomechanical functions is outmoded.[51] They also serve as more refined sensors.[52] Stifle stability is dynamic as far as muscle control (active forces) is concerned.[15,48,49,53,54] Cranially, the quadriceps muscle and the patellar tendon provide support. The popliteal muscle and probably also the hamstring muscles and the gastrocnemii provide additional support to the stifle on its caudal aspect.[55]

In the dog, both cruciate ligaments are composed of two component parts which behave independently and differently from one another at different portions of the loading cycle.[16] The loading of the various bundles varies as some fibres are stressed and others are not depending on the angle of the stifle joint. The particular role of the cruciate ligaments and especially the importance of their separate bundle parts as restraints of stifle joint motion have been studied mostly in human and canine cadavers.[38,39,40,42,47,56-62] Most assessments of ligamentous function have been based on the changes in laxity observed after sequential cutting selected ligaments. The actual proportion of their combined contributions to sustaining load varies with the angle of stifle flexion. Because of combined interactions, an isolated lesion of any of the component parts of any of the cruciate ligaments does not necessarily provoke clinically detectable instability.[39,59]

Hyperflexion of the stifle joint will normally not occur because of the contact between the thigh muscles and the gastrocnemius muscle.[7] The cruciate ligaments spiral on themselves, and they are naturally twisted upon each other when the stifle is flexed. Since the normal standing angle of the stifle in a dog is about 140 degrees, stifle collapse during the stance phase is also prevented by this twisting.[16,63,64] The other extreme of motion of the stifle, overextension, is completely borne by the tension in the cruciate ligaments.[7] Hereby, the cranial cruciate acts as a primary restraint whereas the slightly longer CaCL can be considered to be only a secondary restraint.[7,16,25]

Because of their anatomic relationship, both cruciate ligaments constitute in the physiological rotatory action of the tibia during craniocaudal motion, although they are anatomically close to the axis of tibial rotation.[60] In subtle balance with the capsular structures, the collateral ligaments, muscles, the condylar geometry and joint surface contact, the cruciate ligaments control and produce rotatory motion of the tibia relative to the femur.[8,15,25,26,36,60,65,66] An increased angle of flexion of the stifle joint is also accompanied by increased internal rotation of the tibia if unrestricted.[8,23,24,65,67] A portion of valgus load is transformed into an axial rotatory force as the lateral collateral band begins to relax.[12,25,68,69] As the stifle flexes, the cruciate ligaments are not only wrapped upon each other but also spiral on themselves.[7,16,25] The natural twist of the cruciate ligaments is tightened even more by initiation of increased internal rotation.[47] The higher strain in the ligaments limits the amount of normal internal rotation of the tibia on the femur.[16,20,25,26] As the stifle extends, the lateral collateral ligament tightens. The lateral femoral condyle moves cranially, causing external rotation of the tibia. This motion has classically been described as the screw-home mechanism.[65,68-70] In extension, the medial and lateral collateral ligaments become the primary restraints of rotation, and the cruciate ligaments can only provide a secondary check due to the tension in both ligaments.[15,20,65] No singular limiting effect on external rotation is provided by the cruciate ligaments in dogs, even not as secondary restraint structures.[16,26,65,71] By external rotation of the tibia, the fibres of the cruciate ligaments start to unwrinkel, and strain decreases.[8,20,65] Therefore these ligaments can not provide any restraint against external rotation.

Axial tibial rotation of the canine stifle joint is coupled with varus-valgus rotation.[12] In a stable stifle joint, the collateral ligaments are considered to be the cardinal primary ligamentous stuctures to provide sideways restraining moments when stifle motion is restricted. In fact, they share their function by the other joint structures and ligaments.[12,59,65,66] The degree of stresses on the cruciate ligaments during medial and lateral opening of the joint space generally increases slightly with the degree of flexion of the stifle joint, for the collateral ligaments begin to relax as the stifle is flexed.[12,65] Both cruciate ligaments together are important secondary complements against varus and valgus angulation. They become primary restraints if there is a tear of one of the collateral ligaments.[59,61,65] In the fully hyperextended stifle joint, the cruciate ligaments, by themselves, can block joint opening.[59] In cases of varus force, the CCL will always have to sustain larger strains than the CaCL although these forces are still much lower than these sustained by the lateral collateral ligament. For medial restraints (valgus force), the proportion of contribution of the CaCL becomes greater with increase of the flexion angle.[12,59]

The cranial cruciate ligament

The CCL is the fine-tuner of stifle joint motion and guides the stifle through its helicoid of motion.[6] The structural characteristics of the CCL clearly play an important part in the rather complex behaviour of the ligament. It has long been realised that maintaining the integrity and stability of the stifle joint could hardly be accomplished by a CCL, constituting only one single band of fibres with constant tension as the stifle moves.[1] Tension in the cranial cruciate varies greatly in various positions of stifle flexion. Every change of the joint angle alters the tension on the separate bands and indicates the suitability of the cranial cruciate to withstand the multi-axial stresses of normal function and range of motion.

By weigth bearing, active forces are generated that create cranial tibial thrust.[49,67] In a sound joint, the intact CCL opposes cranial projecting of the proximal tibia.[46,48] During normal daily function, however, the CCL carries only small loads.[72] Joint compression and muscle actions greatly contribute to the achieved joint stabilisation.[54,73] By CCL-muscle reflexes, direct loading of the ligament causes inhibition of the quadriceps muscles and simultaneously increases the activity of the hamstring muscles in order to reduce CCL loading.[74]

The CCL has to limit extremes of motion about the stifle.[4,6] The CCL is twisted through approximately 90 degrees, as the stifle is flexed from full extension to a right joint angle.[42] In concert with the CaCL, hyperflexion is limited.[16,63,64] As the joint extends, hyperextension of the stifle is limited by contact of the CCL with the osseous wall of the intercondylar fossa.[14] The cranial cruciate serves as the primary check against hyperextension of the stifle joint.[7,16,25,75] The entire ligament, both the craniomedial and the caudolateral bundle component, is taut at full extension.[1,16] The contribution to restraining hyperextension of the stifle is larger for the caudolateral component which is under the greatest tension in extension.[1,39]

More important and more specific than its limiting functions, the ligament has to provide a stabilizing effect of the tibia on the femur throughout the whole range of motion, resisting forces that would cause the tibia to translate cranially relative to the femur and, to a lesser degree, resisting forces that would cause tibial rotation during flexion of the stifle.[25,61] The chief function of the CCL is to resist cranial drawer movement of the tibia with respect to the femur.[16,57] A primary restraint is provided against straight cranial drawer as well as against cranial drawer combined with internal tibial rotation.[60,76] The dog's stifle is CCL-dependent during the stance phase of gait.[54] According to Slocum and Devine[48,77], the CCL is only a backup mechanism for control of the cranial projecting of the proximal tibia as a dog walks, and experiences no stresses as long as the cranial tibial thrust is effectively opposed by the caudal pull of the biceps femoris and hamstring muscle group. Only if these active muscle forces are insufficient to counteract cranial translation of the tibia, the cranial cruciate will provide the first passive restraint. Since there will not be a perfect balance at all times and due to the functional cranial to caudal slope of the tibial plateau, the CCL must intermittently resist cranial tibial thrust.[67,76,78] With the stifle in extension, the entire CCL is taut. As such, both component parts are limiting cranial translation of the tibia relative to the femur.[1,16] Near full extension, the CCL is the sole structure to limit cranial drawer motion, since tension in the hamstring muscles lacks to provide extra restraint.[75] The craniomedial part of the CCL is the major contributor to craniocaudal stability in all positions of flexion.[8,76] Because of slackening of the caudolateral bulk during flexion, only the craniomedial part which thightness continues, is primary responsible for maintaining craniocaudal stability. Meanwhile, the other joint structures seem to contribute less to craniocaudal stability as the joint flexes.[79] The relaxed caudolateral component only acts as a weak secondary restraint to this unidirectional cranial translating force. It only starts to play a role when the craniomedial band is damaged or severely stretched.[39,71] The caudolateral component is responsible for restraint of internal rotation.[76]

A correct understanding of these matters is imperative if reconstructions are to restore normal stifle physiology. The goal of reconstructive methods should not only be to alleviate the existing instability of the symptomatically unstable stifle, but also to mimic normal kinematics as closely as possible.

The caudal cruciate ligament

The significance of the CaCL in the stability of the stifle in dogs is far less important than that of the CCL.[80-83] During the extremes of joint motion, the component parts of the CaCL are alternately taut or slackenend. In the extended stifle joint, the cranial bundle will be loose whereas the caudal will be tight. The inverse situation happens in flexion.[16,26] In contrast with the individual functions of the CCL, the functional anatomy of the caudal cruciate bundles is not clinically important. Selective cutting of only one of the component parts does not allow caudal drawer under any joint angle.[16,26]

Although the caudal component of the caudal cruciate is taut in extension, the bundle functions to limit hyperextension of the stifle only should the somewhat shorter and slightly stouter cranial cruciate be damaged, and thus can be considered to be a secondary restraint against hyperextension.[7,16]

Prevention of caudal displacement of the tibia on the femur is the cardinal and only primary role of the CaCL.[8,16] The clinical importance of this cruciate ligament in the dog is somewhat under discussion because of the angle of the stifle during stance and gaiting.[80] In a flexed stifle joint, the cranial component of the CaCL is a primary restraint against caudal instability owing to looseness of the collateral ligament in this joint position.[25,26,65]

Although being advocated previously[15], the canine CaCL alone does not seem to limit external rotation of the tibia when the stifle is not fully extended and the lateral collateral is relaxed.[80,82] Experimental isolated damage to this ligament does not lead to rotatory instability at any joint angle.

1.1.5. MICROANATOMY AND ULTRASTRUCTURE

Both cruciate ligaments are covered by a fairly uniform fold of the synovial membrane which incompletely divides the stifle joint in the sagittal plane.[17,84] This layer of synovial tissue continues over the horns of the menisci.[85] Synovial lining of the cruciate ligaments is only not discernible on the surface in direct contact with the other cruciate ligament.[33] The synovial envelope makes the cruciate ligaments extrasynovial structures, protected from the degradative effects of the synovial environment, although they are in fact intra-articular.[16,17,86] The envelope originates at the caudal synovial membrane proximally and extends to the cranial joint capsule distally, and is richly endowed with branches of vessels originating from both the cranial and caudal aspect of the stifle joint.[84,87] The enveloping paraligamentous membranes mainly consist of dense connective tissue, small fibroblasts, and some adipocytes.[1,88] An intima and a thin subintimal layer can be histologically distinguished. The former is presented as a single layer of synoviocytes, and the latter as areolar tissue containing small vascular structures.[33]

Relative to the enveloping membranes, the cruciate ligaments are rather hypocellular.[1] The cruciate ligaments are composite collagenous tissues in which the collagen is arranged in a typical hierarchical structure. The collagen fibrils, being the smallest visible structure by electron microscopy, are organised into fibres, then subfascicles, and finally fascicles are formed.[19,28-30] Sheaths of loose connective tissue are enclosing the respective collagenous entities.

The cranial cruciate ligament

The synovial fold covering the CCL originates caudally at the intercondylar notch and extends to the cranial aspect of the tibial insertion.[87] At that point, the paraligamentous tissue communicates with a fold of the distal joint capsule.

On the gross level, the canine cranial cruciate is traditionally described as a two-component band.[1,16] This uncomplicated and distinct subdivision certainly does not carry through to its intricate microarchitecture.[1] Each ligament bundle is a multifascicular structure, and contains many wavy fascicular subunits. The fascicles located at the periphery of the CCL appear to follow a spiral path of waviness around the fascicle axis.[22,30,40,89] The helical angle approximates 25 degrees, being nearly optimal regarding to tensile strength.[31]

Fascicles are composed of numerous subfascicles.[19,28-30] In the canine CCL, there is a great variability in the elliptical shaped fascicle size, since fascicles may be composed of one to ten subfascicles, subdivided by loose endoligamentous tissue.[1,30] In humans, the fascicular units are bundles with a diameter ranging from 0.25 to 3 mm.[28,89] Small fascicles are found embedded in loose connective tissue with ovoid cells. The thicker ones, in contrast, often are densely arranged and the surrounding cells are fusiform.[29,30,88] There is also a considerable range of variation for the subfascicular density and for the amount of loose areolar connective tissue in which the subfascicles are embedded according to distinct fuctional regions within the same ACL.[29]

Subfascicles contain bundles of collagen fibres, the major constituents of the CCL. Each fibre bundle is not oriented such that it is isometric during stifle joint motion.[40] Every subtle three-dimensional change in the position of the stifle joint therefore differently recruits fibres of the CCL.[90] Individual fibres do change length by straightening of their waveforms as they are recruited into tension. Such is not visible at a gross anatomical level, but is conformed by histological assessment.[30,40]

Fibrils, composed by organisation of repeated collagen subunits, are joined form the fibres.[1,33,87,88] The collagen fibril morphology and architecture is also characterised by uniform waveforms parallel to the long axis of the fascicle (Fig 3 A). The internal collagen fibrils are nearly straight while the fibrils undergo a maximum undulation at the fascicular periphery. At the osseous attachment sites of the CCL, the collagen fibres are not arranged entirely parallel to the longitudinal axis of the ligament and, especially in younger specimens, columns of chondroid cells do penetrate into the CCL (Fig 3 B).[20,87] At the contact point of the CCL with the caudal cruciate, the collagen fibres are more dense and oriented tangential to the surface instead of parallel to the long axis.[33]

Ultrastructurally, the CCL is a heterogenic composite structure formed by an extracellular matrix composed of macromolecules with highly specific arrangements and interactions.[88,91] Collagen is the chief macromolecule prevalent in the framework of the CCL. In excess of 90 percent of the collagen content of the CCL is type I collagen, the remaining collagen constituent being of type III.[92-94] The molecules are produced by the fibroblasts in the loose supporting connective tissue. The cells are present in long parallel columns between the collagen fibres, their axes parallel to the surrounding collagen fibres. Neurovascular components follow the same longitudinal orientation.[1,84,87,89] The complex micro-architecture of the viscoelastic CCL is further composed by about 5 percent of elastin.[88] Delicate elastic fibres can be found in the narrow spaces separating the primary collagen bundles.[33] Furthermore, the tightly packed longitudinally running collagen fibres are associated with a very small portion of proteoglycan and glycoprotein macromolecules.[88] The functional contribution of these components is extremely important for maintaining the viscoelastic properties of the CCL. Continuous interactions of the cells with the macromolecules of the ligament monitor the normal maintenance of the matrix in spite of load, aging, and injury.[88] Collagen fibres submitted to mechanical forces act as electrochemical transducers to the constituent connective tissue cells. The cellular metabolic activity and thus the organisation of the extracellular matrix and the maintenance of its glycosaminoglycan content are modulated indirectly by mechanical factors.[95]

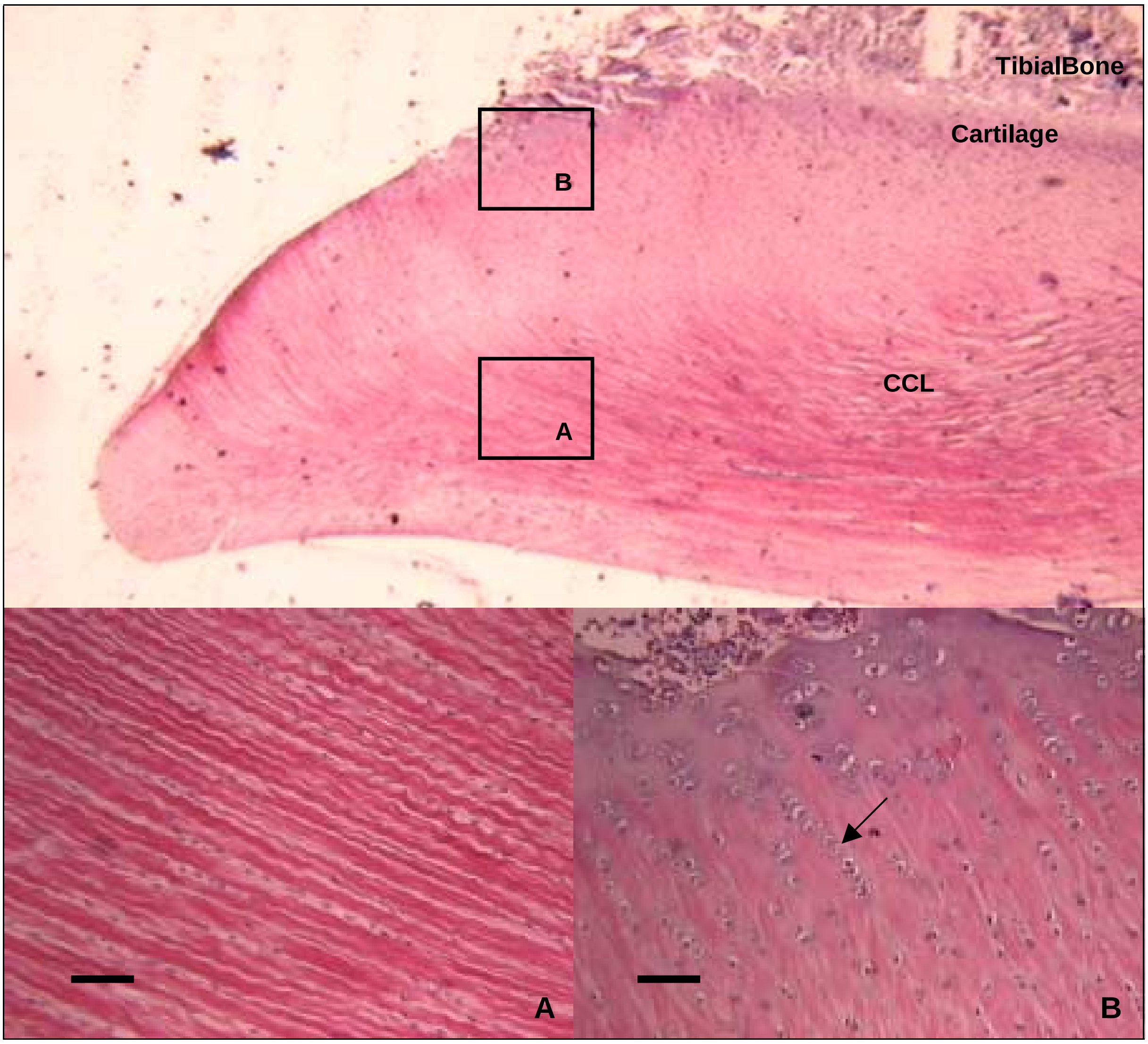

Fig 3. Normal cranial cruciate ligament (CCL) of a 4-month-old Riezenschnauzer, harvested at its tibial attachment site (H&E stain)
A. Along the CCL, dense collagen is aligned parallel to the longitudinal axis of the ligament (bar=100µm) **B.** At the osseous attachment site of the CCL, the collagen fibres are not arranged entirely parallel to the long axis of the ligament. Columns of chondroid cells (arrow) do penetrate into the CCL (bar=100µm)

The caudal cruciate ligament

The CaCL is ensheathed by two folds of the synovial membrane. The cranial envelope originates proximally from the cranial aspect of the joint capsule, while distally the caudal fold originates from the caudal aspect of the joint capsule.[87]

When compared to the CCL, the CaCL is more heavily structured.[43] A dense arrangement of collagen fibres is found in the area in contact with the CCL. Those fibres maintain an orientation tangential to the surface of contact, even when the cruciate ligaments start to twist about one another.[33]

1.1.6. MICROVASCULARITY

The normal vascular anatomy of the canine stifle is similar to that reported in the human knee.[84] The major vascular contribution to the centre of the stifle joint occurs via branches of the middle genicular artery.[96-99] This vessel arises from the popliteal artery, penetrates the caudal joint capsule, and passes craniodistally to the fossa intercondylaris, running cranially between the cruciate ligaments (Fig 4).[100]

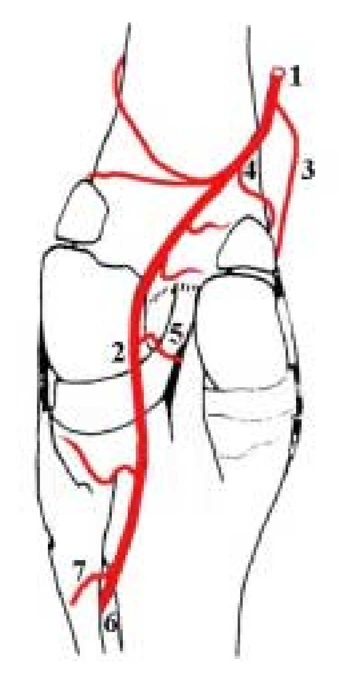

Fig 4. Caudal view of the major blood supply to the stifle joint in the dog

1. Femoral artery
2. Popliteal artery
3. Descending genicular artery
4. Proximal medial genicular artery
5. Middle genicular artery
6. Cranial tibial artery
7. Caudal tibial artery

The blood supply to both cruciate ligaments is predominantly of soft tissue origin. The infrapatellar fat pad and the well-vascularised synovial membranes which form an envelope around the cruciate ligaments are the most important sources of vessels and the major pathway for delivery of nutrients.[84,87,101-103] The synovial vessels arborise into a finely meshed network of paraligamentous vessels which ensheaths the cruciate ligaments throughout their entire lengths (Fig 5, Fig 6).[84] The contribution to the blood supply to the cruciate ligaments from the osseous attachments is negligible.[19,84,98,99,101]

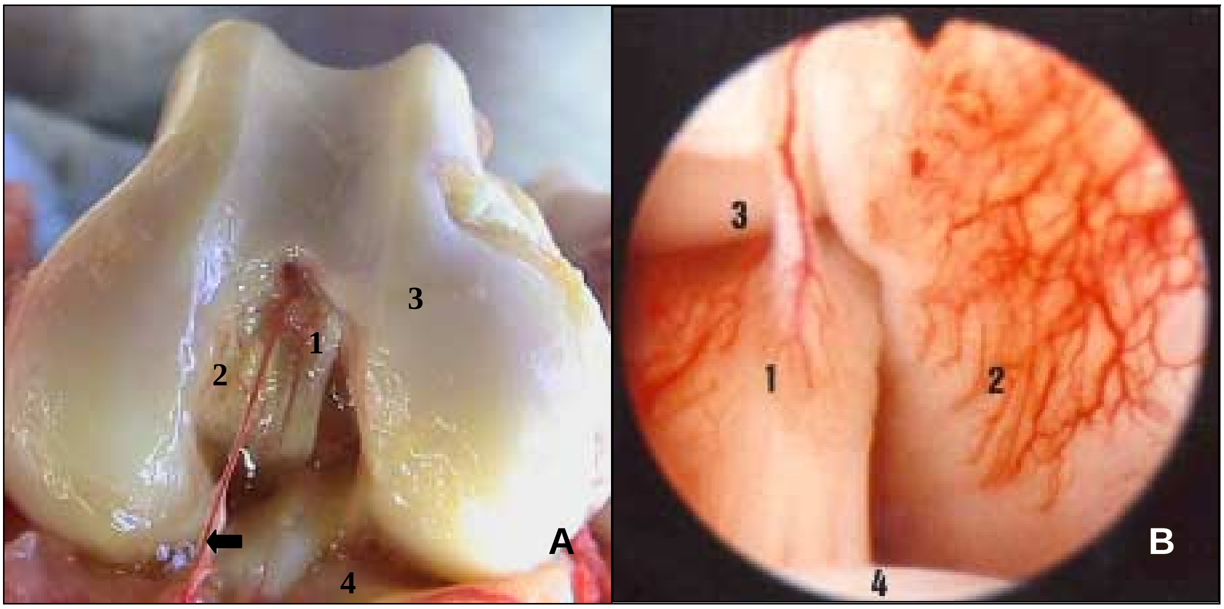

Fig 5. Superficial vascularisation of normal cruciate ligaments in the dog
A. Macroscopic view after injection of latex in a canine cadaver specimen
B. Arthroscopic view of a stifle joint in a normal dog

1. Cranial cruciate ligament 2. Caudal cruciate ligament 3. Lateral femoral condyle 4. Tibial plateau
Arrow: Artery originating from infrapatellar fat pad

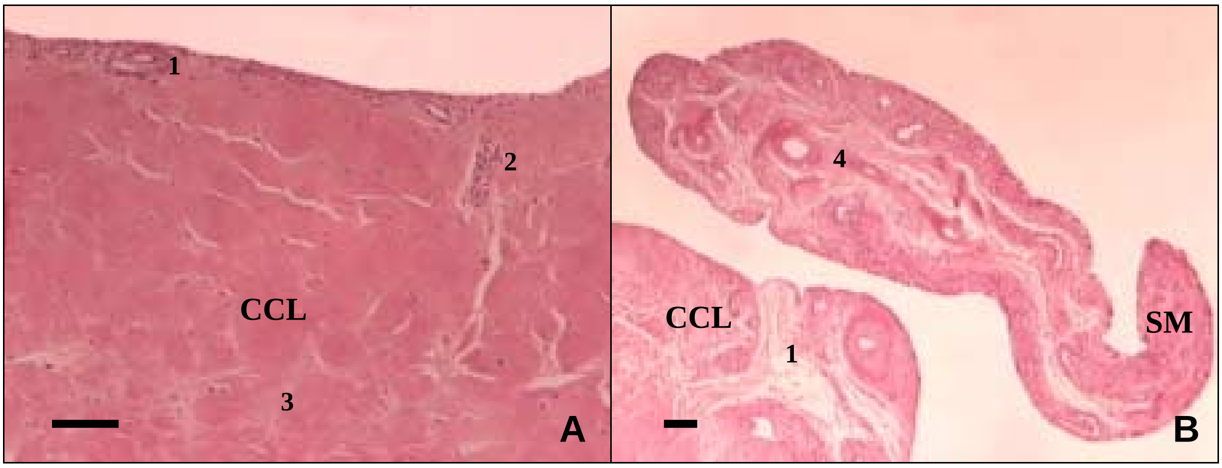

Fig 6. Normal cranial cruciate ligament (CCL) of an adult dog (H&E stain)
A. The CCL is ensheathed by paraligamentous vessels (bar=100µm)
B. The well-vascularised synovial membrane (SM) forms an envelope over the CCL (bar=100µm)

1. Paraligamentous vessels 2. Anastomosis between paraligamentous and endoligamentous vessels
3. Hypovascular zone 4. Synovial vessels

In the inner part of the cruciate ligaments, around and along the bundles of collagen fibres, an endoligamentous vascular network is found along its supporting connective tissue.[84,87] The larger vessels, usually one artery accompanied by two veins, mainly course in a longitudinal direction both proximally and distally and lie parallel to the collagen fascicles.[87] Some of them have a tortuous path in the interfascicular areolar tissue.[89] Only small capillaries branched off from the longitudinal endoligamentous vessels are seen to run in a transverse direction, encircling the collagen bundles.[87]

Anastomoses exist between extra- and intraligamentous blood networks. Paraligamentous vessels penetrate transversely into the cruciate ligaments (Fig 6 A). Their branches ramify and anastomose with the endoligamentous vessels. In contrast, the endosteal vessels do not often anastomose with the endoligamentous network, especially not at the tibial insertion site.[87,103,104] Most endosteal and endoligamentous vessels terminate in loops without crossing the ligamentous-osseous junction.[84,87]

The cruciate ligaments are not only nourished by microvessels. Significant nutrient uptake also occurs by passive permeation from the synovial fluid.[103,105,106]

The cranial cruciate ligament

The vascular roots of the CCL lie in the surrounding soft tissues. The vast majority of vessels originates from the infra-patellar fat pad cranially and from the fold of the synovial membrane caudally.[84,101,102,104] The vascular structures at the proximal part of the CCL are more numerous and have a larger diameter compared with those at the tibial side.[20,87] Most of them originate from a branch of the middle genicular artery and from some branches of the distal genicular arteries.[97-99,102,107] In humans, the largest branch of the middle genicular artery descends along the cranial surface of the ACL.[98]

There are numerous endosteal vessels at the ligamentous-osseus junctions. However, communications with intrinsic endoligamentous vessels are quite poor. Especially at the tibial insertion area most of the endosteal vessels seem to terminate in subchondral loops instead of crossing the ligamentous-osseous junction.[84,87] A number of endosteal vessels communicate with the paraligamentous vascular network overlying the CCL.[87] There are also vessels from the menisci anastomosing with the paraligamentous vascular plexus.[87]

The core of the midportion of the CCL is less well vascularised in comparison with the remainder of the ligament.[8,20,33,84,87,101,102,104,108] This anatomical feature of a relatively hypovascular mid-zone might contribute to the pathogenesis of cranial cruciate disease as discussed later.

The caudal cruciate ligament

The caudal synovial fold also provides the major contributing vessels to the CaCL. Most of them originate from branches of the middle genicular artery and from some branches from the other genicular arteries.[97,98] A twig divides halfway the CaCL into an upper and a lower branch, which both continue along the ligament.[102,104]

In general, the vascular arrangement and the structural characteristics of the vasculature inside the CaCL and the CCL are similar.[84,87,104]

The web-like network of paraligamentous and synovial vessels surrounding the CaCL appears to be slightly more extensive than the vascular plexus seen around the CCL.[84,101,102] However, the CaCL does not have a more abundant intrinsic vascular supply than the CCL.[19,98,99,107] Endosteal vascular communications are present proximally and distally, although they are rare.[87,104]

1.1.7. NEUROLOGY

Three major articular nerves arise from the saphenous nerve, the tibial nerve, and the common peroneal nerve to innervate the periarticular tissues of the canine stifle joint (Fig 1).[109] Besides purely anatomic studies on the nerve supply to the stifle joint, a lot of neurophysiologic experiments have been carried out. Most investigations of the innervation of the cruciate ligaments have been performed on cats or in human corpses. Between various mammals, however, the similarities seem in this respect to be far more prominent than the differences.[51,97,110] In the dog, the medial articular nerve is the largest supply to the stifle joint. It branches from the saphenous nerve at about mid-thigh. Some of its branches course through the infrapatellar fat pad to terminate within the proximal or distal attachments of the cruciate ligaments or within the meniscal horns.[109] The posterior articular nerve is variably present in dogs. Its branches arise either directly from the tibial nerve or from a muscular branch of the tibial nerve.[109] The posterior articular nerve runs to the caudal aspect of the joint capsule, where it may communicate with branches of the medial articular nerve.[109] In cats and humans, the posterior articular nerve arises from the tibial nerve usually below the popliteal fossa, and is the most constant and the largest of the stifle joint articular nerves, and the cruciate ligaments are mainly innervated by its branches.[111-113] The lateral articular nerve branches from the common peroneal nerve at the level of the fibular head, deep to the biceps femoris muscle.[109] It supplies the lateral portion of the stifle joint.[109] The main trunk of the nerve bundles is found at the femoral end of the cruciate ligaments, an area that becomes strained only at high loads.[19,109,114,115] Other nerves may also contribute afferent fibers to a variable extent to the cruciate ligaments.[109,116] Most of the nerve fibres within the cruciate ligaments course along the perilagamentous and endoligamentous blood vessels in their passage through the interfascicular areolar spaces. Therefore, it was previously believed that their function was primarily associated with autonomic nervous regulation of blood flow[19,89] what later proved to be a misunderstanding.[51]

Mechanoreceptors have been described in human as well as animal cruciate ligaments, while their exact role in proprioception is not completely elucidated. Proprioceptive receptors are found within most soft tissues of the stifle and its surrounding.[115,117,118] The sensory network within the cruciate ligaments plays an extremely important role in the neurosensory system around the stifle joint. By reflex arches, periarticular muscle groups are triggered to contract in order to avoid ligamentous injury by extremes of motion.[51,74,89,113,115,119,120] It is not a

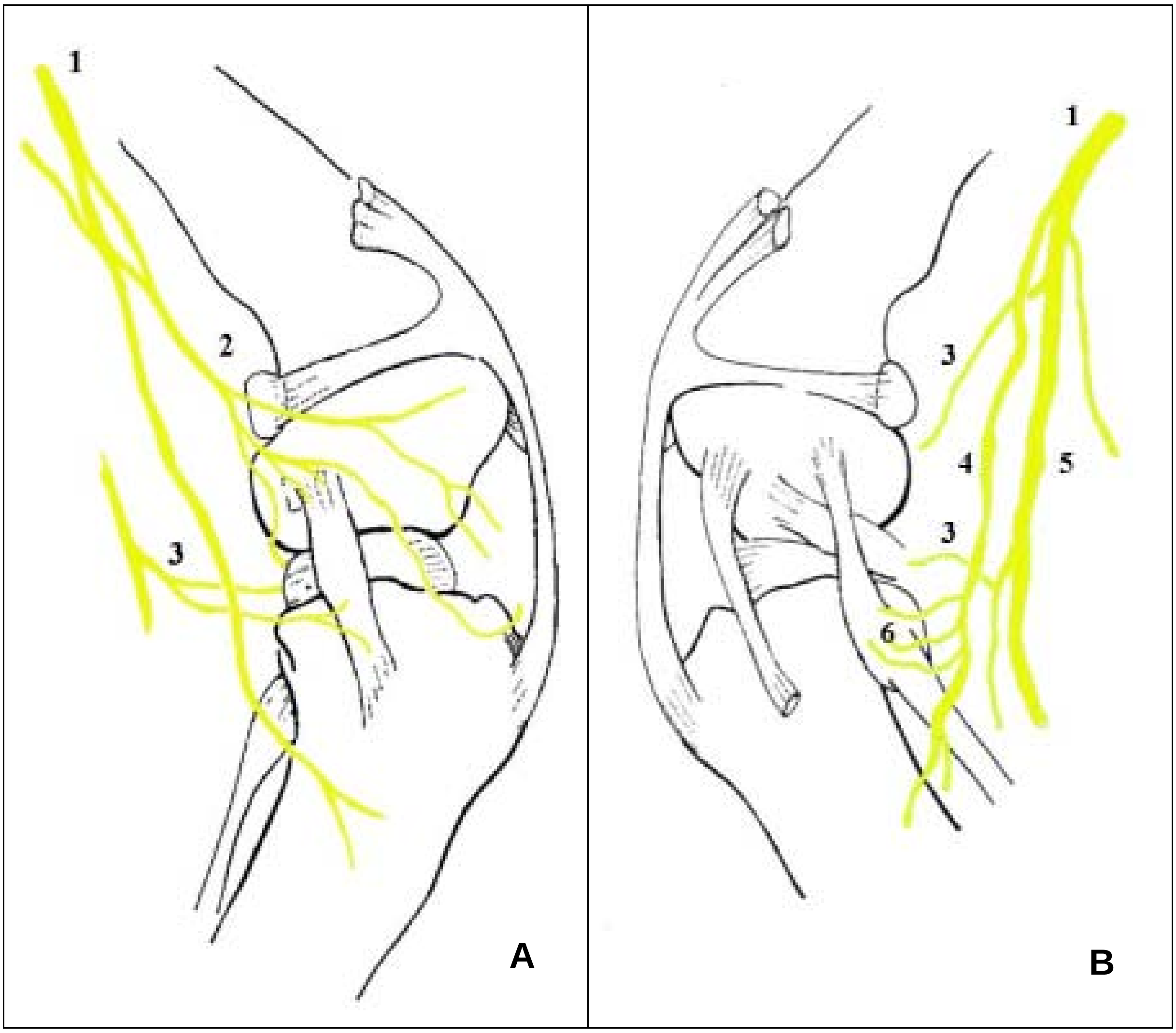

Fig 1. The major nerve supply to the stifle joint in the dog
A. Medial view
B. Lateral view

1. Saphenous nerve 2. Medial articular nerve 3. Posterior articular nerve 4. Common peroneal nerve 5. Tibial nerve 6. Lateral articular nerve

matter of conscious perception, but rather a reaction to mechanically-evoked electrical signals. The middle third of the cruciate ligaments is less densely equipped with sensory endings and is the primary viscoelastic component of the ACL, providing resistance to deformation at low- and moderate-load levels.[51,112,116,119]

Sensation of pain might be transmitted by a small population of free nerve endings which ramify in the cruciate ligaments.[89,117,121,122] However, the synovia seem to serve as primary pain receptors.[119] The cruciate ligaments contain both rapidly- and slowly-adapting receptors with low and high thresholds to mechanical deformation.[51,117,123] Mechanoreceptors are located near the surface of the cruciate ligaments and respond to longitudinal extension and deformation of the ligament, monitoring proprioceptive information.[117,123]

The cranial cruciate ligament

The cranial cruciate muscle reflex plays a physiologic role during stifle function.[120] When the CCL is loaded in cranial drawer, hamstring reflex activity is observed.[74,120] In dogs, the load threshold to trigger the CCL-muscle reflex is well within the working range of motion of the stifle and appears to be only 1 to 10 per cent of the loading required to rupture the CCL.[113] In humans, loss of ACL proprioceptive function is thought to contribute to increased joint laxity over time through loss of dynamic stabilising reflexes.[89,121,124] Of course, lesions to other structures in and around the joint contribute to the proprioceptive deficits encountered in an ACL-deficient knee.[125]

Neural elements associated with the CCL are located primarily in its richly vascularised synovial coverings.[114] Mechanoreceptors within the cruciate ligament itself provide proprioceptive information and indicate local reflex patterns to protect the ligament from tearing and warn against possible joint damage.[116,119] In men, there is particularly rich innervation of the tibial origin of the ACL[114], while in dogs a higher number of receptors is encountered in the proximal third of the CCL.[122]

The CCL is relatively insensitive to pain because it only contains rare free nerve endings.[117]

The caudal cruciate ligament

In dogs, some branches of the medial articular nerve pass cranially through the joint capsule to supply an extensive innervation of the femoral attachment of the CaCL.[109] An independent twig of the posterior articular nerve enters the joint capsule after giving off smaller branches to the fat pad, and finally terminates in the attachment of the CaCL to the tibia.[112] As for the CCL, the mechanoreceptor organs in the CaCL were found primarily at either extremity close to the attachments of the ligament.[112,115]

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1.2. Predisposing and etiological factors in canine cranial cruciate ligament disease. A long list of possible contributors

Traditionally, injury to the cranial cruciate ligament (CCL) in dogs has been classified in 2 main modes: a degenerative syndrome in middle-aged to older, small to medium-sized dogs and a traumatic condition in young large breed dogs.[1,2] Current observations have challenged these traditional views of CCL disease. Both groups are incontestably interrelated and various causes of CCL damage are not mutually exclusive. Pure traumatic CCL rupture in dogs is only an incidental event, occurring in any breed and at any age.[3-6] More often, the dog is performing daily activities within the physiological loading range at the time of rupture.[5,7-9] This form of nontraumatic rupture is termed spontaneous CCL rupture.

The integrity of the CCL may be lost due to direct trauma of the stifle joint if the breaking strength of the CCL is exceeded.[1,10-14] A few mechanics of traumatic CCL damage are recognised in the dog. Sudden hyperextension may occur when a dog steps into a hole while running, or when it is caught in a fence or gate.[12] The CCL will rupture as the distance between its attachment sites exceeds the length of this ligament.[15] A sharp turn while the foot is weight-bearing produces excessive internal rotation of the tibia. The CCL becomes very tightly twisted, and fibres are torn loose by rotation against the lateral femoral condyle.[11,12,16] Extreme cranial tibial thrust is stressing the CCL during landing after a jump from a height.[17,18] The purely traumatic form of ACL rupture predominates in men as a clipping injury in football or an hyperextension injury during skiing.[19-21,a] In dogs, it does not often seem to be the sole causative factor.[3,5,6,18]

The complete etiopathogenesis of spontaneous CCL rupture in dogs remains largely enigmatic in the majority of cases although much attention has already been focused on trying to identify factors that might predispose to injury. Mechanical strength is gradually decreased by progressive and apparently irreversible degenerative changes within the cruciate ligament itself and the susceptibility to damage due to minimal trauma or even normal loading becomes greater.[22-26] Before rupture of the CCL becomes clinically apparent, previous episodes of incremental partial tearing due to imbalance of forces causing tissue fragility to mechanical tension have been considered.[15,24,27]

Several surveys attempted to gain information of the type of dog affected by cruciate disease.[2,6,16,28-31] Age, breed, body weight, and gender all have been considered as risk factors in the development of CCL rupture. Comparison with the normal canine population is mostly lacking in these studies. Therefore, it might be questioned whether most reported data are genuine differences in the prevalence of spontaneous CCL rupture.[6,32]

Other contributing factors responsible for ligament degeneration and weakening are numerous. The microstructure of the collagen fibrils composing the CCL deteriorates when the dogs get older.[22-24] The central core of the cruciate is the most vulnerable part because of its poorer vascularisation.[11,12,22,24,33-38] If normal aging processes were a primary and sole cause of spontaneous CCL rupture, however, the frequency of bilateral cruciate disease would be higher than actually observed.[39]

A high percentage of patients are overweight and inactive.[32] In obese dogs, the ligament is repeatedly submitted to higher stresses what might accelerate degenerative processes.[40-42] A sedentary life style weakens the collagen of the CCL itself but also the other secondary soft tissue stabilisers.[16,26]

Skeletal abnormalities have been associated with increased strain placed on the CCL and predisposition of dog to CCL rupture. Chronic patellar luxation, angular shaft deformities, and conformationally straight in the hind limbs may all contribute to extra stress on the CCL.[2,11,12,17,25,43-47] Inappropriate sloping of the tibial plateau is also hypothised as a factor in the pathogenesis of CCL rupture.[15,48-50] Because there is a contact between the intercondylar fossa and the CCL, a narrowing of the intercondylar notch might also contribute to ligament fibres impingement and subsequent CCL failure in dogs,[51-53] as has been reported in human beings.[54-57] Such intercondylar notch stenosis may be a primary congenital or a developmental abnormality, or may be secondary to degenerative changes in the stifle joint.

Nontraumatic ACL rupture is not well documented in the human literature.[21] The degenerative processes that occur in spontaneous tendon rupture in men,[58] however, appear similar, histologically, to that occurring in the CCL of dogs.[24]

Many provoking factors remain unidentified to date. Evidence raised that immune phenomena play a role in several types of joint pathologies in dogs.[59-61] In cases of immune-mediated synovitis, a gradual relaxation of the cruciate ligaments can be encountered.[36,40,62,63] Elevated auto-antibody titers to collagen were detected in dogs with cruciate disease.[59] However, the presence of anti-collagen auto-antibodies does not necessarily imply that the initiation of CCL rupture is immune-mediated. Exposure of ligamentous collagen from a torn cranial cruciate might incite an antigenically stimulated joint inflammation. Further research in this field is highly required to explain all unanswered questions.

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[a] Ascherl R. Personal communication 2000

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1.3. Cranial cruciate ligament rupture in the dog. A review of diagnostic techniques

SUMMARY

Different techniques are available for diagnosing cranial cruciate ligament (CCL) rupture in the dog. A review is given on clinical features and laxity tests. Direct and indirect radiographic signs are described. Less available diagnostic modalities that may be useful in the diagnosis and diffential diagnosis of cruciate insufficiency are briefly discussed.

INTRODUCTION

Sometimes, the clinician will suspect a cranial cruciate ligament rupture (CCL) based on the history reported by the dog owner. However, individual clinical signs can vary greatly.

In the vast majority of cases, the dog becomes acutely lame following rupture of the CCL. It refuses to use the affected limb which is held in a flexed position. Thereafter, the limb will be carried in a walking position, without putting weight on it.[1] After a week to 10 days, the dog start using the leg but walks with a distinct limp. At rest, only the toes touch the ground.

In more than half of the cases, the owner is not aware of a real cause of the injury. If he is, most of the dogs were jumping or running on uneven territory.[2-4]

Quite often, the problems are more insidious. In the early disease state, the only clinical signs are a stiffer hindlimb gait, an irregular pace, or excercise intolerance. Sometimes, the affected leg is dragged.[5] During the last decade, an increasing number of young, large breed dogs have been presented with intermittent hind limb lameness. Often the problem can be attributed to stifle instability due to partial tearing of the CCL.[5-7]

Particularly bilateral rupture of the CCL is often erroneously attributed to neurologic disorders.[8,9]

DIAGNOSIS

Clinical examination

Inspection—The dog has to be viewed from behind and from the side at rest in the standing position to assess the position and angle of the stifle joint and to assess the degree of weight-bearing.[10] The patient's stance should be carefully screened for skeletal abnormalities which may predispose to CCL rupture.[11]

Some affected dogs are not able to sit in a full squat. They hold the affected limb in a non-physiological way beside the body because pain or fibrosis impede full flexion of the stifle.[12,13]

Most of the dogs are presented with a well-defined unilateral lameness.[3] In some cases, the dog is bilaterally stiff without an obvious limp.[5] A change in limb angulation might be detected.[14,15] At touchdown, the stifle joint is often kept in extension to avoid pain due to impingement on the menisci.[16]

Palpation—The exact clinical diagnosis of stifle lameness is not an easy matter and requires experience and skill. As in humans,[17,18] CCL rupture is overlooked initially in a rather high proportion.

Palpation of the affected stifle usually elicts a painful response.[10,19,20] The joint is obviously swollen what causes indistinct margins of the patellar tendon. The patellar tendon might be relaxed due to cranial displacement of the tibia.[21] A firm medial swelling due to capsular fibrosis or even new bone formation can be felt in longstanding cases.[2,9,20,22] Atrophy of the quadriceps muscle group can be appreciated very soon after the start of the problems.[1,5,11,23,24] In cases with serious pain and crepitation during passive motion, osteophytosis is almost always present on the preoperative radiographs.[25]

It is not imperative for concurrent meniscal damage to produce a clicking noice or a snap as the medial condyle is forced over the caudal edge of the medial meniscus. An audible click can be produced by the femorotibial instability only as well.[26-28]

Classically, increased endorotation of the tibia in combination with a cranial drawer sign are pathognomonic features for rupture of the CCL.[3,29-31] The stifle is tested in an unloaded condition so that only the ligamentous contribution to joint stability is to be detected. The drawer sign has been described on a semi-flexed stifle, by exerting cranial pressure on the fibular head (Fig 1 A). Correct positioning of the examiner's hands is important in performing the test properly.[9] Meanwhile, one should avoid inward rotation at the tarsal level and the femur has to be immobilised.[10] The goal of the drawer test is to evaluate the integrity of the CCL by determining cranial translation of the tibia ('drawer sign'). The amount of abnormal displacement depends of course upon the choice of the original neutral position of the tibia.[32] Since testing is often painful, the dog's resistance to manipulation and increased muscle tone might mask the cranial shifting of the proximal tibia. In inconclusive cases, sedation or even general anaesthesia will be necessary to make a correct diagnosis of subtle instability.[5,11,19] Additionally, the same test should be repeated with the stifle joint under a greater angle of flexion. In cases where there is only partial rupture of the CCL, only the craniomedial bundle might be damaged. On a quite straight leg, tension in the intact fibres of the caudolateral band can provide enough craniocaudal stability to give negative test results.[20,33] Special attention should also be given to the interpretation of the cranial drawer movement in skeletally immature dogs. A certain degree of cranial drawer of the proximal tibia is normal but it comes to an abrupt stop and is not associated with pain or effusion.[5] Therefore, comparison with the clinical findings in the opposite hind leg often is helpful.

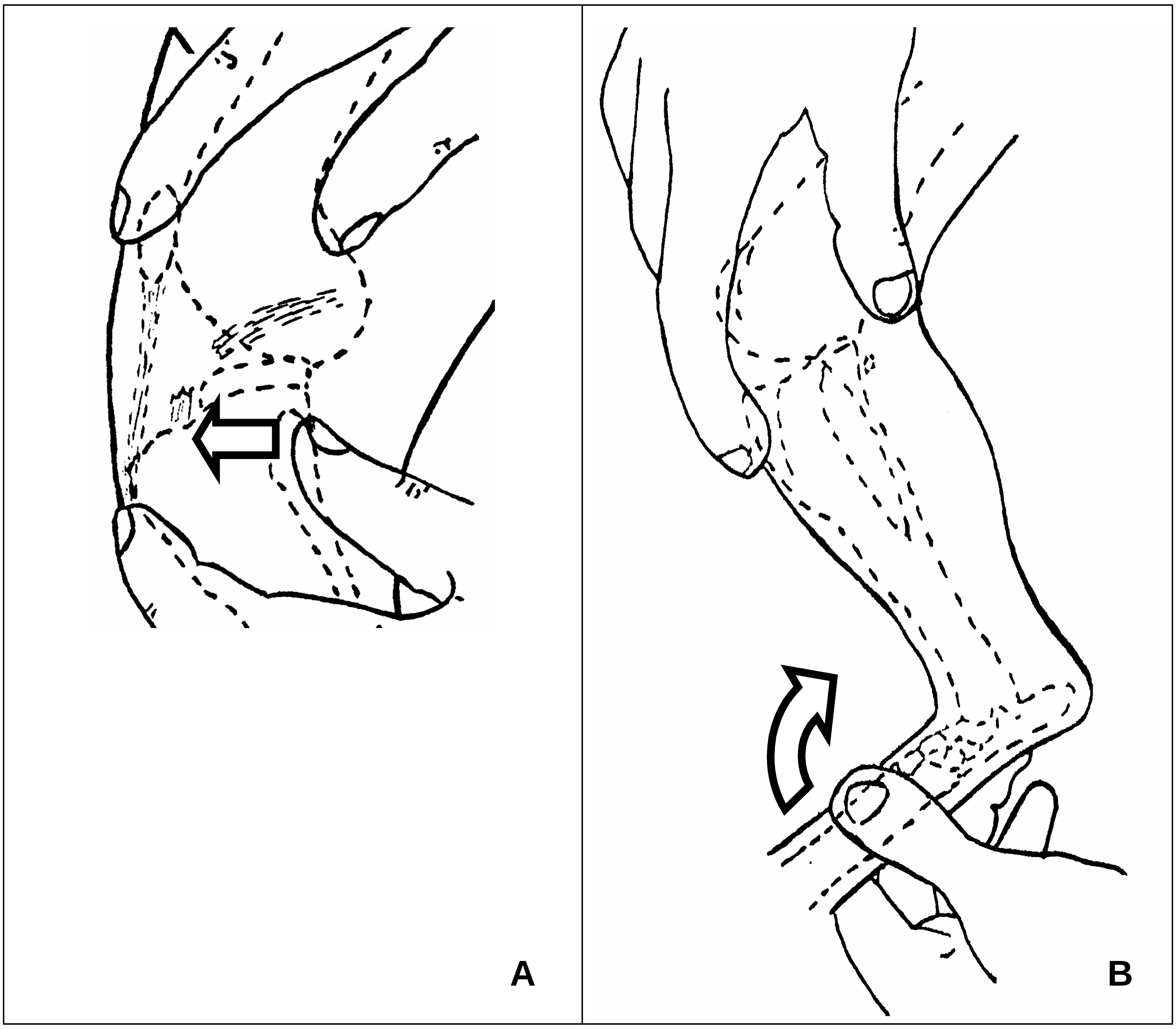

Fig 1. Manual tests to check for cranial cruciate instability in the dog
A. Cranial drawer test
B. Tibial compression test

In addition to the cranial drawer test, the tibial compression test is a reliable alternate diagnostic tool whenever the craniocaudal instability is difficult to diagnose.[3] It is tested on the stifle joint in a weight-bearing position, by placing the index finger on the tibial crest while the palm of the hand contours the femoral condyles. The other hand alternately extends and flexes the tibiotarsal joint (Fig 1 B). This movement mimics the contractions of the gastrocnemius muscles. In cases of rupture of the CCL, the tibia displaces cranially in respect to the femur what can be seen or palpated. Sedation is hardly ever necessary. Less pressure is exerted on the peri-articular tissues, which makes the subluxation of the proximal tibia less painful than when elicted by the cranial drawer test. A slight mechanical advantage is also encountered by counteracting the muscle tone since a conscious patient is less able to resist these forces. Another advantage is the ease of testing in larger dogs as compared to the classical cranial drawer test.[3,34]

In the early post-traumatic phase, similar results on instability are found by the classical cranial drawer test and the tibial compression test. In chronic situations of cruciate deficiency, both tests are less reliable. Thickening of the joint capsule and fibrosis increase the stability of the stifle joint and obscure the diagnosis of cruciate deficiency.[3,10] Cranial displacement of the proximal tibia can also be blocked by the presence of a torn meniscus.[10,26] During the manual tests, relatively small forces are excerted. Especially in cases of partial rupture and in heavy dogs, a false negative test result can be found, although the patient suffers clinically from joint laxity during normal activities.[11]

Whenever rupture of the CCL is complicated by tearing of the collateral ligament, a varus or valgus deviation is created by exerting stresses.[34,35] In such cases, there is also a tremendous increase in rotational instability on the extended stifle.[30]

Radiographic examination

Radiographs are a helpful adjunct to a careful history and a meticulous physical exam to support a tentative diagnosis.[21] Pathologies other than cruciate disease can be ruled out by studying soft tissues and bony structures. A standard lateral projection of the affected stifle is indicated in the diagnosis of CCL rupture. In very few cases, a craniodorsal view is mandatory.[5,36]

Direct signs—In some cases, a certain degree of displacement of the tibia relative to the femoral condyles can be appreciated on the lateral projection, even when no special appreciation of this area is made.[2] Backward sliding of the proximal tibia due to tension in the hamstring muscles might be blocked by a bucket-handle tear of the meniscus.[16] In smaller breeds with prominent tibial tuberosities, a false impression can be given that the femur is articulating abnormally far backwards.[23]

Indirect signs—The first radiographic signs following CCL rupture are mainly situated in the soft tissues: the infrapatellar fat pad is no longer visible and the caudal joint capsule is distended.[5,11] Apart from thickening of the capsular shadow, osteoarthrotic changes become visible.[37] Larger dogs have consistently more severe radiographic signs of DJD.[38,39] Within three to four weeks after experimental sectioning of the CCL, macroscopically visible arthrosis is present.[40] The first changes are a sharpening of the distal and proximal rim of the patellar bone, followed by irregular bony proliferation on these spots and osteophyte formation alongside the ridges of the trochlear groove (Fig 2).[2,5,39,41]

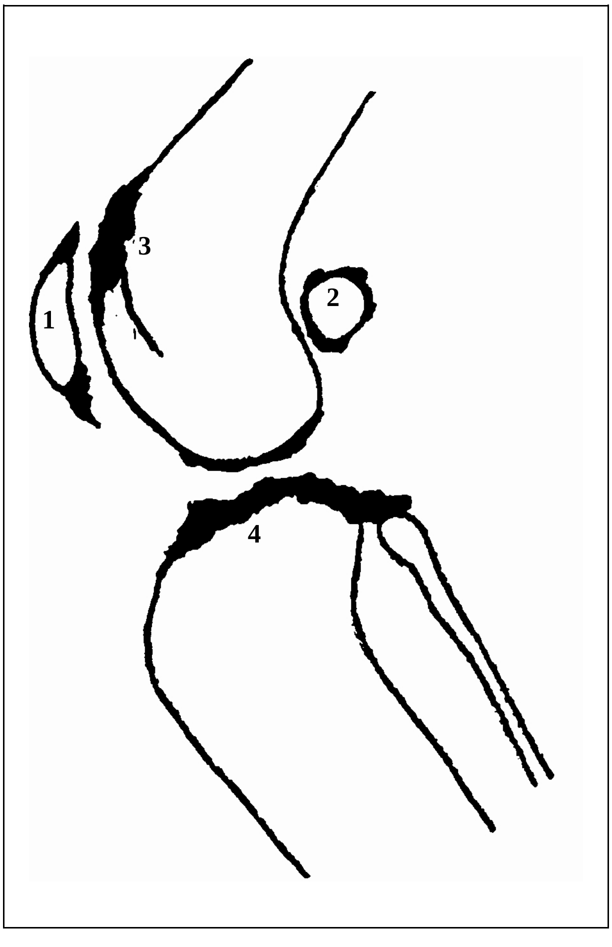

Fig 2. Localisation of the osteoarthrotic changes in cruciate-deficient stifle joints in the dog

1 lipping of the distal and proximal patella
2 osteophyte formation on the fabellae
3 sclerosis of the trochlear groove
4 sclerosis of the tibial plateau

Radiographic signs of DJD are not exclusively specific for CCL pathology, unless avulsion fragments are seen.[42,43] When blurring and osteophyte deposits are seen at the tibia site of attachment of the CCL, they can be considered pathognomonic of ligament pathology.[44,45] Increased sclerosis along the tibial plateau and on the rims of the femoral condyles can become apparent.[46] In longstanding cases, osteophytes form a 'balcony' caudal to the tibial plateau.

In contrast with humans,[47-50] assessing the dimensions of the intercondylar notch is not commonplace in dogs.[41,51,52]

It is also mandatory to screen radiographically the contralateral stifle joint. Certain early changes encountered on radiographs can contribute to the prediction of bilateral cruciate problems.[5,53]

Normal cruciate ligaments were screened succesfully in dogs' stifles by contrast arthrography but the technique did not appear helpful in evaluating cruciate pathology.[54,55]

Arthroscopy

If the diagnosis on clinical and radiological findings remains tentative, arthroscopy is a useful diagnostic tool. It is relatively atraumatic compared to exploratory arthrotomy.[56,57] Dogs, like human patients,[58,59] regain a normal gait much faster following an arthroscopic procedure than after an arthrotomy.[56,60] Especially in the diagnosis of partial cranial cruciate rupture, arthroscopy can be very useful.[56,61,62] During the procedure, specific flexion and extension angles, rotation, and varus and valgus stresses have to be used to augment the efficacy and reliability of this examination method.[60] In cases of severe inflammation, hypertrophic villi might blur the view.[62,63] To detect simultaneous meniscal lesions, new portals should still be evaluated as arthroscopy fails to detect damage to the menisci in 50 per cent of the dogs.[57,61,64]

The increasing popularity of intra-articular reconstructive techniques means that exploratory arthrotomy remains somewhere between diagnosis and treatment.[56] In dogs, arthroscopic-assisted CCL reconstructions are still in the experimental phase.[65,66]

Other techniques

Ultrasonography of the stifle can be used as completion of radiographic examination.[67-69] Although a diagnosis of CCL rupture in dogs is possible by ultrasound, it can be very difficult to reproduce sonographic findings in the canine stifle.[68,69]

Scintigraphy provides an indication of disease processes in many joint disorders. It appears to be a useful method for staging OA in unstable canine stifle joints, supplying additional information to that seen on radiographs.[70] Even in human medicine, however, scintigraphical findings do generally not provide information on the status of the ACL unless there is an avulsion of the attachment.[71]

Computed tomography is also superior to standard radiography in the detection of very small avulsion fragments.[a]

Magnetic resonance imaging is becoming more and more popular in the diagnosis of cruciate ligament and meniscal injuries in man and has proven to be extremely accurate.[72-78] Being totally non-invasive, the technique also does not expose the patient to ionising radiation. Magnetic resonance has an accuracy exceeding that of arthrography and has been demonstrated to be as sensitive and specific as arthroscopy whenever the ACL can be brought clearly into view.[11,73] In dogs, normal cruciate ligaments were screened successfully by magnetic resonance.[79-81] However, only limited information was given on their clinical relevance as diagnostic tools in pathological joints.[81]

CONCLUSION

In the majority of cases, a thorough clinical examination of the dog leads to a tentative diagnosis of CCL rupture. The injury is often not recognised early in the disease process. Radiography of both stifle joints is a particularly useful supplement to clinical examination. To avoid the risk of morbidity associated with an unnecessary arthrotomy, the diagnosis can be confirmed by viewing the CCL with an arthroscope.

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[a] van Bree H. Personal communication 2001

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1.4. Cranial cruciate ligament rupture in the dog. A review of treatments

SUMMARY

A review of treatment of cranial cruciate ligament (CCL) rupture is outlined. Conservative treatment as well as extra- and intra-articular techniques are considered. Many surgical procedures have been listed. Among veterinarians, there is no consensus on the techniques for repairing a torn CCL in the dog.

INTRODUCTION

Surgical repair of a ruptured cranial cruciate ligament (CCL) in dogs has been well-assimilated into veterinary publications. Nevertheless, a lot of controversy is still evoked by treating ruptured CCLs in the dog. The fundamental rationale of surgery is to restore stifle stability and to prevent further deterioration of the joint after debridement. The enormous variety of surgical techniques described in the literature indicates that none has proved to be totally satisfactory.[1,2] Outcome is variable and seems to be relatively independent of technique. Until now, more than one hundred techniques have been documented.[3] Roughly, the surgical procedures can be divided into three major categories (extracapsular, intracapsular, and tibial plateau leveling techniques). The main principle of the extracapsular techniques is to buttress the tissues lateral to the joint by craniocaudally oriented sutures.[1] Another extra-articular way of stabilising the cruciate deficient stifle joint is fibular head transposition.[4] Plenty of materials have been studied for intracapsular replacement of the damaged CCL. A strip of the fascia lata was the first prosthesis ever used.[5] Other autografts such as skin,[6] the tendon of the peroneus longus muscle[7] or the long digital extensor muscle,[8] and a part of the patellar bone attached to the straight patellar ligament[9] are described as natural substitute materials. On the other hand, synthetic prostheses have also been considered. In one study, nylon[10] was implanted, followed by Teflon[11] and Terylene[12] implants. Recently, there has been more interest in collagen-inducing materials e.g. carbon fibres[13] and polyester[14]. The tibial plateau leveling techniques require orthopaedic reconstructions of the proximal tibia to neutralise cranial tibial thrust during weight bearing.[15-17]

THERAPY

In 1926, Carlin first mentioned CCL rupture in the stifle joint of the dog.[18] It was the start of a whole cascade of studies and reports on possible causes and methods of treatment.[2] The first really extensive scientific study was published in 1952.[5]

Conservative treatment

According to Paatsama and Arnoczky, conservative treatment in dogs is a waste of time.[1,5] They recommended immediate surgical stabilisation. However, other researchers found a 90% success rate after non-surgical treatment in dogs weighing less than 15kg. Heavier dogs did not do so well, with only 1 in 3 having an acceptable clinical outcome.[9,19,20] The surprisingly good results of non-surgical treatment in small dogs might be attributed to the lower demands and the smaller loads on the unstable stifle. Most often, those patients are geriatric and thus less active as well.[20] Conservative treatment should be considered a viable alternative to surgical stabilisation for these patients, at least initially.[21] In the presence of generalised joint disorders such as rheumatoid arthritis and lupus erythematosus, operative treatment of the ruptured ligament is completely contra-indicated.[22]

Restricted activity (short walks on the leash) for 3 to 6 weeks, weight control and analgesic medication during periods of discomfort are part of the conservative protocol.[20] Anti-inflammatory drugs might be administered for short periods to treat arthritis pain.[19,22,23]

Surgical correction

Instability leads to progressive degenerative changes within the affected stifle joint shortly after the injury. For this reason, conservative treatment is often a waste of time.[1,5] Whether or not the CCL rupture should be treated surgically, depends on functional as well as on objective criteria.[24]

In cases of severe instability, especially in large breed dogs or working animals, or when problems are present for more than 6 to 8 weeks, surgery is strongly recommended.[19,22]

There is no unanimous opinion on possible regeneration and healing of partially ruptured CCLs.[25-28] It is not fully clear whether such cruciate ligaments have to be replaced or whether further tearing can be avoided.[26] Several investigations show that lameness and pain during manipulation of the affected stifle joint are also present in cases of partial tearing of the CCL, even when there is minimal or no detectable instability.[25,27,28] Therefore, surgical intervention is also required in these cases.

Meniscal pathology is often seen concurrently with or as a consequence of rupture of the CCL and always requires surgical intervention. It is mainly the medial meniscus which shows disease.[29-36] Meniscal surgery is performed following the arthrotomy and before the CCL is repaired. Most mensical injuries are amendable to partial resection, removing only the abnormal section (Fig 1 A). Partial meniscectomy is to be preferred where possible over total meniscectomy because it has been shown to produce less degenerative joint changes (DJD).[33,35,37,38] Other surgeons prefer total meniscectomy due to the smaller risk of iatrogenic laceration of the joint cartilage or CaCL with the scalpel blade (Fig 1 B).[30,39] Quite recently, meniscal release was introduced to prevent meniscal damage in cruciate deficient stifles with intact menisci at the time of arthrotomy.[40] The caudal horn of the medial meniscus is freed by a sagittal incision just medial to its lateral attachment on the intercondyloid eminence (Fig 2 A) or by an incision caudal to the medial collateral ligament (Fig 2 B). The purpose of meniscal release is to allow the medial meniscus to move away from the crushing action of the medial femoral condyl during cranial translation of the tibia.[40-42]

The first surgical method of treating CCL rupture in dogs was introduced in 1952 and was based on the concept of ligament replacement with autologous tissue.[5] Many years later, a new surgical concept was developed where the craniocaudal joint instability was corrected without any attempt to replace the ruptured CCL.[43] Several comparative studies document the efficacy of different stabilisation techniques.[9,44-46] In 1976, Knecht published a comprehensive review of the surgical methods of treatment.[2] Several modifications have been developed since.[3] According to Arnoczky, no one technique has been proven to be superior in all categories of patients.[22]

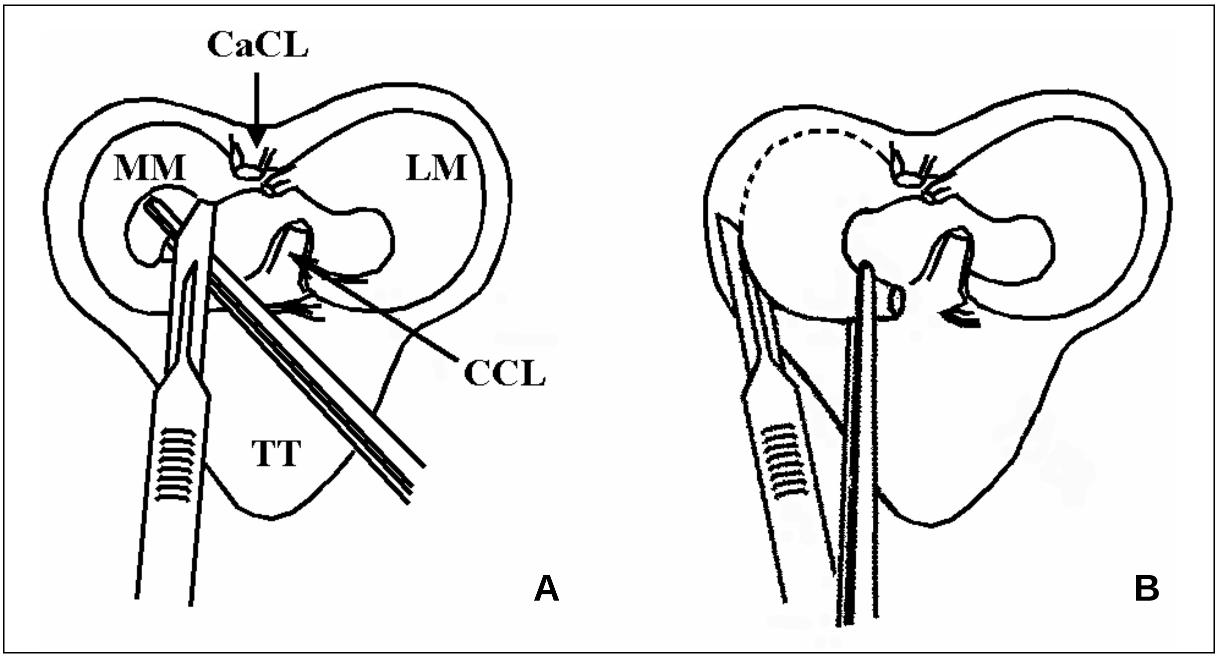

Fig 1. Principle of meniscectomy in the dog in case of a damaged medial meniscus
A. Partial meniscectomy. A curved hemostat is attached to the torn strip of the meniscus and the remaining peripheral attachments are dissected free
B. Total meniscectomy. Incision of ligament and capsule attachments

CaCL Caudal cruciate ligament, CCL Cranial cruciate ligament, LM Lateral meniscus, MM Medial meniscus, TT Tibial tubercle

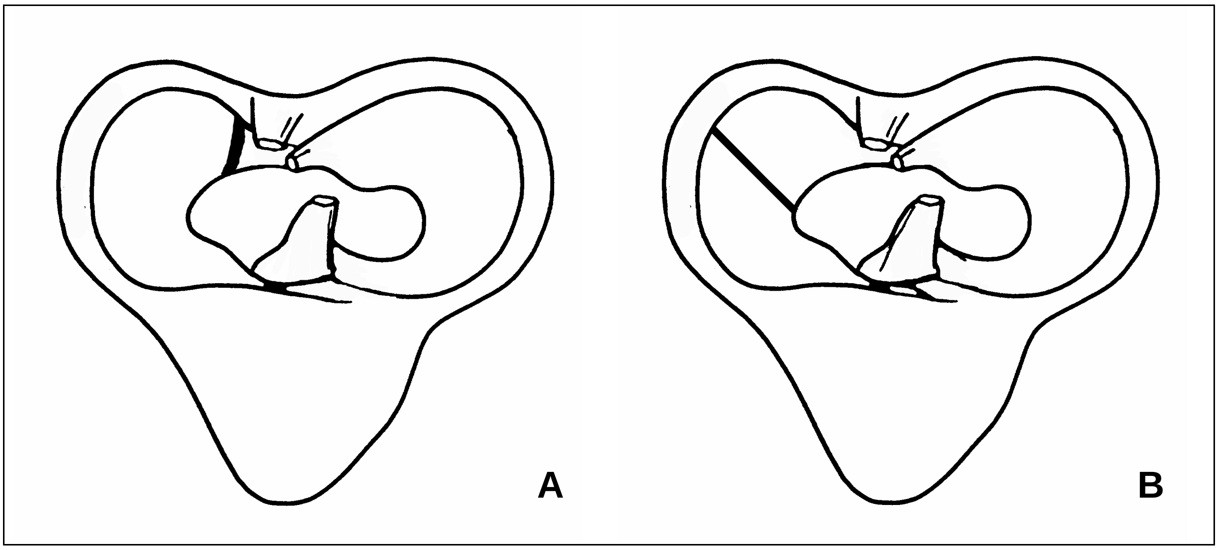

Fig 2. Principle of meniscal release in the dog in case of an intact medial meniscus
A. Incision just medial to the lateral attachment of the caudal horn of the medial meniscus
B. Incision caudal to the medial collateral ligament

Extra-articular techniques—In cats and small dogs, satisfactory postoperative results are achieved following extra-articular stabilisation of cruciate-deficient stifle joints.[43,47] Even in heavier dogs, lateral imbrication techniques are used.[48,49]

While there are many extra-articular techniques, the basic principle is to stabilise the joint by reinforcing and thickening periarticular soft tissue by craniocaudally oriented sutures.[1] Generally, these procedures are easy to perform. Biomechanically, these extra-articular procedures are far from ideal.[50,51] The normal degree of inward tibial rotation in respect to the femur is also prohibited and abnormal loading can occur. Complications, such as tearing of soft tissues or of the suture material, are encountered.[52,53]

One of the first techniques described uses multiple Lembert sutures in chromic catgut on the lateral aspect of the joint capsule.[43] Pearson and others improved this technique by placing three layers of sutures.[54] Meanwhile, De Angelis and Lau described a single mattress suture in Polydek, from the lateral fabella sesamoid to the lateral third of the straight patellar ligament or through a bone tunnel in the tibial crest (lateral fabellotibial loop).[55] In a modification of this technique, an extra medial suture was placed.[52] The synthetic material can be replaced by an extra-articular fascia lata strip to restore normal stifle biomechanics in dogs under 15 kg of body weight.[56] Olmstead published on 5 years experience with stainless steel wire as lateral buttress in dogs of various weights.[57] A few years ago, a crimp clamp system has been developed for nylon leader material to avoid large bulky knots when creating the loop.[58] Irrespective of the material used, however, all lateral fabellotibial sutures may break or loosen after surgery. But it is believed that short-time stabilisation allows periarticular fibrosis to become established, which provides long-term stifle joint stability.[57,59] In practice, lateral suture stabilisation is still the preferred method of repair in small dogs.[49]

Another technique providing lateral and medial support was developed by Hohn and Newton in 1975.[60] A medial arthrotomy is performed, the caudal belly of the sartorius muscle is transected and reattached more cranially to the straight patellar ligament. Laterally, 2 mattress sutures are placed on the capsule. Then, the biceps and its fascia lata are plied over the patellar ligament and sutured.

More recently, an easy extra-articular procedure has been introduced by Meutstege. He recommends low imbrication of the lateral fascia using a resorbable suture material, after cleaning-up of the affected joint.[48]

In a last extra-articular technique, the head of the fibula is attached in a more cranial position, by a tension band wire or by the use of a cortical screw.[4,61] In this way, the lateral collateral ligament is reorientated and tensioned to stabilise the cruciate-deficient stifle joint.

Intra-articular techniques—The intra-articular techniques are theoretically preferable over the extra-articular as they allow for more accurate substitute of the ruptured CCL.[62] Even in cases of fresh tearing and perfect apposition, the CCL will not regain its original strength.[63] Only by anatomic restoration of recent CCL avulsion fractures, normal ligament function during all positional changes of the stifle joint can be restored.[64]

Extensive studies examined the properties of ideal substitue materials and the true anatomical position.[65] The prosthesis should mimic the original cruciate in preventing cranial displacement of the tibia and in controlling hyperextension of the stifle.[22] Incorrect orientation of the graft might result in wearing of the material leading to a definite failure.[66]

In 1952, a modification on the human Hey Groves technique[67] was described as a method of treatment in cranial cruciate deficient dogs.[5] A fascia lata strip is created to construct a transplant ligament. It is pulled through the joint via a hole drilled in the lateral femoral condyle to the intercondylar groove and a tunnel drilled from the point of attachment of the CCL to a point medial to the tibial crest. The strip is tightened and reattached to the straight patellar ligament. Small changes in the technique have been described since the first publication.[2] Singleton fixed the graft at the proximal and at the distal end of the bone tunnels by use of orthopaedic screws.[68] A major modification was introduced by Rudy.[37] Osteophytes are removed, meniscectomy is performed whenever there is damage, and an orthopaedic wire is applied from the lateral fabella to the tibial tuberosity to act as an internal splint.

Instead of using the fascial graft, Gibbens lead chemically treated skin through bone tunnels oriented as originally described by Paatsama.[6] Meanwhile a patellectomy is performed if concurrent patellar luxation has to be corrected. Other experiments were carried out: Leighton tested untreated skin,[69] Foster and colleagues drilled the bone tunnels more cranially without opening up the joint.[70]

For the ‘Over-the-Top’ technique, the medial third of the patellar ligament, the craniomedial part of the patella and fascia lata are all included in the flap.[66] The freed strip is pulled proximally through the intercondylar groove and it is attached to the soft tissue above the lateral femoral condyle. To better mimic the anatomical insertion place, the graft can be lead under the intermeniscal ligament first.[71] Another possibility is to prepare a lateral strip, as Denny and Barr did, which can be lead through an oblique tunnel in the tibia, starting from the original place of insertion of the CCL.[72,73]

Other tendon transpositions have been used: the tendon of the peroneus longus muscle,[7] the long digital flexor tendon[74] and the long digital extensor tendon[8,75,76]. In experimental trials, reconstruction of the cruciate ligaments was done by fresh and freeze-dried allografts of patellar tendon and fascia lata.[77,78] Freeze-dried specimens are well-tolerated, while fresh allografts may induce a foreign body response. Implantation of frozen bone-CCL-bone allografs is clinically not yet supported.[79] Alternative methods of stabilisation of the CCL deficient stifle such as popliteal tendon transposition are still in the experimental phase.[80]

Veterinary surgeons as well as human orthopaedists became very interested in the possible use of different synthetic materials to substitute a ruptured CCL.[22] Notwithstanding the positive results of preliminary studies, synthetic prostheses are still infrequently used in the veterinary world.[81] Reconstructive materials have to be at least as strong as the original ligament, and preferably even stronger.[82] Of course, biological inertia of the prostheses is also necessary, and only minimal tissue reaction may be provoked by the implantation.[83,84] Removal of a synthetic implant may become obligatory at any time postoperatively.[85] Another drawback is the relatively high cost of the implants.[86] Support for double-bundle reconstructions for clinical use are so far not found.[87,88]

Several synthetic substitute materials have been tested. In 1960, Johnson started to use braided nylon.[10] In the same year, a publication appeared on the use of Teflon-tubes.[11] A lot of materials followed, although a large number of them were used without preliminary studies.[2] Besides Teflon meshes,[89] supramide,[90,91] Terylene[12] and Dacron[14] were implanted. For use in dogs, a special Polydek prosthesis was developed.[83] Fragmentation of carbon fibre substitutes has stimulated two opposing interpretations.[92] According to some researchers, a neoligament develops progressively within the gradual weakened meshwork,[13] others argue that only a constant inflammatory response is stimulated.[93] Polyester also acts as a scaffold-type device.[14,94] It can be used as a fibre bundle or as a tape.[94-97]

More recently, arthroscopically-assisted intra-articular replacement of a ruptured CCL also gains more popularity in the veterinary world.[97,98]

Tibial plateau leveling techniques—The common objective of the classical extra- and intra-articular procedures is the elimination of the cranial drawer sign.[22] In 1984, a new concept was introduced by the study on cranial tibial wedge osteotomy.[15] To gain joint stability, an orthopaedic reconstruction is required which enhances the action of the stifle flexors of the thigh. It has to be followed by another stabilising technique to control internal rotation of the tibia. Tibial plateau leveling osteotomy (TPLO), using a curved osteotomy and a special plate for fixation, has been introduced in 1993.[16] In a modification, a wedge osteotomy to the level of the tibial plateau and screws for fixation are used.[17] The goal of

TPLO surgery is to neutralise cranial translation of the tibia during weight bearing and ambulation. The cranial drawer sign during passive manipulation is not eliminated. The principle of the surgery is to rotate the sloped tibial plateau until it is level, thus causing the weight bearing forces to be compressive only. It is recently postulated, however, that the procedure generates caudal tibial thrust making stifle stability dependent on CaCL integrity.[99] In order to avoid excessive stress on and damage to the caudal horn of the medial meniscus, a medial meniscal release is performed by transection of the lateral attachment of the caudal horn as adjunct procedure.[40,42]

In humans, the importance of rehabilitation programs is well-understood. Conditioning of the antagonist muscles (hamstrings) seem to play an important role to stabilise a knee lacking the original ACL.[100] Little note is taken to the benefits of postoperative rehabilitation on the final outcome of surgery in dogs so far.[23,98,101,102]

PROGNOSIS AFTER TREATMENT

Conservative treatment gives a satisfactory clinical improvement in about 85 per cent of dogs weighing less than 15 kg but only in 19 per cent of heavier patients.[9,19,20] All animals develop osteoarthritis (OA).[1,103] Furthermore, there is an increased risk of future damage of the medial meniscus.[104]

The success rate of surgical treatment is multi-factorial and depends on surgeon experience and on the studied population. The subjectivity of the surgeon in assessing clinical and radiographic results influences the outcome as well.[73]

Most of the authors report a satisfactory functional recovery in 80 to 98 per cent of the dogs operated on. After successful surgery, the limb is fully functional within 8 to 12 weeks postoperatively.[71,72,91,94,105] According to others, however, optimal results are only achieved after 12 months.[3,106]

No correlation can be shown between postoperative stability and the progression of osteophytes.[107-110] It is clear that OA increases in the postoperative period. Until now, no technique is able to stop this evolution.[109,110] On the other hand, the clinical success seems independent of the degree of radiographic OA.[23,28,107,108]

The percentage of patients with concomitant meniscal injury seems related to the chronicity of the untreated cruciate injury.[104] This phenomenon is not related to the age nor to the sex of the dogs. The firmly attached medial meniscus runs the risk of being compressed between the moving joint surfaces in the unstable stifle joint.[111] The final prognosis is negatively influenced by the concurrent damage to the medial meniscus. The progression of OA changes is sped up, before and after surgery, when meniscal damage is present.[4,104,112]

There is no unanimity on the success in chronic cases with severe OA. Some studies do not show a significant increase in recovery.[113] Others suggest that pre-operative DJD adversely affects the final results.[22,69,76] Older dogs also carry a poorer prognosis and might benefit more from conservative treatment with anti-inflammatory drugs and painkillers.[22]

In some cases, rupture of the contralateral CCL is encountered due to chronic overload.[12,106] A bilateral problem is seen in about one third of the cruciate patients, with an interval of a few months.[9,12,16,26,114,115] This relatively high incidence of contralateral damage within a year, further supports the hypothesis of degenerative etiology.[26,114,115]

CONCLUSION

The plethora of techniques and prosthetic materials indicates that the ideal therapy for CCL rupture has not yet been invented. All surgical treatments only provide temporary stability. Meanwhile, periarticular fibrosis is responsible for the final stability of the stifle joint, notwithstanding the technique used. Little improvement has been made in preventing the progression of DJD after surgery. However, clinical success seems independent of the degree of joint changes.

Cruciate disease remains an enigma on which a lot will be said and published in the future. The choice of treatment will greatly depend on the surgeon’s preference, since the ideal technique has yet to be discovered.

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CHAPTER 2

THE TIBIAL COMPRESSION TECHNIQUE AS A RELIABLE RADIOGRAPHIC TEST FOR CRANIAL CRUCIATE INSTABILITY IN DOGS

2.1. Diagnosis of cranial cruciate ligament injury in dogs by tibial compression radiography

2.2. Use of compression stress radiography for the detection of partial tears of the canine cranial cruciate ligament

2.3. Radiographic measurement of craniocaudal instability in stifle joints of clinically normal dogs and dogs with injury of a cranial cruciate ligament

2.4. Popliteal sesamoid displacement associated with cruciate rupture in the dog

2.1. Diagnosis of cranial cruciate ligament injury in dogs by tibial compression radiography

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SUMMARY

Stress radiographs were taken of 42 sound stifle joints, of 5 stifles with pathologies other than cruciate disease, and of 72 stifles with surgically confirmed cranial cruciate ligament (CCL) damage. The stifles were also examined by the cranial drawer test. No false positive compression radiographs were obtained. In the 72 stifles with cranial cruciate damage, instability was diagnosed on the stressed view in all but two cases. The sensitivity of the radiographic tibial compression test was 97 per cent, compared with 86 per cent for the cranial drawer test; the specificities of the tests were 100 per cent and nearly 98 per cent, respectively.

The tibial compression radiograph is a simple, objective aid in the diagnosis of cranial cruciate damage in dogs.

INTRODUCTION

Cranial cruciate ligament (CCL) injury is a common problem in dogs, and is generally evaluated by physical examination. The most consistent findings are joint swelling and instability of the stifle. To assess the instability two tests - the cranial drawer test and the tibial compression test - are often used in veterinary practice. For the cranial drawer test,[1] the stifle is slightly flexed and gentle cranial pressure is exerted on the head of the fibula with the thumb. At the same time the femur is supported with the other hand, the thumb behind the lateral fabella, so that counter-pressure can be applied.[2] A positive sign is obtained when the tibia can be pushed cranially. The tibial compression test[3] mimics the contraction of the gastrocnemius muscle group, whereby the stifle joint is fully extended. The tip of the index finger of the hand that immobilises the femur, rests on the tibial tuberosity, and the hock joint is repeatedly flexed and extended with the other hand. This test is positive when a cranial displacement of the tibial tuberosity can be felt under the index finger of the upper hand.

CCL injuries can be difficult to diagnose by these classical clinical tests alone.[2,4,5] The cranial drawer test can sometimes not be elicted or fully assessed, and the impression of relative displacement and rotation during clinical examination is often not very accurate.[6,7] A combination of several manual and radiological biomechanical tests has been recommended for the clinical diagnosis of cruciate ligament instability in humans.[5] A radiograph shows the spatial relationship between the bones at the joint level. The position of the tibia in relation to the femur will be related directly to the status of the supporting ligaments which originate on one bone, and insert on the other.[8] On a neutral view of a normal canine stifle in 90° of flexion, the perpendicular on the femoral axis that runs just cranial to the fabellae, will be almost tangential to the caudal projection of the lateral tibial condyle.[9] In a small number of cases, the cranial displacement of the proximal tibia may be visible on a standard lateral radiograph, without any special stresses being applied to the leg during the positioning.[10-13] This particular sign is called 'Cazieux-positive', and always indicates a ruptured CCL.[9] The abnormalities will be accentuated on stressed views.[14] A technique for obtaining a tibial compression radiograph has been designed for dogs suspected of having damage to the CCL. For this technique, the stifle is fixed at an angle of 90° of flexion, while manual stress is exerted on the metatarsals in order to flex the hock joint maximally. A ruptured CCL will then allow the proximal tibia to move cranial in relation to the distal femur.

This study was designed to evaluate the accuracy and usefulness of the tibial compression radiographic technique.

MATERIALS AND METHODS

Dogs—The stifle joints of two groups of dogs were used to provide control tibial compression radiographs. Ten sound control dogs were radiographed bilaterally, and in addition the normal stifle of 22 unilaterally affected patients was radiographed, to provide a total of 42 compression radiographs of normal stifles. These 32 dogs had a mean age of 5.7 years and a mean bodyweight of 26.0 kg. Five other dogs were screened, three during an arthrotomy procedure to correct medial patellar luxation, one dog with chondromalacia, and one with idiopathic synovitis which was screened during diagnostic arthroscopy of the affected stifle. The five dogs all had intact ligaments.

Tibial compression radiographs were taken in all dogs suspected of having damage to the CCL which were submitted to the Department of Medical Imaging from November 1992 until June 1995 (Table 1). The cranial drawer test was assessed by several examiners with different levels of experience. In general, it was first applied while the dog was conscious. Whenever the result was negative or uncertain, it was repeated after the dog had received a sedative (Thalamonal), before the radiological examination.

Table 1. Numbers and breeds of dogs suspected of having damage to their cranial cruciate ligament

Breed	**Number of cases**
Rottweiler	17
Labrador Retriever	9
Poodle	8
Boxer	7
Berner Sennen	6
Crossbred	5
Golden Retriever	5
Husky	5
Maltese	4
Dobermann	4
Pointer	3
Great Dane	2
St Bernard	2
Stafforshire Bull Terrier	2
Yorkshire Terrier	2
Other breeds	12
Total	93

Confirmation of damage to the CCL was obtained during the arthrotomy or arthroscopy of 72 joints, 59 with complete, and 13 partial ruptures of the CCL. The dogs with surgically confirmed cruciate injuries ranged in age from one to 12 years (mean 4.8 years) and in body weight from 5.5 to 70 kg (mean 30.9 kg).

The findings during surgery were correlated with the results of the cranial drawer test and the radiographic tibial compression test.

Positioning—A sedative (Thalamonal) was administered intramuscularly before the radiographic examination. The dog was positioned in lateral recumbency, with the affected stifle resting on the x-ray cassette. A standard lateral view was taken of both stifles with the joints in 90° of flexion (‘neutral’). For the stressed position (‘tibial compression’), the stifle was fixed at the same angle of flexion, while manual stress was exerted on the metatarsals by an assistant, in order to flex the hock joint maximally (Fig 1). Care was taken not to twist the leg during this procedure, so that both femoral condyles were maximally superimposed on to each other. The x-ray beam was collimated as much as possible and lead protection was applied to the hands of the assistants.

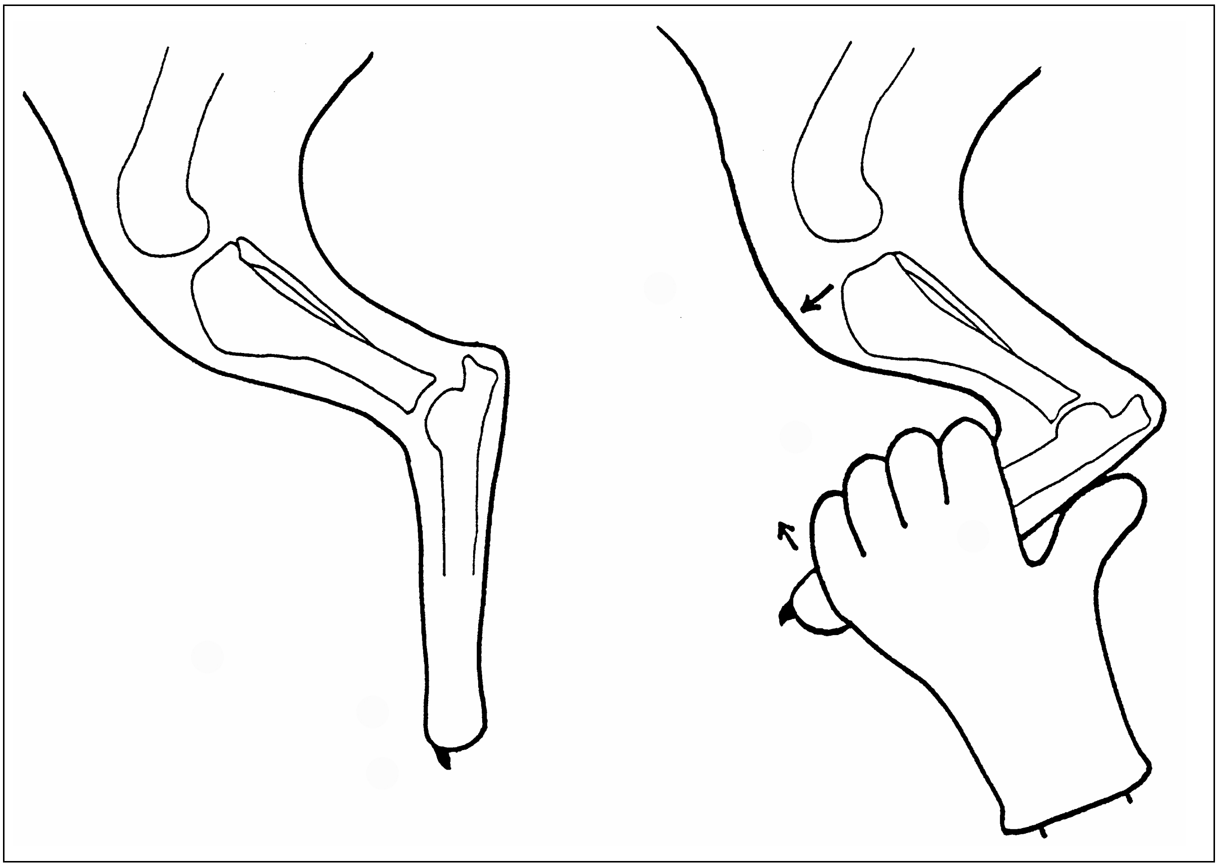

Fig 1. Diagram showing the principle of tibial compression radiography by manual positioning

Interpretation of tibial compression views—The radiographs were read separately by two of the authors (HdR and PvB) before the outcome of the arthrotomy or arthroscopic procedure was known.

The following criteria were used to assess the instability of the joint on the stressed radiographs. In obviously positive cases, the vertical line tangential to the caudal margin of the femoral condyles ran far behind the caudal projection of the tibial plateau (Fig 2). When less displacement was present, the position of the lateral intercondylar tubercle of the tibia in relation to the contour of the lateral femoral condyle helped to assess the cranial shifting of the proximal tibia. The position of the popliteal sesamoid was also helpful.

Fig 2. Radiographic images of a cruciate-deficient stifle joint showing **A.** a neutral view and **B.** a stressed view

RESULTS

Of the 72 joints with known cruciate problems, 13 (18%) had CCLs which were partially torn, and the other 59 were completely ruptured (Table 2). In six dogs, damage to the CCL was diagnosed in both stifle joints. However, only the tibial compression radiographs of the second injured stifle were included in this study.

The stress radiographic analysis has a specificity of 100 per cent; no false positive tibial compression radiographs were obtained and no displacement was apparent in the stifle joints of either the control group, or in the group with stifle pathology other than cruciate injury. In contrast, a cranial drawer test was positive in one case of medial patellar luxation, although the CCL was found to be completely intact during arthrotomic inspection of the joint. The manual test has a specificity of nearly 98 per cent.

The sensitivity of stress radiography was 97 per cent. In the 72 stifles with cranial cruciate damage, instability was apparent on the stressed radiographic view in all but two cases (one complete and one partial rupture). In the latter case, the popliteal sesamoid appeared far more distal on the stressed radiograph of the affected stifle than on the tibial compression view of the unaffected stifle. The probability of making a correct diagnosis of cruciate injury (accuracy) based on tibial compression radiography was 98 per cent.

The manual cranial drawer test were applied to 64 of the 72 joints with cranial cruciate disease (Table 2). The test was not always done by one of the authors, but by several clinicians with varying degrees of experience. The test gave false negative results in nine cases (six complete ruptures and three of 11 partial ruptures), giving a sensitivity of 86 per cent for diagnosing cruciate injury in affected joints.

Tibial compression radiographs were positive in six of the joints which gave a negative cranial drawer test. Finally, in two CCL-deficient stifle joints, both the cranial drawer test and the radiographic tibial compression test were negative.

Table 2. Results of the radiographic tibial compression test and the manual cranial drawer test on the 72 stifle joints shown to have either partial or complete rupture of the cranial cruciate ligament by arthrotomy or arthroscopy

	Partial rupture CCL (13)				**Complete rupture CCL (59)**			
	Intact MM (10)		**MM tear (3)**		**Intact MM (45)**		**MM tear (14)**	
Test result	**TC-RX**	**CD-DR**	**TC-RX**	**CD-DR**	**TC-RX**	**CD-DR**	**TC-RX**	**CD-DR**
Positive	9	3	3	1	44	29	14	13
Negative	1	3	0	0	1	5	0	1
Uncertain	0	3	0	1	0	5	0	0
Not recorded	0	1	0	1	0	6	0	0

CCL Cranial cruciate ligament, TC-RX Tibial compression radiographic test, CR-DR Cranial drawer test, MM Medial meniscus

DISCUSSION

In contrast with the physical tibial compression test,[3] the stifle is held at an angle of 90° while making the tibial compression radiograph. The canine CCL is formed by a craniomedial and a caudolateral bundle; the former is under tension during the whole range of motion of the stifle, while the latter is loose when the joint is flexed.[15] These features can have an effect in cases of partial rupture of the cranial cruciate. At full extension, a false negative result is likely if only the craniomedial bundle of the ligament has ruptured, because the caudolateral bundle can mask the instability. In flexion, however, the caudal bundle of the cranial cruciate will always be loose, regardless of the state of the cranial bundle. As a result, fewer cases of incomplete damage will be missed when the tibial compression stress is exerted on a flexed stifle joint.

Great care has to be given to certain aspects of radioprotection during the tibial compression technique, because the dog has to be restrained while the radiograph is taken. Sedation is advisible so that minimal restraint is necessary, and the x-ray beam should be carefully collimated and the handlers' hands should be protected by lead. Investigations are underway to modify the technique and eliminate the necessity for manual positioning of the limb. Under general anaesthesia, a figure-of-eight dressing with an elastic gauze bandage has been applied to span the tarsal joint. More clinical cases need to be studied first before the value of the modification can be assessed.

Stress radiographs are positive whenever there is an abnormal spatial relationship between the proximal and distal components. In the case of a positive tibial compression radiograph, the proximal tibia will appear too far cranially in relation to the distal femur when stress is applied. The sesamoid bone in the tendon of the popliteus muscle will also often appear to be displaced distally. A distomedial displacement of the popliteal sesamoid has only been reported twice, and both cases suffered avulsion of the popliteus muscle.[16,17] To the authors' knowledge, distal displacement due to rupture of the CCL has not previously been reported. They consider that the sesamoid bone appears more distally on tibial compression radiographs when there is damage to the cruciate ligament. In a small number of dogs the popliteal sesamoid does not ossify, and therefore remains invisible on radiographs.[18] In this study, the popliteal sesamoid was not ossified in 6 per cent of the dogs radiographed. They were all small breed dogs, with an average bodyweight of 9.2 kg.

The cranial drawer test, rather than the clinical tibial compression test, was used for the clinical assessment of joint laxity. General clinicians are less familiar with the latter test and some of the clinical data were obtained from records which, in most cases, included only the results of the cranial drawer test.

No false positive tibial compression radiographs were obtained, because no displacement was apparent in any of the stifles in the control group. Similarly, among the dogs with problems other than cruciate disease, only negative stressed views were encountered. Thus, a positive radiographic test always indicates either a partial or complete tearing of the CCL. False negative results were obtained in only two cases and the test had a sensitivity of 97 per cent. In comparison, the diagnosis would have been missed in about 14 per cent if only the cranial drawer test had been applied. This test had a sensitivity of 86 per cent. Furthermore, this test gave a false positive result in one out of the five cases of stifle pathology other than cranial cruciate disease.

For this study, no special attention was paid to the existence of degenerative changes in the affected joints and their possible influence on the outcome of the clinical and radiological tests.

Several types of arthrometers ('gonylaxometers' or 'goniometers') have been tested on human knees in order to define the normal and pathological craniocaudal stability of the knee joint during loading of the proximal tibia.[7,19-22] Their main disadvantage is the high cost of the specially instrumented devices, and a second drawback is the low accuracy that can be achieved owing to the interposition of soft tissue and relative movement around the stifle other than pure translation.[8,22-24] On radiographs these problems are eliminated by working with bony landmarks.

On the basis of these observations, the tibial compression technique is a reliable radiographic test for cranial cruciate instability in dogs. A positive result always indicates either partial or complete rupture of the CCL.

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2.2. Use of compression stress radiography for the detection of partial tears of the canine cranial cruciate ligament

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SUMMARY

Twenty-three cases of partial rupture of the cranial cruciate ligament (CCL) were reviewed. All of these patients were evaluated for clinical and radiographic signs of instability. Nine cases showed a negative drawer sign on manual assessment. A positive radiographic tibial compression test was obtained for all stifle joints with a partially ruptured CCL. In 13 cases, the site of injury and the appearance of the torn ends were evaluated. The final diagnosis of partial CCL rupture was made by direct visualisation and probing of the CCL during arthrotomy (22 cases) or arthroscopy (one case).

INTRODUCTION

Damage to the cranial cruciate ligament (CCL) in the dog is the stifle injury most commonly encountered in any small animal practice.[1] Originally, partial rupture of the CCL was considered to be rare in the dog.[2] The clinical importance of partial tearing of the cranial cruciate has been questioned by Zahm[3] and by Heffron and Campbell[4] among others, because of the often relatively minor joint instability. More recently, there has been more unanimity of opinion concerning the generation of lameness, pain on manipulation and stifle joint effusion associated with incomplete damage to the CCL, even though no or only slight instability might be demonstrable clinically.[5,6] Nevertheless, clinical reports with a special emphasis on partial CCL rupture are rather sparse in veterinary literature.[5-8]

CCL injuries, and in particular partial tearing of the ligament, are still often overlooked at the time of the initial injury. In a large number of cases, the veterinarian encounters difficulties in eliciting instability by a physical examination only, with no detectable cranial drawer sign in response to the small manual forces used on manipulation of the affected stifle joint. Exploratory surgery of the affected stifle joint has been necessary to disclose partial rupture of the CCL in the past.[6,7]

In obscure cases of knee injury in human orthopaedics, arthroscopic investigation following careful physical examination is a direct standard diagnostic procedure and a valuable tool to determine the rational treatment.[9-11] Arthroscopy of the canine stifle joint allows direct visualisation and careful probing to reveal minor surface fraying or subsynovial tears.[12-14] Unfortunately, the basic equipment needed to perform arthroscopy, and veterinarians with sufficient experience of arthroscopy, are not widely found in veterinary practices.[12,15]

The purpose of the present study was to investigate the use of compression stress radiography for the clinical diagnosis of partial CCL tearing in dogs.

MATERIALS AND METHODS

The surgical reports of all dogs that underwent orthopaedic surgery of the stifle joint at Ghent University Veterinary School from the beginning of February 1996 to the end of January 1998 were reviewed. Partial tearing of the CCL was diagnosed in 23 stifles (23 dogs). For these dogs, the records were reviewed for data such as breed, age at time of presentation, bodyweight and gender. Furthermore, data on history and findings during the physical examination were carefully studied.

For each case, neutral and stress radiographs were available for both the injured and contralateral stifle joints. Whether or not cranial drawer was noted during the physical examination, stress views were performed in cases of stifle lameness using a technique previously described by de Rooster and others.[16,17] Briefly, the dog is positioned in lateral recumbency. A standard lateral radiograph of the stifle joint is first taken at 90° flexion. While maintaining this angle of flexion of the stifle joint, the hock joint is maximally flexed by manual stress and a second picture is taken. (The technique of tibial compression radiographs is not possible in the UK because the Ionising Radiation Regulations forbid manual holding of animals for radiography. Currently, investigations are under way to modify the technique [elastic gauze figure-of-eight dressing] and hence eliminate the need for manual positioning of the limb.)

For the present study, the radiographs were all re-read in a blinded manner by the principal investigator (HdR) to grade osteoarthrotic (OA) changes and to assess radiographic displacement. The OA scoring system used was based on a global score (grade 0 to 3), according to the criteria of Brünnberg and others[18] (Fig 1).

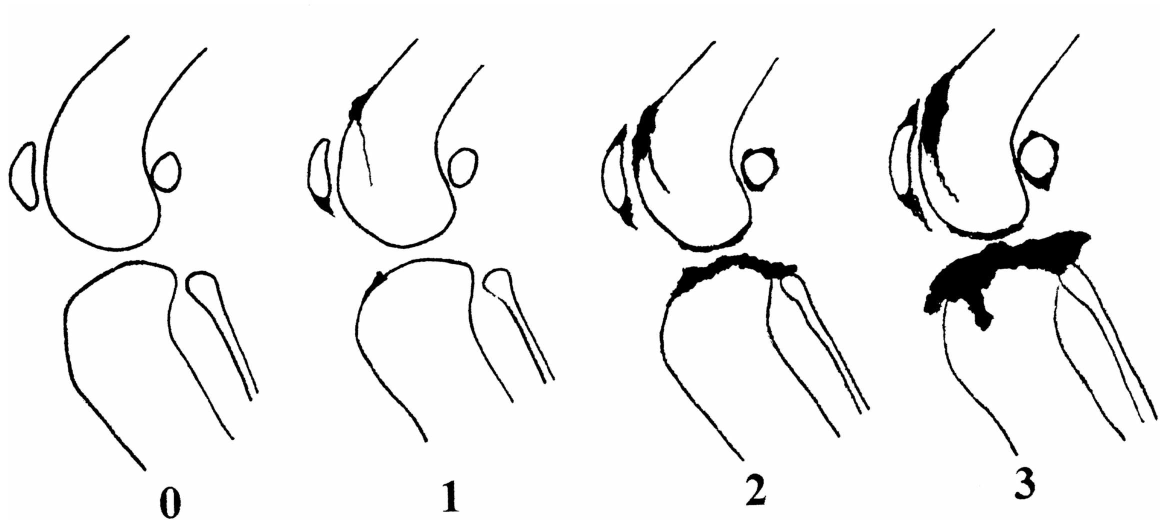

Fig 1. Radiographic grading of osteoarthritic (OA) changes (based on Brünnberg et al. 1992)

0. No signs of OA
1. Mild signs of OA, lipping of the distal patella, sclerosis of the trochlear groove
2. Moderate signs of OA, lipping of the distal and proximal patella, osteophyte formation on the fabellae, sclerosis of the trochlear groove, sclerosis of the tibial plateau
3. Severe signs of OA, all above-mentioned signs, osteophyte proliferation caudal to the tibial plateau, sclerosis in the long digital extensor muscle groove

Surgical findings were compared. Macroscopic inspection of the CCL occurred at the time of arthrotomy in all but one case. If no obvious tearing was seen, careful probing of the individual bundles, comprising the CCL, was carried out with a curved haemostat to detect any incompetent fibres.

In the last 13 cases, the main staff surgeon was asked to assess the location of tearing of the CCL. The site of the injury was recorded by the region of the tear (proximal, central, distal or interstitial), and the nature of the remnants (absorbed, unchanged or granulated) was also recorded.

Data on which of the two functional components of the CCL was damaged were not available from the surgical reports.

Precise determination of the percentage of tearing of the CCL proved not to be possible, since the original thickness of the ligament can only roughly be estimated.

RESULTS

Thirteen different breeds were presented with partial tearing of the CCL. Mean bodyweight of the patients was 33.9 kg (range 8 to 65 kg). The mean age at time of presentation was 3.9 years (range 0.6 to 12 years). Only five of the 23 dogs were male. The mean period from initial lameness to examination was 3.7 months (range 0.2 to 104 months).

A negative cranial drawer sign was encountered in nine cases, whereas the radiological tibial compression test was positive for cruciate instability in all the cases. OA changes were present in all but one dog. Only mild degenerative changes were seen radiographically in 14/23 dogs, moderate arthrosis in a quarter of the cases and severe signs of OA in the remaining two patients.

The final diagnosis of partial CCL damage and possible meniscal injury was made during surgical examination at arthrotomy performed by the same surgeon in all but one dog. This individual had only a diagnostic arthroscopic examination, which was not followed by any stabilising surgery.

Upon entering the joint, the CCL was found partially ruptured in 18 out of the 23 cases. In the remaining five joints, no obvious tears were found instantaneously, but careful probing revealed a fibrillated and torn component (interstitial tearing) and a badly stretched ligament in three cases. One further ligament showed minor surface fraying of its fibres, but no detectable laxity, and the remaining dog showed calcifications within the ligament on its preoperative radiographs, although the bulk of the CCL appeared to be grossly intact by anatomical inspection at the time of arthrotomy.

In five cases, simultaneous tearing of the medial meniscus was encountered.

The anatomic location of the tearing was recorded in 13 cases. A femoral avulsion fragment was seen in the only case which involved the origin of the CCL, while distal tearing of a ligament bundle occurred in five other cases. In two cases, the rupture was located in the mid-portion of a ligament band and, in the remaining five cases, the tearing was interstitial.

The ruptured ends were found to be rounded but almost unchanged in five of the 13 cases, and the torn ends of the partially ruptured CCL were totally atrophied in one further dog. In two other cases the stumps were abundantly granulated.

With the limited number of cases available, associations between the presence or absence of a detectable cranial drawer sign and factors such as the degree of radiographic OA, the duration of the clinical signs of lameness, meniscal damage and the region of the ligament injury could not be made (data not shown). The same was true for associations with background variables, such as patient age and body weight (data not shown).

DISCUSSION

The prevalence of partial CCL damage is very difficult to assess accurately. Subclinical tearing may occur more frequently than is realised. It is postulated that quite some cases of partial rupture are only presented to the veterinarian once the damage has become already complete.[18]

The aetiopathogenesis of partial tearing of the CCL remains obscure. For most of the dogs with partial CCL, a history of trauma is absent.[5] The loads that account for partial rupture of ligaments probably do not reach the level of ultimate breaking strength.[20,21] Increased fragility of degenerated ligament tissue under physiological loading conditions is suggested.[22] Microfailure is the beginning of a serial process that progresses to involve major fibre bundles. Tearing of the CCL is the result of the initiation of this continuing process of successive overload of the collagen fibres.[23]

Spontaneous healing of the torn mature ligaments seems an unlikely event.[21,24,25] Furthermore, in the human knee it has been stated that weakening of the anterior cruciate ligament will stress the secondary restraints and, in time, stretch them as well.[26]

There can be difficulty in arriving at a diagnosis of partial CCL tear. Difficulties in establishing the diagnosis of cruciate instability by physical examination alone are especially encountered in long-standing cases of cruciate disease, in cases with only partial tearing of the ligament or if the CCL is incompetent but not truly ruptured.[13] Capsular thickening and joint distension may contribute to a false impression of stability.[5,27]

The cranial drawer test demands a certain portion of the CCL to be torn. The remaining intact portion of a partially ruptured ligament might obscure existing laxity at certain joint angles and resists drawer motion to varying degrees.[4,6] Despite testing for a clinical cranial drawer sign at various angles of joint flexion, the test remained negative in nine of the 23 dogs with partial rupture in the present study.

In an attempt to improve the diagnostic accuracy of clinical evaluation of cranial cruciate instability, tibial compression radiography has been introduced.[16,17] Tibial compression stress radiography is a valuable asset in the diagnosis of canine stifle instability due to cranial cruciate tearing. It is a useful technique to prove (or disprove) a tentative diagnosis of CCL damage, especially when there is a lack of cranial drawer sign on clinical examination. All cases of partial rupture in the present study showed a positive tibial compression radiograph, although in nine dogs the cranial drawer test was negative.

The accuracy of the radiographic tibial compression test was calculated to be 98 per cent in canine cruciate disease.[17] However, diagnostic arthroscopy or exploratory arthrotomy might still be indicated if radiographic examination is not suggestive of CCL damage, but no further abnormalities can be detected.

Arthroscopy provides an accurate means of detecting tearing of the CCL whenever a doubtful diagnosis remains after physical and radiological evaluation of the affected stifle joint.[13] Gross anatomic inspection of arthritic joints at the time of arthrotomy will not always reveal obvious macroscopic damage to the CCL, although histological examination of such apparently undamaged CCLs does often disclose rupture of individual fibrils.[2]

The canine CCL is composed of two functional bands.[4,28] The craniomedial subdivision is more spiral and longer than the caudolateral division, and remains taut during both flexion and extension of the stifle joint. The caudolateral portion is taut in the extended joint, but becomes relaxed as the stifle joint is flexed. In the case of an isolated partial rupture in the dog, the more common bundle part to be injured seems to be the craniomedial band.[5-7,19,29] Because of its smaller size and its permanent tension, the craniomedial bundle is more prone to damage, especially during flexion when accompanied by internal rotation.[5,8,30] Unfortunately, there were no data available for the studied cases on which of the two functional bands of the CCL was ruptured.

In 13 dogs in the present study, the region of ligament damage was recorded. During tensile tests on canine bone-CCL-bone units, the mid-portion of the ligament is the predominant area of failure.[21,31] In the studied cases of partial rupture, only two out of 13 partial ruptures occurred in the central area. A possible explanation is given by the lower force levels acting on the ligament, resulting in incomplete tearing.

From clinical observations, it has been established that torn ends often remain normal after partial rupture, whereas they most often disintegrate after complete rupture. In only one case of partial damage of the CCL in the present study did the torn ligament ends seem to be completely absorbed by the time of corrective surgery. Disruption of their major blood supply is the most common reason for prompt disintegration of the stumps.[24] In the other cases, CCL tissues have been removed for further histopathological and immuno-histopathological investigations.

Tibial compression stress radiography is able to detect partial tears of the CCL. It is an easy and reliable technique which does not require expensive equipment or a high level of technical proficiency.

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2.3 Radiographic measurement of craniocaudal instability in stifle joints of clinically normal dogs and dogs with injury of a cranial cruciate ligament

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SUMMARY

Craniocaudal laxity of the stifle joint of dogs was determined when joints were positioned in tibial compression or neutral position. Relative displacements of bony landmarks were measured on paired lateral radiographs of 10 normal dogs, 29 stifle joints with varying injury to the cranial cruciate ligament (CCL), and 19 unaffected contralateral stifle joints. Two measuring techniques were customized for use in dogs.

A wide range in measurements of laxity was found for stifle joints with intact CCLs. Differences in degree of damage to the ligament and medial meniscus cannot be deduced from the amount of relative displacement measured on radiographs. Pathologic changes to the CCL will not necessarily induce detectable changes in laxity of stifle joints in dogs.

INTRODUCTION

Lameness of the hind limbs in dogs is often associated with the stifle joints. Instability resulting from damage to a cranial cruciate ligament (CCL) represents the majority of ligamentous injury to the stifle joints.[1]

Damage to a CCL in dogs is often overlooked at the time of initial injury. Classically, clinical diagnosis of cruciate disease is made on the basis of results of the cranial drawer[2] and tibial compression[3] tests. In many dogs, veterinarians encounter difficulties eliciting instability during physical examination only. Detection of craniocaudal instability may be masked by factors such as muscle tone caused by pain or stress, effusion, torn menisci, or periarticular fibrosis that develops in chronic cases of cruciate disease.[4]

Indirect signs of cranial cruciate rupture can be assessed on a standard lateral radiographic view of an affected stifle.[5] On a radiograph of a joint in a stressed (tibial compression) position, a cranial shift of the proximal portion of the tibia will be visible in most dogs with CCL rupture.[6,a] In such dogs, exploratory arthrotomy or diagnostic arthroscopy to disclose CCL rupture can be avoided.

The objective of the study reported here was to provide data on laxity of the stifle joint in clinically normal dogs, which could be used by clinicians when attempting to diagnose CCL rupture. The accuracy and usefulness of 2 measuring techniques for dogs with suspected damage to the CCL, without obvious radiographic displacement on lateral radiographic view with the joint positioned in tibial compression, was assessed.

MATERIAL AND METHODS

Animals—Two distinct groups of intact stifle joints (normal joints in clinically normal dogs and unaffected contralateral joints in dogs with cranial cruciate deficiency) were examined. Careful attention was given to clinical details such as joint effusion, range of motion, signs of pain elicited during passive manipulation, and radiographic evidence of signs of early osteoarthritic (OA) changes. Radiographs of normal stifles were obtained from 10 clinically normal dogs; dogs were screened bilaterally, and none had a history of orthopedic problems. Only 19 radiographs were acceptable for use in the study, because excessive rotation of the femur caused 1 radiograph to be discarded from the group.

Radiographs of 19 unaffected stifle joints of dogs with unilateral hind limb lameness were available for inclusion in this study. Of all unilaterally lame dogs, 4 were excluded because of bad radiographic positioning, 3 were not radiographed at the time of initial examination, and 3 were excluded because the dogs developed lameness in the second stifle joint before analysis of the study was completed.

Four distinct cruciate pathologic categories were identified in affected joints: complete rupture of the CCL alone; complete rupture of the CCL with concomitant medial meniscal damage; partial rupture of the CCL alone; and partial rupture of the CCL with concomitant medial meniscal damage. The only dogs included in the study were those that had appropriate radiographs, had damage confirmed at the time of arthrotomy, and did not have obvious radiographic displacement.

Twenty unilaterally lame dogs were evaluated intitially; 10 had complete rupture of the CCL alone, and 10 others had complete rupture of the CCL with concomitant medial meniscal damage. Six dogs that had stifle joints with partial rupture of the CCL and 3 with partial damage of the CCL and simultaneous tearing of the medial meniscus were also used in the study.

Procedure—Positioning of each dog and radiographic technique have been described in detail elsewhere.[6] Briefly, each dog was positioned in lateral recumbency. A standard lateral radiographic view of the stifle joint was obtained with the joint at 90° of flexion (neutral position). While maintaining the angle of flexion of the stifle joint, the tarsal joint was maximally flexed by use of manual pressure, and a second radiograph was obtained (tibial compression position).

Measurement of tibial displacement was performed by use of two techniques. The techniques were customized from those used in human medicine[7-9] to account for canine anatomy (Fig 1) and were used to determine whether either of these procedures would be useful in dogs. The practice of using two transparent templates with vertical and horizontal intersecting lines was adapted from the measuring procedure developed by Kennedy and Fowler.[7] In the first technique, the vertical line of template 1 was placed on the radiograph tangential to the fossa extensoria on the lateral femoral condyle. Template 2 was then placed on the radiograph, such that its horizontal line was superimposed on the horizontal line of template 1 and its perpendicular line was placed tangential to the most caudal point of the lateral tibial plateau (Fig 2 A). Distance between the two vertical lines was then recorded (mm). For the second technique, the horizontal line of template 1 was placed on the radiograph along the subchondral plate of the medial tibial plateau (ie, parallel to the joint line). The vertical line was placed on the radiograph tangential to the most caudal margin of the lateral tibial condyle. Again, horizontal lines of both templates were superimposed; however, with this technique, the perpendicular line on template 2 passed through the caudal margin of the lateral femoral condyle at the level of the physeal line (Fig 2 B). Both techniques were performed on paired lateral radiographs, with the stifle joint without stress (neutral) and with stress (tibial compression). The difference in distance between the two radiographic landmarks of joints in the neutral and tibial compression positions was regarded as the amount of relative craniocaudal laxity.

Additional results were obtained by use of an adjustment made on the basis of size of each dog. This was accomplished by measuring the width of the femoral bone immediately proximal to the femoral groove and perpendicular to the long axis of the femur. Initial measurements were then divided by the diameter of the femur of that particular dog, and each resulting value was multiplied by 100 to achieve an adjusted value. Radiographic magnification was not considered, because the stifle joint was in direct contact with the radiographic cassette.

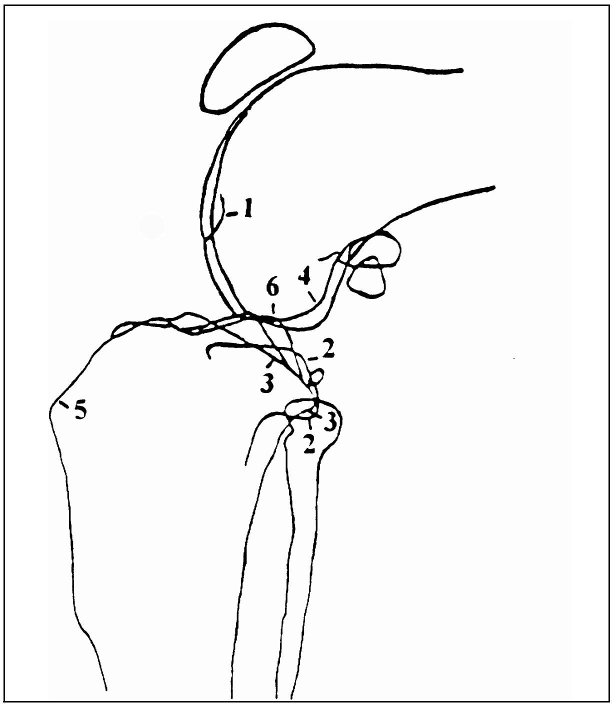

Fig 1. Bony landmarks used to determine craniocaudal instability in the stifle joints of dogs with and without injury to the cranial cruciate ligament

1. Fossa extensoria
2. Lateral tibial condyle
3. Subchondral plate medial tibial plateau
4. Lateral femoral condyle
5. Tibial tuberosity
6. Lateral intercondylar tubercle

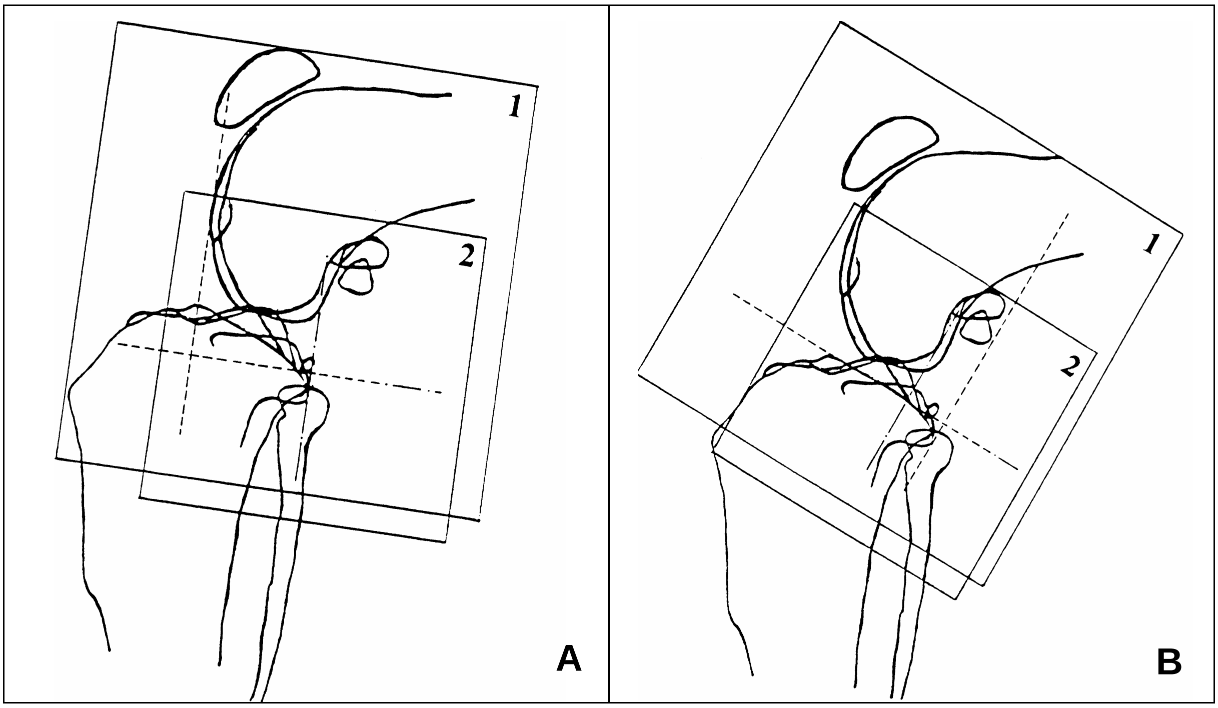

Fig 2. Measurement of craniocaudal instability of the stifle joint

A. By use of the first technique. Notice that the vertical line of template 1 is placed over the fossa extensoria and the vertical line of template 2 is placed over the caudal margin of the lateral tibial condyle

B. By use of the second technique. Notice that the horizontal line of template 1 is placed over the subchondral plate of the medial tibial plateau and caudal margin of the lateral tibial condyle, whereas the vertical line of template 2 is placed over the caudal margin of the lateral femoral condyle

All measurements were made by the principle investigator (HdR). Reported values were the mean of two measurements. Investigators were unaware of the identity of the dog from which each radiograph was obtained, and neither clinical nor joint findings were known prior to obtaining the measurements.

Analysis of data—An initial analysis was made separately for each group of joints (normal, unaffected contralateral, partial rupture without medial meniscal damage, partial rupture with meniscal damage, complete rupture without medial meniscal damage, complete rupture with meniscal damage). On the basis of clinical criteria, initial groups of joints were fused 2 X 2, according to status of the CCL alone without regard for damage to the medial meniscus. Even so, stifle joints with intact CCLs were considered as 1 group when significant differences between normal joints in clinically normal dogs and unaffected joints in dogs with unilateral hind limb lameness could be detected and the statistical tests had sufficient power.

A Kruskal-Wallis one-way ANOVA with Bonferroni adjustment was used to evaluate results; a value of $P < 0.05$ was considered significant. Results were evaluated among the various groups (with and without CCL and medial meniscal injury) for each joint and each group of joints determined on the basis of status of the CCL (intact, partial rupture, complete rupture). In addition, outcomes of sets of measurements (with and without adjustment for body size of each dog) were compared.

RESULTS

Means of all measured values were summarized (Table 1). Measurements in the unaffected contralateral stifle joint of dogs with any degree of rupture of the CCL did not differ significantly from those in the normal stifles of clinically normal dogs between technique 1 and 2. In neutral rotation with the stifle joint flexed 90°, forward displacement of the tibia with respect to the femur (mean ± SD) was 1.2 ± 0.9 and 1.1 ± 1.0 mm in presumably intact joints (ie, normal joints in clinically normal dogs and unaffected contralateral joints in unilaterally lame dogs) for technique 1 and 2, respectively.

Table 1. Mean (SD) amount of tibial displacement (mm) obtained from radiographs of various stifle joints of dogs

Techniques	N	Mean	SD	Techniques	N	Mean	SD
Technique 1				Technique 1 adjusted			
Normal	19	1.3	1.0	Normal	19	7.4	5.6
Contralateral	19	1.1	0.8	Contralateral	19	8.0	6.7
Intact (all)	38	1.2	0.9	Intact (all)	38	7.7	6.1
Partial	6	4.0	3.3	Partial	6	16.5	12.5
Partial + MM	3	2.0	1.0	Partial + MM	3	10.9	3.1
Partial (all)	9	3.3	2.8	Partial (all)	9	14.6	10.4
Complete	10	3.2	2.6	Complete	10	22.0	22.8
Complete + MM	10	5.2‡	3.5	Complete + MM	10	32.6‡	31.1
Complete (all)	20	4.2‡	3.2	Complete (all)	20	27.3‡	27.1
Technique 2				Technique 2 adjusted			
Normal	19	1.0	1.1	Normal	19	5.5	5.5
Contralateral	19	1.1	0.8	Contralateral	19	6.6	4.4
Intact (all)	38	1.1	1.0	Intact (all)	38	6.0	5.0
Partial	6	3.7	1.6	Partial	6	17.1	10.2
Partial + MM	3	4.3	2.1	Partial + MM	3	14.0	12.8
Partial (all)	9	3.9†	1.7	Partial (all)	9	16.1†	10.4
Complete	10	5.0‡	2.5	Complete	10	30.5‡	15.9
Complete + MM	10	5.9‡	2.6	Complete + MM	10	36.0‡	22.9
Complete (all)	20	5.4‡	2.6	Complete (all)	20	33.3‡	19.4

Significantly (*P<0.05, †P<0.01, ‡P<0.001) increased displacement in affected stifle joints, compared with stifle joints with intact cranial cruciate ligaments
Normal Normal stifle joints of clinically normal dogs, Contralateral Unaffected contralateral stifle joints of dogs with unilateral hind limb lameness, Intact Normal + Contralateral, Partial Partial rupture of the cranial cruciate ligament without meniscal damage, Complete Complete rupture of the cranial cruciate ligament without meniscal damage, MM Medial meniscal tear

For technique 1, a significant difference was not found in displacement for the various groups of affected joints, compared with displacement for joints with intact CCLs; an exception was the group of joints with complete CCL rupture and concomitant medial meniscus damage ($P < 0.001$). Results were then grouped according to status of the CCL injury; regardless of the state of the medial meniscus, significant differences could not be found between the group with intact cruciate ligaments and the joints with partial tearing of the CCLs. In contrast, measurements in joints with complete rupture (without or with meniscal tearing) differed significantly ($P < 0.001$) from presumably normal stifles.

Use of technique 2 resulted in a significant difference for joints that had complete rupture of the CCL with ($P < 0.001$) and without ($P < 0.001$) meniscal injury, compared with joints from the intact cruciate group. Again, a difference was not detected between measurements made in stifles with intact CCLs and those in stifles with partially ruptured CCLs with or without meniscal tearing; this was attributed to the small sample sizes. A significant increase in displacement was found overall for the group of stifle joints with partial ($P < 0.01$) and complete ($P < 0.001$) rupture of the CCL, compared with displacement for joints with intact CCLs. A significant difference was not found between joints with partial and complete rupture of the CCL.

Measurements normalized to account for size of each dog did not influence results for either technique. Similarly, they did not alter results for any group.

DISCUSSION

Damage to the CCL is often overlooked at the time of initial injury. Tibial compression radiographs can be helpful when establishing a diagnosis.[6] Measuring the distances between distinct bony points could be useful for dogs with less obvious radiographic displacement of the tibia.

Stifle joints of clinically normal dogs were screened, using physical examination and radiography, and diseases were not found. Initially, results for stifle joints of these clinically normal dogs were compared with the laxity measured in the unaffected joints in dogs with a unilateral cranial cruciate deficiency; differences were not found. Moreover, reports in which investigators used the contralateral unaffected limb as a control limb have been validated in dogs for determining geometric properties radiographically.[10] Therefore, we compared craniocaudal laxity of the stifle joint in cruciate-deficient dogs with values obtained from all dogs with intact CCLs.

A cutoff point for intact (ie, presumably normal) stifle joints could not be defined, because a wide range of measurements of laxity was found for both groups of joints with intact CCLs. Similar findings have been published for the stifle joint in humans.[11] Clinically evident pathologic changes will not necessarily produce results that are outside this range for presumably normal joints. This finding complicates the diagnosis of injury to CCLs. Craniocaudal instability in association with a meniscal tear and the amount of instability in joints without meniscal lesions was not significantly different for either of the measuring techniques, regardless of the amount of damage to the CCL. Therefore, differences in degree of damage to the CCL or the medial meniscus cannot be deduced from the amount of displacement. A marked overlap in results was evident between joints with partial and complete rupture of the CCL.

The observed measurement variability reported here cannot be related solely to variation among dogs. A considerable part may be attributable to the technique. Variability can be caused by imperfect positioning and angling of the stifle joint, the breed-dependent shape of bony landmarks, and inaccuracy of measurements on superimposed templates. The major drawback of the measuring techniques reported here was the need for perfect radiographic positioning and the difficulty in identifying certain landmarks. For technique 1, it was not always possible to precisely locate the fossa extensoria. Whenever the vertical line of template 1 was not exactly tangential to this osseous landmark, the perpendicular line would provide an incorrect orientation, and measurements along that line would be inaccurate. For the same reason, the technique 1 was extremely sensitive to alterations in the angle of flexion of the stifle joint for the tibial compression position, compared with that of the neutral position. Locating the subchondral plate of the medial tibial plateau in technique 2 also caused a few problems. These technical difficulties may account for some of the variability encountered.

The amount of relative displacement may vary because of differences in the size of each dog. An unanticipated finding in this study was that adjustments for size of each dog did not have a beneficial effect on the variability of our results. This also may have indicated that the mechanisms of the measuring techniques, apart from the dogs, contributed to the greatest extent.

In a number of stifles with damage to the CCL, cranial displacement of the proximal portion of the tibia is already clearly visible on a lateral radiographic view of the stifle joint in a neutral position (ie, Cazieux-positive).[b] In reaction to applied stresses, there will be additional shifting of the bones relative to each other. In such cases, however, the measured difference in relative displacement between radiographs of the joint in tibial compression and neutral position will turn out to be much smaller than the actual displacement. Because it is almost impossible to reproducibly determine the physiologic preinjury neutral position, some researchers have tried to measure total craniocaudal drawer motion by use of instrumental devices.[12] We did not include such results in our data, because we believe they would have falsely influenced the final results. In Cazieux-positive joints, obviously smaller absolute values on the radiograph of the injured stifle joint in a neutral position, compared with those of the contralateral limb in a similar position, can be measured by use of technique 1. If technique 2 is used, the vertical line of template 2 will be found caudal to the vertical line of template 1 on the radiograph of the tibial compression position for the lax stifle joint.

Further investigation will determine whether more appropriate osseous landmarks can be found for use with these techniques. Such landmarks should be easier to define and less dependent on rotational effects and changes of joint angle.

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2.4. Popliteal sesamoid displacement associated with cruciate rupture in the dog

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SUMMARY

Distal displacement of the popliteal sesamoid is a useful parameter in the interpretation of tibial compression radiographs in cases of cranial cruciate ligament (CCL) rupture in the dog. An accuracy of 99 per cent and a specificity of 100 per cent were achieved by assessing the localisation of the sesamoid bone in the diagnosis of cruciate disease.

INTRODUCTION

Dogs, like cats, have a sesamoid in the tendon of origin of the popliteus muscle (at the junction of the tendon and muscle proper). No similar structure is found in humans or in most other species.[1]

The sesamoid bone in a normal stifle articulates with the lateral condyle of the tibia.[2] It should be clear from radiographs that the localisation of the sesamoid varies with the degree of contraction of its muscle. When the stifle is fully extended, the popliteus muscle is maximally relaxed, and the bone will then articulate with the craniodistal part of the articular surface of the lateral tibial condyle. At a greater angle of flexion (increased contraction of the popliteal muscle), the sesamoid will shift more proximally, articulating progressively more with the lateral surface of the lateral meniscus.[3]

Distomedial displacement of the sesamoid bone has only been reported twice, both in cases of avulsion of the popliteus muscle.[1,4] The displacement could be visualised on a standard lateral radiograph of the affected stifle joint.

To the present authors' knowledge, distal displacement of this bony structure in the dog has not previously been reported following cranial cruciate ligament (CCL) rupture.

Table 1 Breed distribution

Breed	Number	Pathology	Breed	Number	Pathology
American Cocker Spaniel	2	CCL c	American Staffordshire Terrier	1	CCL p
Beauceron	2	CCL c	Bernese Mountain Dog	2	CCL p
Belgian Malinois	1	CCL c	Dobermann	1	CCL p
Bernese Mountain Dog	2	CCL c	French Mastiff	1	CCL p
Bichon Frise	1	CCL c	Giant Schnauzer	1	CCL p
Bouvier des Flandres	1	CCL c	Labrador Retriever	1	CCL p
Boxer	1	CCL c	Mixed-breed	1	CCL p
Cairn Terrier	1	CCL c	Rottweiler	3	CCL p
Chihuahua	1	CCL c	West Highland White Terrier	1	CCL p
Chow Chow	1	CCL c			
Coton de Tulear	1	CCL c	Boston Terrier	1	MPL
Dobermann	1	CCL c	Fox Terrier	1	MPL
English Bulldog	2	CCL c	French Bulldog	1	MPL
English Cocker Spaniel	1	CCL c	Maltese	1	MPL
Golden Retriever	2	CCL c	Miniature Pinscher	1	MPL
Labrador Retriever	4	CCL c	Poodle	2	MPL
Maltese	2	CCL c	Pug	1	MPL
Mixed-breed	7	CCL c	Yorkshire Terrier	2	MPL
Napolitan Mastiff	1	CCL c			
Nizinny	1	CCL c	Belgian Malinois	1	Normal
Poodle	3	CCL c	Boxer	1	Normal
Rottweiler	15	CCL c	Braque St Germain	1	Normal
Saint Bernard	1	CCL c	German Shepherd Dog	2	Normal
Shih Tzu	1	CCL c	Labrador Retriever	1	Normal
Siberian Husky	1	CCL c	Mixed-breed	1	Normal
Silky Terrier	1	CCL c	Rottweiler	2	Normal
Staffordshire Bull Terrier	1	CCL c	Yorkshire Terrier	1	Normal
Welsh Springer Spaniel	1	CCL c			
West Highland White Terrier	1	CCL c			
Whippet	1	CCL c			
Yorkshire Terrier	5	CCL c			

CCL c Complete cranial cruciate ligament rupture, CCL p Partial cranial cruciate ligament rupture, MPL medial patellar luxation

MATERIALS AND METHODS

In cases of stifle lameness presented to the Department of Diagnostic Imaging of Domestic Animals at Ghent University, a tibial compression stress radiographic examination is carried out irrespective of the presence of detectable clinical craniocaudal instability.[5] This technique has been described previously.[6] Briefly, the dog is positioned in lateral recumbency and a standard lateral radiograph of the stifle is first taken at 90° of flexion. While maintaining this angle of flexion of the stifle joint, the hock joint is flexed maximally and a second picture is taken.

Seventy-eight joints with confirmed CCL rupture (66 cases of complete damage and 12 cases of partial tearing) were reviewed (Table 1). Twenty control stifles were also included and, in addition, 10 cases of medial patellar luxation were screened radiographically. Special attention was paid to possible craniocaudal displacement of the proximal tibia with respect to the distal femur and to the position of the popliteal sesamoid. The respective localisations on the lateral neutral x-ray and on the stressed view were compared. Furthermore, the contralateral stifle views were also used for relative comparison of the localisation. All radiographs were examined twice.

Finally, a cadaver specimen was dissected to determine the normal position of the different landmarks in the canine stifle and their relative changes after section of the CCL with or without application of tibial compression forces (Fig 1).

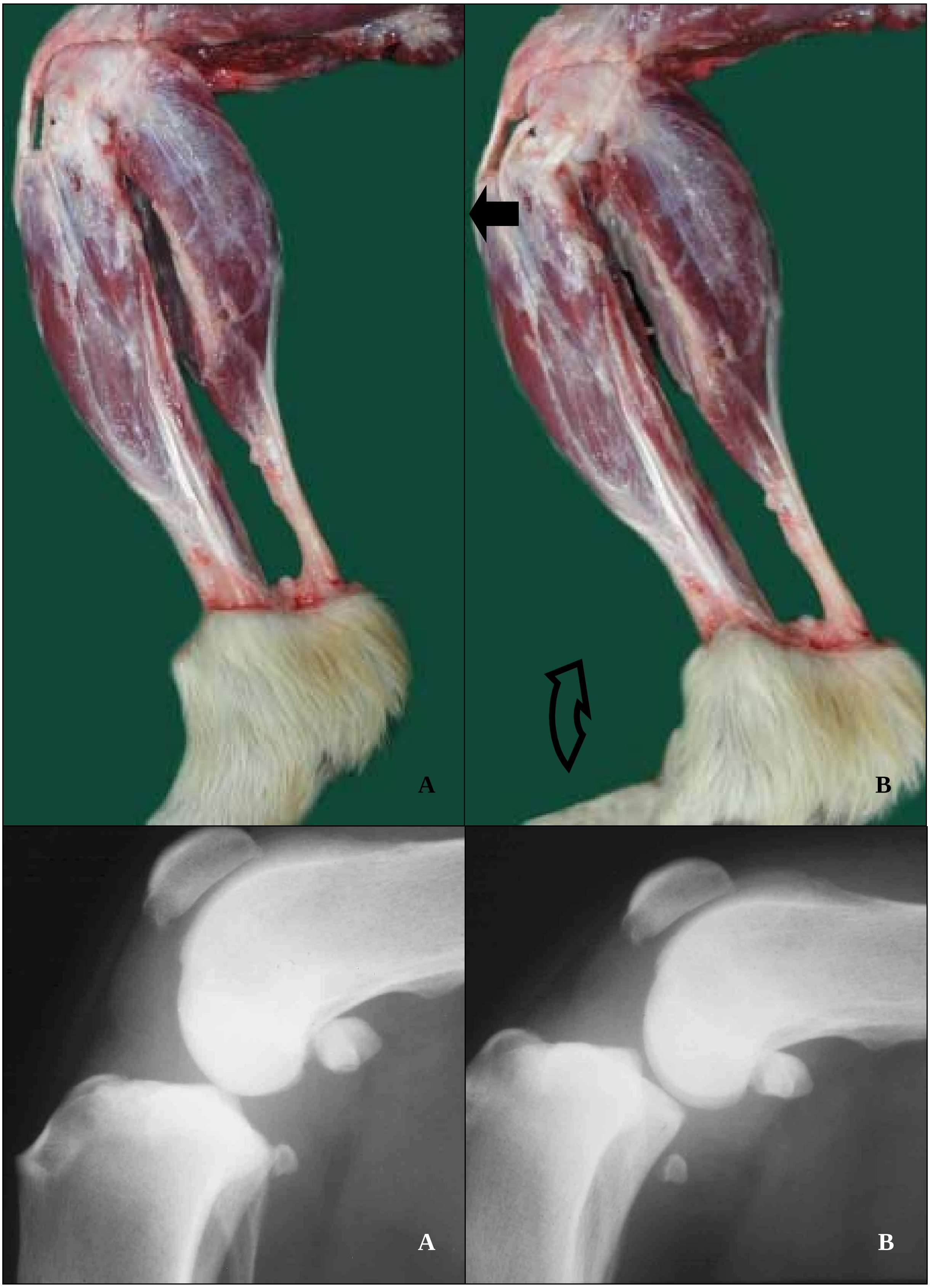

Fig 1. Dissected cadaver specimen in **A.** Neutral position **B.** Stressed position
Manual flexion of the hock (open arrow) induces cranial tibial thrust (closed arrow)

RESULTS

The popliteal sesamoid had failed to ossify in 6 per cent (6/108) of the dogs radiographed. All belonged to the small breeds (less than 15 kg bodyweight), with an average bodyweight of 9.2 kg. None of the bilaterally normal dogs used as controls in this study had unmineralised sesamoid bones.

Distal displacement of the popliteal sesamoid was not detected in any of the control cases, nor in cases of isolated medial patellar luxation. In all the cases with obvious craniocaudal displacement of the proximal tibia relative to the distal femur, a distal shift of the popliteal bone was also clearly visible. Even when less tibial displacement was present on the tibial compression radiograph, the distal displacement of the sesamoid was always noted. Craniocaudal instability is not, however, always that obvious, although in these critical cases of cruciate damage, the popliteal sesamoid could still be found displaced distally in seven out of eight joints (Fig 2).

Fig 2. Bilateral radiographs of an eight-year-old Rottweiler with left-sided cruciate instability **A.** Stressed view of the unaffected right stifle. The popliteal sesamoid (arrow) is superimposed on the caudal tibial plateau **B.** Stressed view of the affected left stifle. A distal displacement of the popliteal sesamoid (arrow) can be seen

DISCUSSION

In stable canine stifle joints, the popliteal sesamoid (if ossified) can be seen superimposed over or proximal to the caudal tibial plateau. Distomedial displacement of the popliteal sesamoid has only previously been reported in cases of avulsion of the popliteal muscle.[1,4] The present authors feel, however, that the sesamoid can also be found more distally when there is CCL damage.

A displaced sesamoid can be readily encountered on a standard neutral radiograph. Such cases are called Cazieux-positive.[7] This easily identified parameter now also proves to be reliable on tibial compression radiographs whenever cruciate instability is suspected. In the present study, an accuracy of 99 per cent and a specificity of 100 per cent were achieved in the diagnosis of cruciate disease by assessing the localisation of the sesamoid bone. This means that, in most cases, more complex and time-consuming measurements on tibial compression radiographs are unnecessary in grading craniocaudal displacement to assist in the diagnosis of CCL injury.

There remains a small group of canine patients in which the above mentioned criterium of distal displacement of the popliteal sesamoid cannot be used due to the lack of ossification of the popliteal sesamoid bone. Mineralisation of the popliteal sesamoid sometimes fails to occur so that the structure may not be visible during radiographic examination.[3,8] According to McCarthy and Wood[3] about 16 per cent of dogs have a radiographically invisible popliteal sesamoid. From the present data, however, only six per cent of the canine stifles were found not to have a mineralised sesamoid, and this problem was only encountered in small breed dogs.

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CHAPTER 3

BIOMECHANICAL BEHAVIOUR OF THE CANINE CRANIAL CRUCIATE LIGAMENT AND ITS SYNTHETIC SUBSTITUTES

3.1. Load-controlled tensile tests

3.2. Displacement-controlled tensile tests

    3.2.1. Biomechanical properties of artificial cranial cruciate ligaments

    3.2.2. Biomechanical properties of braided polyester tapes intended for use as intra-articular cranial cruciate ligament prostheses in dogs

3.1. Load-controlled tensile tests

SUMMARY

In dogs, braided polyester is used as intra-articular substitute material in dogs with injury to the cranial cruciate ligament (CCL). The breaking strength of the prosthesis should at least approximate the strength of the original CCL as determined under identical loading conditions.

The breaking strength of normal CCL was determined in 44 canine cadavers, elongated at a loading rate of 0.1 kN/s. The *in vitro* breaking load of the canine CCL approximated 3 times the body weight. A significant correlation existed between the body weight of the dogs tested and the ultimate breaking strength of their CCL.

The breaking strength of flat braided polyester tapes of 4 and 8 mm, mounted as knotted loops, was determined under similar testing conditions as the cadaver preparations. The 4 mm polyester loops broke at a mean load of 440 N, whereas 860 N was needed to break the 8 mm loops. Ethylene oxide gas sterilisation did not decrease the breaking strength of braided polyester.

Based on the experimental results, a 4 mm polyester tape would be a valuable choice for replacing a torn CCL in dogs up to 15 kg of body weight.

INTRODUCTION

The cranial cruciate ligament (CCL) is a unique ligamentous structure, hidden in the center of the stifle joint in all terrestrial mammals, important for maintaining stifle joint stability.[1,2] Injury to the ligament is detrimental for the joint.[3] CCL replacement techniques have become popular as surgeons strive to restore normal stifle kinetics after CCL rupture.[4]

The behaviour of the CCL in the physiologic range of loading mainly relies on assumptions. *In vivo* loading of the CCL encountered in normal use is likely much smaller than the load required to rupture the ligament under test conditions.[5-7] *In vitro* observations on breaking strength of the CCL have been documented in various species. The results of single traction experiments in the absence of surrounding soft tissues have been published in man[7-13], monkeys[9,14], horses[15], cattle[6], rabbits[16,17], goats[18,19], sheep[20], and dogs[8,13,21-24]. On the other hand, direct measurement of *in vivo* forces remains tricky. Only in the goat, *in vivo* loading experiments of the CCL during spontaneous activity has been reported hitherto.[25]

The search for an ideal substitute for the successful management of a torn CCL has attracted the attention of human and veterinary surgeons for the last decades. Inspired by a publication on the intra-articular use of polyester in cruciate-deficient dogs[26], veterinary surgeons in Belgium started to use this material to stabilise canine stifle joints after CCL rupture. At that point, mechanical *in vitro* studies on the material properties of braided polyester tapes were totally lacking. To deal with the urgent need of biomechanical data on this polyester substitute, load-controlled tensile test protocol was instituted.

The paper reports preliminary results on the breaking strength of the natural CCL related to the body weight of the cadaver dogs and on the strength of polyester prostheses of various sizes. Meanwhile, the effect of ethylene oxide gassterilisation on the strength properties of braided polyester was assessed.

MATERIALS AND METHODS

Cadavera—All specimens were obtained from fresh cadavera from adult dogs of various breeds and ages. None was destroyed for this specific purpose. Forty-four hind limbs were harvested (21 pairs and 2 individual legs). The body weight of each donor cadaver was registrated and ranged from 7.5 kg to 50 kg (mean 24 kg). No data on the ages of the dogs tested were available. All stifles were considered normal, based on the absence of radiological signs of DJD on lateral radiographs.

The cadaver limbs had their skin removed and were disarticulated at the coxofemoral joint. The shafts of tibia and femur were cleared of soft tissues. The hind legs were shortened by a saw cut through the femur and the tibia, leaving about 15 cm bone proximally and distally to the stifle joint. Two parallel bone tunnels were drilled lateromedially perpendicular to the long axis of the femur and the tibia, while the stifle specimen was fixed under the physiological angle of 140°. The stifle joint was left unopened until just before the test. All soft tissue surrounding the stifle joint, femorotibial attachments and joint structures were carefully transected to isolate the CCL and the menisci. The preparation was only executed at the last moment before mounting the bone-ligament-bone specimen into the testing instrument, to avoid dessication of the CCL.

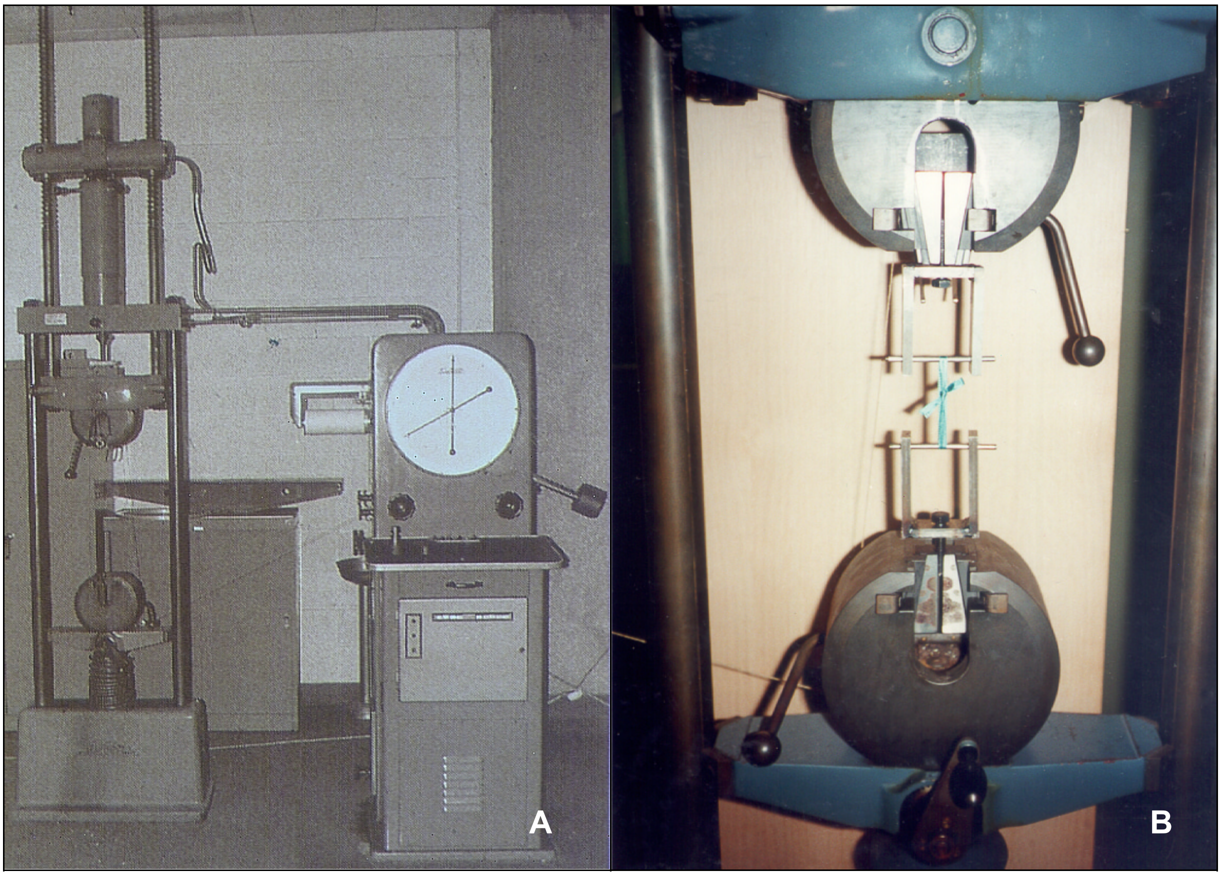

Fig 1. Amsler Bodson electro-hydraulic universal test machine
A. Load and displacement data are drawn on a calibrated strip-chart which is connected to the tensile tester
B. Polyester specimens were mounted around smooth-surfaced steel bars

The specimens were mounted in an electro-hydraulic universal test machine[a] (Fig 1 A). Smooth-surfaced steel bars were driven through the created bone tunnels. The test specimens were elongated to failure at a constant loading rate of 0.1 kN/s. Load and displacement data were drawn simultaneously in a graph on a calibrated strip-chart. The maximum linear load to failure (first significant sign of rupture) could be deduced from the graph as the first recorded peak value.

Polyester—The polyester prostheses are made of green-dyed polyethylene terephtalate[b]. They are braided structures, with a flat cross-sectional configuration, available in various widths. The synthetic prostheses are sterilised in their package by irradiation by the manufacturer. In this series of preliminary tests, polyester tapes with a width of 4 and 8 mm were used. For technical reasons, the samples were all tied around a 170 mm diameter cylinder to create loops. A surgeon's knot was used for the first throw with 4 subsequent single throws placed.

The specimens were mounted around smooth-surfaced steel bars in the electro-hydraulic universal test machine (Fig 1 B). The position of the knot was always choosen midway between the two bars.

With the specimen in a vertical position, a steady and constant vertical pull was applied until the graft failed. The test specimens were elongated to failure at a constant loading rate of 0.1 kN/s. Load and displacement data were drawn simultaneously in a graph on a calibrated strip-chart. The load at which the suture brook was recorded, and the strain due to distraction was determined.

Four 4 mm and four 8 mm polyester samples were tested as single loops. An equal number of each was submitted to the tensile tests as double strand loops, with only one overall knot.

In addition, four samples of 4 mm width were sterilised by ethylene oxide prior to loading to failure. The sterilisation was carried out in a gas steriliser[c], using clingas-118 LG-1, a mixture of 12% ethylene oxide and 88% freon (dichlorodifluoromethane) at a temperature of 40°C and under 1.4 bar (140kPa) of pressure during 6 hours. The completeness of the sterilisation was proved by the coloured indicator on the Steri-Dual package that changed from pink to brown.

Statistical analysis—All data were analysed using the statistical software package Statistix 4.1.

The Pearson correlation test was used to assess the association between the body weight of the cadavera and the load at failure of the CCL. A paired t-test was applied to compare the breaking strength of the left and right CCL in the 21 pairs. Data on the breaking strength of the polyester tapes were analysed using two-sample t-tests. A significance level of 0.05 was chosen.

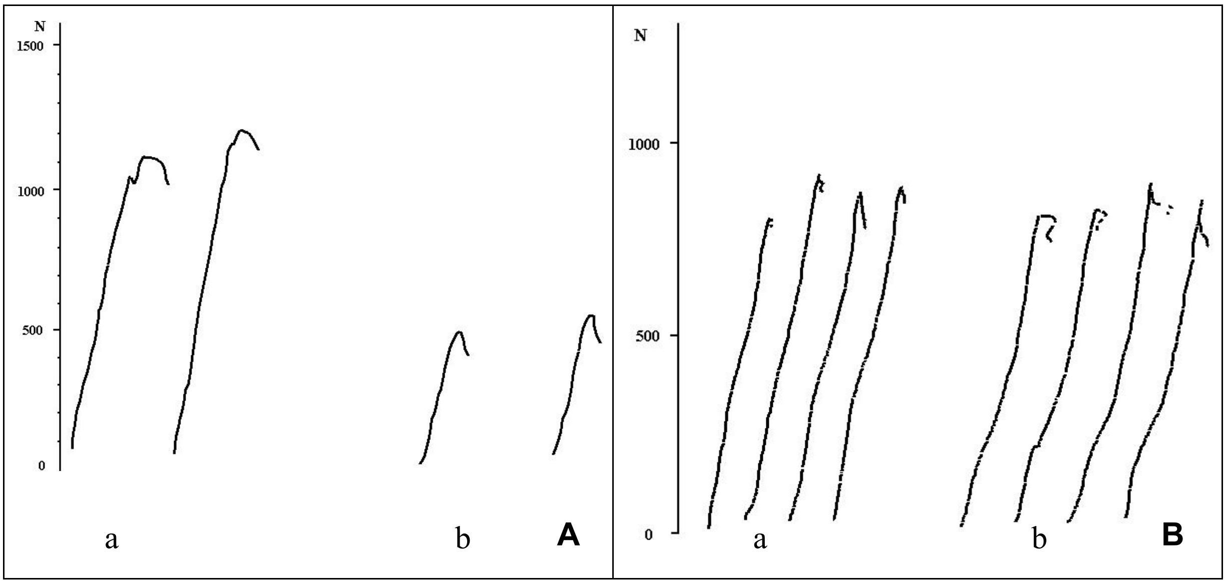

Fig 2. Typical recordings of successful load-controlled tensile tests
A. Load-to-failure curves of right and left cranial cruciate ligaments from the same dog (a) Bouvier de Flandres, 50 kg, breaking load of 1130N and 1210N respectively and (b) Mixed breed, 15 kg, breaking load of 490N and 530N respectively
B. Load-to-failure curves of 4mm double loops (a) and 8mm single loops (b) of the polyester prostheses

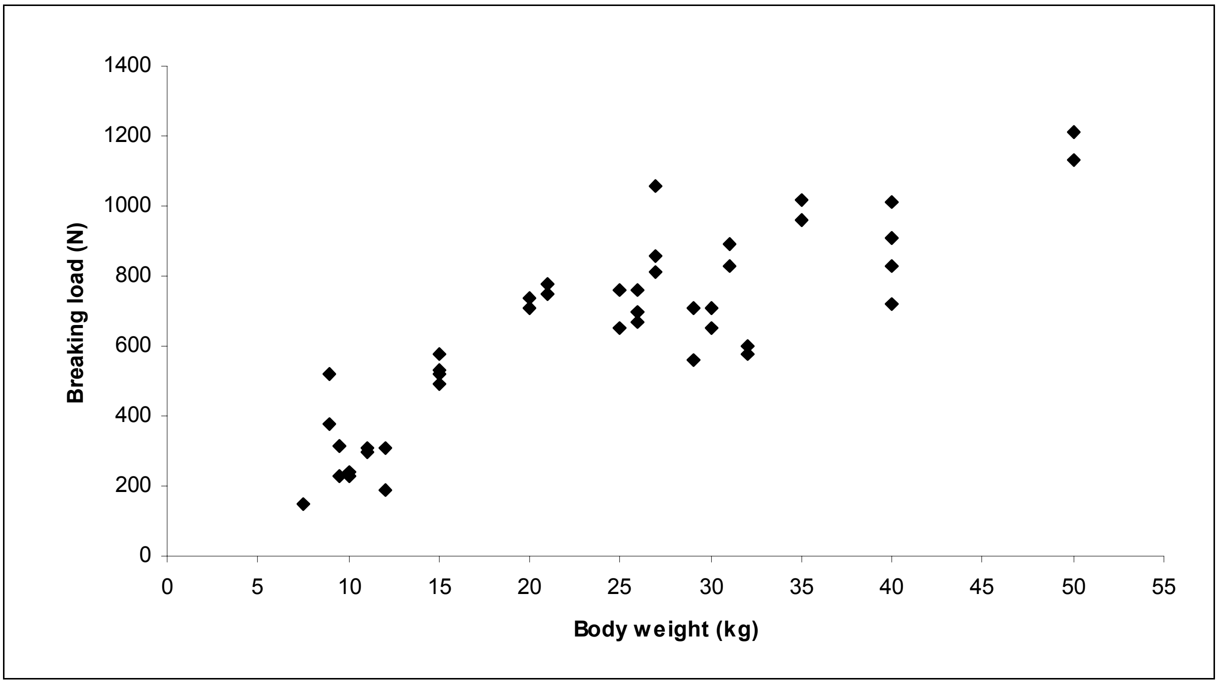

Fig 3. The breaking load of the cranial cruciate ligament of cadaver specimens of various body weights

RESULTS

Cadavera—Typical recordings of successful tests on the left and right CCLs from the same animals are shown in Fig 2 A. The breaking load of the CCL varied from 150 N to 1230 N. A highly significant correlation (r=0.86) was found between the body weight of the donor cadaver and the ultimate breaking strength of the particular CCL, which is also clearly shown in the plotted data (Fig 3).

Statistical comparison showed no difference in breaking load values between both stifles of the same dog. A correlation between lefts and rights as high as 0.95 was calculated.

Polyester— Typical load-to-failure curves are shown in Fig 2 B. In all of the samples, the material failure was situated adjacent to the knot. The mean load at failure for the single loop specimens of 4 mm was 440 N while an average of 860 N was necessary to break the 8 mm tape. Tested as a double strand 870 N and 1580 N respectively were recorded as mean breaking loads for both sizes. Statistical significant differences in the load at failure between the double loops of 4 mm and the single loops of 8 mm width were not observed.

The strain was determined for the single loop knotted materials and amounted to 8.1% and 4.4% for the 4 and 8 mm test specimens respectively. This decrease in plastic deformation with an increasing sample width is statistically significant.

The gross appearance and colour of the polyester tape sterilised by ethylene oxide did not differ from the untreated samples. The mean ultimate breaking value of the sterilised implants was 455 N as compared to 440 N found as average for non-ethylene oxide sterilised specimens. Statistically, there was no significant difference in load at failure. An increase in elongation of the test material was associated with this pretreatment. A mean strain of 11.1% was found after ethylene oxide sterilisation, while only 8.1% was noted for the untreated 4 mm polyester tapes. However, the difference was not statistically significant for the sample sizes used.

DISCUSSION

The ultimate breaking strength of the canine CCL, expressed in kg, under load-controlled tensile testing conditions appeared to approximate 3 times the body weight in dogs of all sizes. Increased body weight was consistently accompagnied by a gradual decrease in the load per kg needed to break the CCL. Others investigators found a factor 4 in dogs weighing 6 to 10 kg.[21] Factors such as age, size, and body constitution may all influence the ultimate strength of the CCL based on the body weight.[23] The results of tested pairs of stifles were consistent with previous studies in which was stated that the mechanical values of right and left sides can be averaged.[6,8,21-23]

Simple load versus elongation curves are also suited for characterisation of synthetic material behaviour during loading. Under constant loading, the polyester prostheses gradually elongated. Failure of individual fibres in the prosthesis at lower than ultimate force levels, prior to complete rupture of the polyester tape was also seen. Including a knot in the test procedure increased the amount of elongation under loading because of the influence of knot tightening.[27] Elongation decreased with an increased width of the polyester tape. The presence of a knot also decreased the ultimate breaking strength of a prosthesis.[28] However, the knotted loops mimicked to a greater extent the clinical use of the ligament. Doubling the width of the polyester prostheses, also doubled the ultimate breaking strength.

Ethylene oxide is a superior gas for sterilisation because of its excellent penetration while causing little to no damage to the material.[29] In a previous clinical study using polyester strands, the prosthesis was pre-operatively woven and sterilised with ethylene oxide.[26] No reference to strength parameters was given. In our tests, ethylene oxide was not found to have any detrimental effect on the appearance nor on the ultimate breaking strength of the polyester tapes. Our preliminary data were recently confirmed in the literature in an article on the mechanical characteristics of extra-articular stabilisation materials.[28] The investigators found no adverse effects on the material characteristics other than a small decrease in stiffness. An increased strain of the gassterilised tested specimens was seen in our studies but could not be proven to be statistically significant.

Based on the ultimate breaking strength data of both the natural CCL and the polyester, a polyester tape of 4 mm width would be a valuable choice for replacing a ruptured CCL in dogs weighing up the 15 kg. An 8 mm tape should be used in heavier dogs.

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[a] Amsler Bodson, Liège, Belgium

[b] Mersilene, distributed by Ethicon Ltd, Belgium

[c] Matachana 118 LG-1, C/Hierro, Barcelona, Spain

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3.2. Displacement-controlled tensile tests

3.2.1. Biomechanical properties of artificial cranial cruciate ligaments

3.2.2. Biomechanical properties of braided polyester tapes intended for use as intra-articular cranial cruciate ligament prostheses in dogs

3.2.1. Biomechanical properties of artificial cranial cruciate ligaments

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SUMMARY

In dogs, injury to the cranial cruciate ligament (CCL) is commonly repaired with artificial textile materials. The dynamic mechanical behaviour of this textile product must be similar to the natural CCL of the dog. Therefore, a test method has been developed to analyze the mechanical properties of the CCL substitute in a realistic way. Modulus, elongation and failure properties are assessed for braided polyester of 4- and 7-mm widths and braided polyamide of 4-mm width potential CCL substitutes.

Braided polyester tape loops are strong and superior to polyamide, although not as strong as the original CCL. Nevertheless, the polyester prostheses should easily be able to resist normal weight bearing forces in all sizes of dogs.

Both sizes of polyester tapes also proved to be able to absorb the shock of traumatic overload, even after cycling, when the amount of energy absorbed prior to failure is reduced. They are not able to elongate and recover to the same extent throughout their entire lifetime as the original structure does.

INTRODUCTION

In dogs, rupture of the cranial cruciate ligament (CCL) is an injury frequently sustained by the stifle, resulting in joint instability (Fig 1).[1] Numerous autologous and synthetic materials have been used for surgical reconstruction of the CCL. A prosthesis should be strong enough and not too elastic in order to restore and also maintain stifle joint stability. Although various artificial prostheses have been reported (e.g., stainless steel, monofilament nylon, multifilament polyester), there is little published information on the mechanical properties of the grafts used,[2,3] nor has a sufficient test method to simulate loading in practice been published. Any replacement material should behave, as closely as possible, like the natural ligament in the normal range of loading and should closely resemble the load-deformation characteristics of the original structure during ultimate loading. According to the literature, the average measured strength of the canine CCL *in vitro* is 46 N/kg body weight.[4-6] Physiological loading of the CCL in the dog has been estimated to be 10% to 20% of its ultimate breaking load only.[7] At the time of traumatic injury, these ligaments are subjected to a sudden load that exceeds their ultimate strength. To simulate this condition, tensile tests at a high extension rate have to be used. During walking or trotting, the cruciate ligaments or their substitutes are subjected to a rapid application and removal of force.[7] This situation can be mimicked by cyclic loading experiments between two force levels.

In this paper, we present data on the material properties of 4 and 7 mm braided multifilament non-absorbable polyester suture materials. Both sizes are commonly used clinically for intra-articular stabilization of CCL-deficient stifle joints in dogs. We compare these with braided polyamide because of the great similarity of the braiding structure and size of the material. We test fast load-to-failure, and we have also designed a test method to match the dynamic loading conditions of the CCL of a walking dog as closely as possible. We determine the behavior of the braided polyester prostheses during cyclic loading and the effects of cycling on the failure properties of braided polyester.

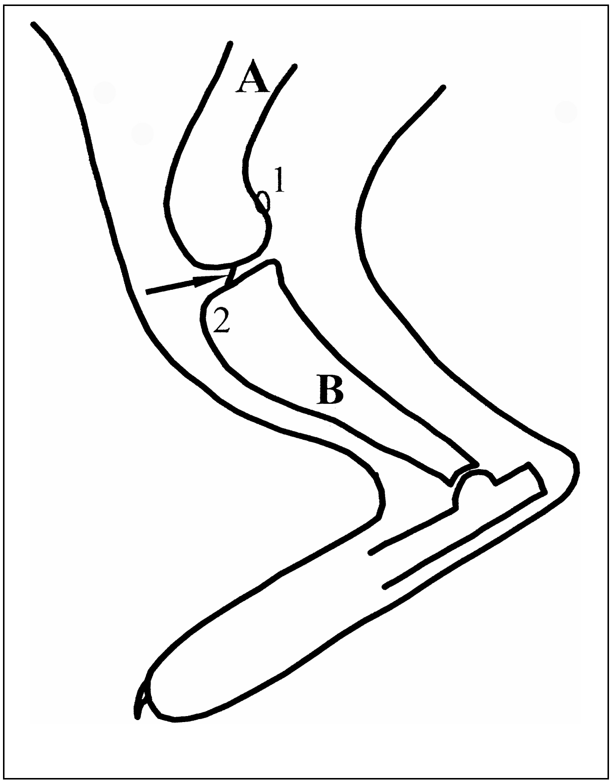

Fig 1. Stifle joint of the dog

Arrow indicates cranial cruciate ligament
A. Upper leg
B. Shinbone
1. Small smooth bony structure around which the CCL substitute is anchored during stabilizing surgery,
2. Tunnel perpendicular to the bony crest through which the CCL substitute is passed during stabilizing surgery

MATERIALS AND METHODS

Our principal author Hilde de Rooster designed special clamping devices to simulate *in vivo* fixation of the CCL substitute, and fabricated proximal and distal clamps to mimic the anatomical anchorage points during stabilizing surgery (Fig 1 and 2).[8] The upper hook consisted of a vertical bar rigidly mounted on a 1000 N loadcell. The lower clamp had a tunnel drilled through a metal bar, oriented perpendicular to the clamp itself and attached to the moving crosshead. The tested prostheses were mounted as loops tied around the upstanding metal device of the upper clamp and through the distal tunnel, the knot being close to the distal anchorage as it would be intra-operatively. A surgical knot was tied and three additional throws were used and tightened securely to square knots, always by the principal author. During surgery, the same knotting is used. Grasping the free ends with needle holders allowed firm tension to be exerted and a tight loop to be formed. The knotted loops had a constant original length of 100 mm.

We used control programs written for the Statimat M tensile tester[a]. A personal computer, working under MS-DOS© was connected to the microprocessor of the displacement-controlled testing machine. Through software programs, appropriate instructions to execute sudden overload and dynamic loading between two force levels could be sent to the Statimat. The data were collected by a built-in load cell and a displacement transducer. Material elongation was zeroed at the lower force limit, since it corresponds to the situation in a moving dog. All tests involved standard climate conditions (65% +/- 2% RH and 20°C +/- 2°C).

We tested flat braided 4 and 7 mm green-dyed tapes made of non-absorbable polyester (polyethylene terephtalate)[b]. For comparison, we also tested 4 mm polyamide[c] blue-dyed tapes.

The study was divided into two major parts. The first section of this investigation characterized the behavior of braided polyester and polyamide in simple load-to-failure tests. To determine the load at failure, the synthetic prostheses were loaded at a constant rate of elongation of 1000%/min until breakage. From the load-displacement data of each set, we obtain structural and material parameters: load at failure (N), strain (%), stiffness (N/mm), energy absorbed to failure (N.mm), and static modulus for the physiologic range of forces (N/mm). To assess the influence of the loading rate on the load-deformation curves, we also tested the polyester prostheses at crosshead velocities of 100, 250, 500, 1000, 2000, 4000, and

8000%/min. Each polyester tape was divided into three equal pieces to minimize the effect of material variability on the deformation rate tests.

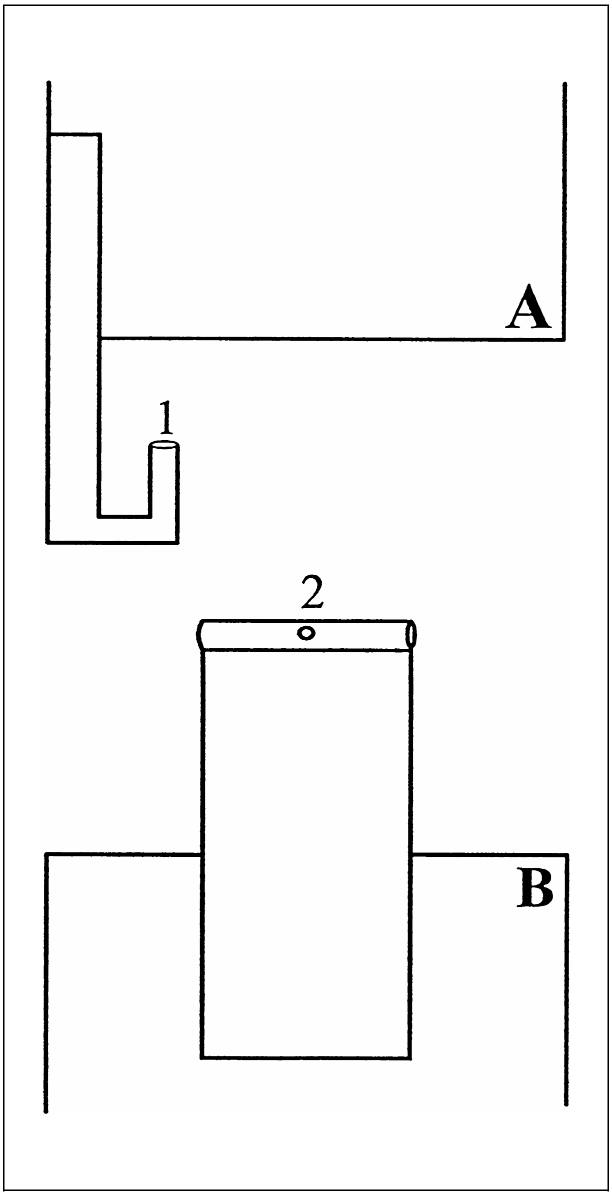

Fig 2. Clamping devices mimicking the bony anchorages in the stifle joint of the dog

A. Upper clamp
B. Lower clamp
1. Round vertical bar around which the CCL substitute is anchored during the loading experiments
2. Tunnel perpendicular to the clamp through which the CCL substitute is passsed during the loading experiments

The second portion of the study investigated the effects of cyclic loading of braided polyester prior to load-to-failure tests to properly reflect biomechanical conditions and abrasion by daily activity. We deduced the test method from previous dynamic loading experiments between two force levels on yarns.[9] Preliminary relaxation studies were set up to determine the resting time between the different cyclic loading sets. The lower and upper force levels were calculated from the weight bearing forces in dogs of about 12 and 25 kg of body weight, respectively.[10] The force limits were thus set at 25 N and 87 N for the 4 mm polyester prostheses, and 42 N and 137 N for the 7 mm tapes. Each polyester tape was cut in half. One strap was repetitively loaded between the two force limits through 25 sets of 2000 cycles at a rate of elongation of 500%/min, representing a dog trotting at 2 Hz.[11] Between each round of 2000 cycles, the synthetic material was allowed to recover for 20 minutes, representing a rest period of the dog. Three loops of each size were tied, cycled, and finally elongated to failure at a rate of 1000%/min. A larger number of experiments was impractical at this stage of the investigations because of the duration of one single test. The other halves of the tapes served as controls and were elongated till break at the same rate without previous cycling.

Analysis of data—Data were analysed using the software package Statistix (Analytical software, Tallahassee, USA), the two-sample t-test or, where appropriate, the paired t-test. Differences were considered significant when p<0.05.

RESULTS AND DISCUSSION

Information on biomechanical properties under loading conditions occurring at the time of acute overload are provided in Table 1. The average loads at failure were 302 and 726 N for the 4 and 7 mm polyester tapes, respectively. The 4 mm polyamide tapes were significantly weaker than the 4 mm polyester (p<0.001).

Table 1. Simple load-to-failure tests

	4 mm polyamide (n=30)			4 mm polyester (n=30)			7 mm polyester (n=10)		
Parameter	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
Load at failure (N)	266.5‡	13.2	4.95	301.8	16.9	5.61	726.4	37.7	5.19
Elongation (%)									
at 20% of failure force	3.016‡	0.321	10.5	2.022	0.325	16.2	4.359	0.461	10.5
at break	17.100‡	0.724	4.23	14.03	1.09	7.46	20.60	1.66	8.06
Stiffness (N/mm)									
at 50% of ultimate strength	27.368‡	0.871	3.18	21.12	2.58	12.19	33.25	2.94	8.84
Energy to failure (N.mm)	2212	157	7.10	2252	170	7.54	7877	736	9.35
Static modulus (N/mm)	8.830‡	0.380	4.30	15.47	1.49	9.62	20.01	2.26	11.3

Significantly (*P<0.05, †P<0.01, ‡P<0.001) different from value for 4 mm polyester

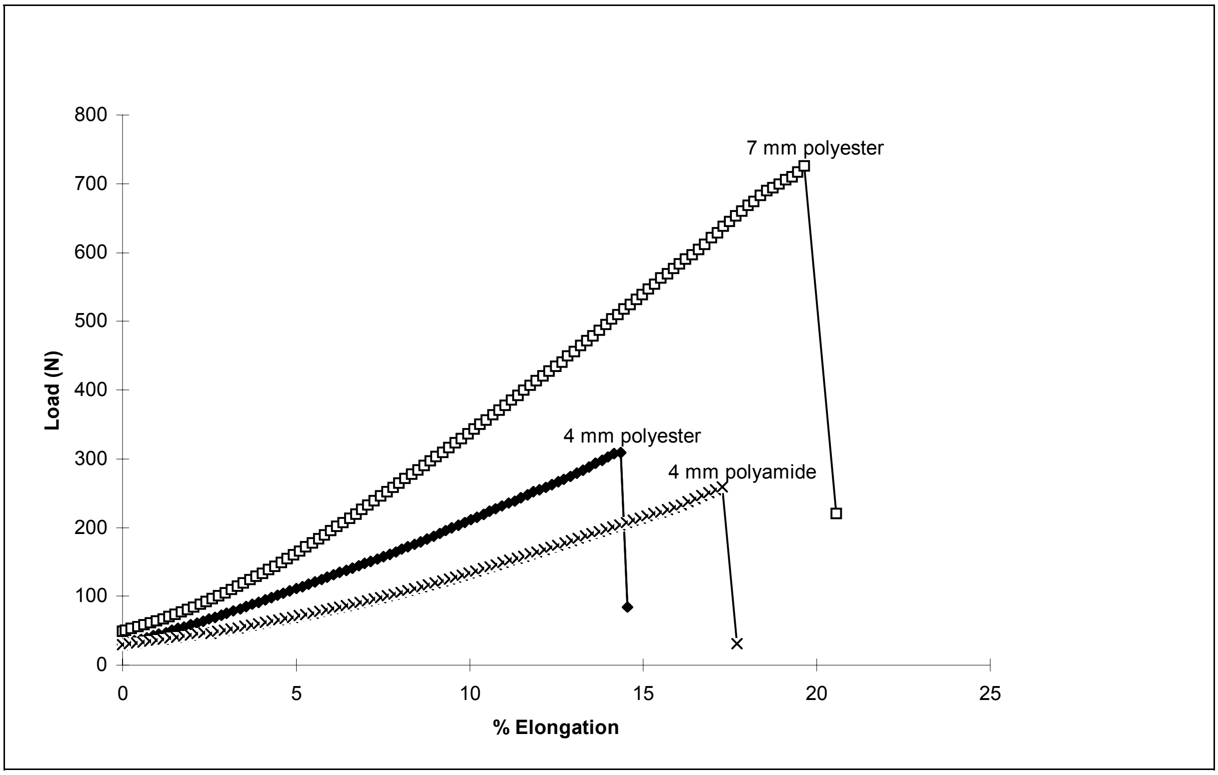

Fig 3. Approximate load-elongation curve of 4 mm and 7 mm polyester tapes and 4 mm polyamide tapes

Typical load behavior curves for the 4 mm polyester, the 7 mm polyester, and the 4 mm polyamide tapes at an extension rate of 1000%/min are plotted in Fig 3. All characteristics of the polyester tapes were superior to the behavior of the polyamide tapes. The initial toe region, under the lower force limits as set for the cyclic loading tests, was not expressed. All curves exhibited a fairly linear pattern up to failure, in contrast with curves obtained with natural ligament specimens, which showed an initial concave and a final convex region.[12] The site of rupture was always located near the knot. We chose a high testing rate for the load-to-failure tests in this study to mimic the loading conditions of acute overload. The extension rates and force limits for the cyclic loading experiments were comparable to those encountered in normal activity. The prostheses were tested in conditions that simulated intra-articular stabilizing surgery. The bony anchorages were mimicked by the design of the clamps, and a surgical knot was tied close to the tunnel of the distal clamp (Fig 2). Including a knot in the test procedure, as would be done intra-operatively, decreases the load at failure for most materials.[3] For technical reasons, the original length of the synthetic loop had to be

100 mm, while the natural CCL in dogs has an average length of only 13.5 to 17.5 mm.[4,13] Testing a longer length of material may result in a decreased ultimate load (weak link theory).

Studying loops provided an evaluation of both the prosthetic material and knot properties. Elongation under loading is a measure of elasticity in combination with knot tightening.[14] The elongation of the material at the lower force level is considered to be the base level for the elongation measurement during the experiments. We measured further length changes relative to this reference point. Elongation prior to this point was completely due to knot tightening. We calculated the strain to failure, expressed as percent elongation since it provides a better expression of real specimen elongation. Strain is the elongation at failure, divided by the mean initial length of the prosthetic loop. Due to the braided nature of the synthetic implants, the composing fibre bundles first stretch in their composition. Braided polyester tapes 7 mm wide elongated to a greater extent than the smaller tape, especially in the first part of the test. Width reduction of the braided material could possibly explain this difference: the 7 mm polyester braids had a higher number of filaments per bundle. The 4 mm braided polyester gave an approximate strain of 14%, whereas the average strain was 21% for the 7 mm tapes. Strain was 17% for the 4 mm braided polyamide tapes, significantly greater than for the 4 mm polyester ($p<0.001$).

The stiffness of the braided polyester tapes only amounted to about 10% of the stiffness in lineair loading described for the real CCL (Table 1).[4] The stiffness at failure of 4 mm polyamide was inferior to the stiffness of 4 mm polyester ($p<0.001$). The 7 mm polyester tapes, being broader, obviously had more resistance to loading than the 4 mm tapes.

In contrast to autografts (biological substitute tissues),[4] the braided synthetic tapes seem to be able to withstand vigorous trauma postoperatively, since they can absorb a great amount of energy up to failure. For the 4 mm polyester as well as the 4 mm polyamide, the energy up to failure amounted to about 2200 N.mm. More than 7000 N.mm of energy could be absorbed by the 7 mm broad polyester implants.

The static modulus indicates the amount of load which is necessary to increase the length of the prosthesis between two force levels. Values were relatively low for both graft widths of the polyester tapes. The modulus for the 4 mm polyamide tape was even smaller ($p<0.001$).

When studying femur-CCL-tibia preparations, the loading rate used during load-to-failure testing significantly influences all failure characteristics.[12] We tested the effect of the extension rate on the load-deformation curve for both 4 and 7 mm braided polyester tapes. The results at 100, 1000, and 8000%/mm are presented in Fig 4.

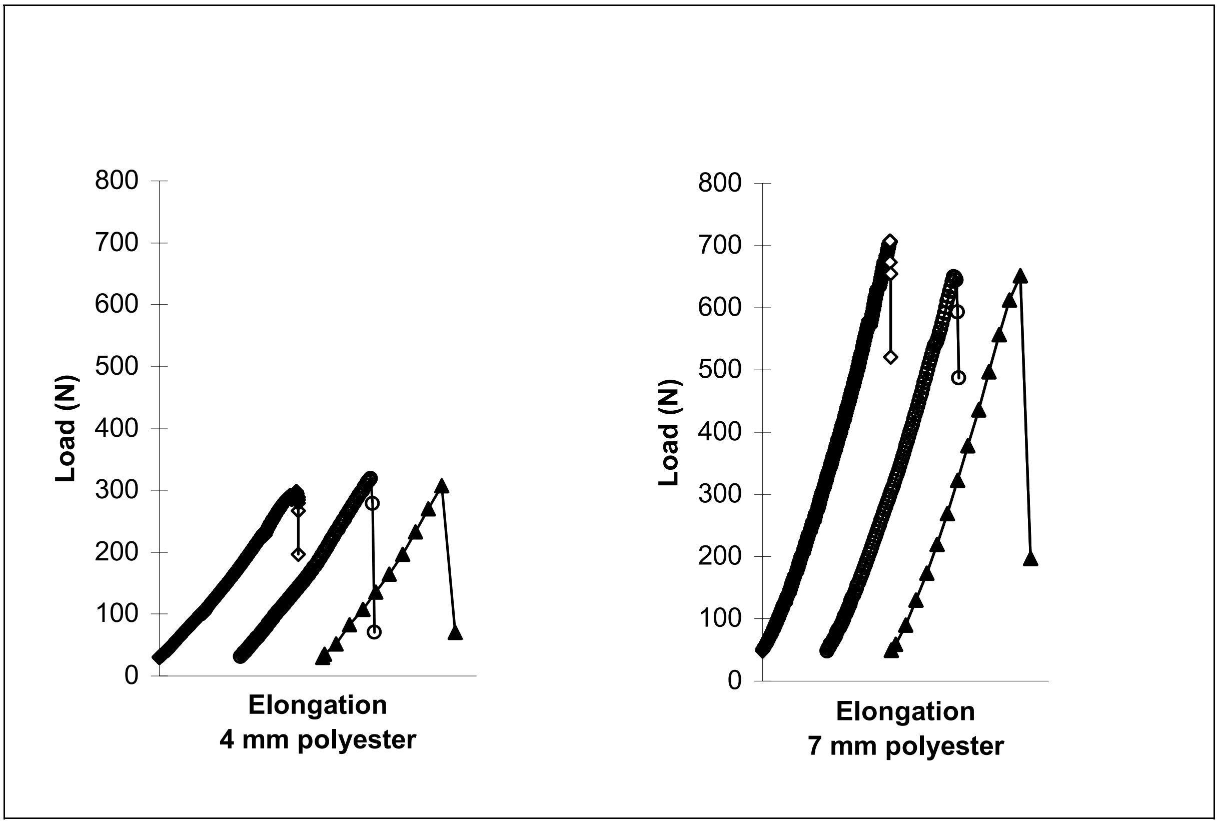

Fig 4. Load-elongation curves of braided polyester tapes at various extension rates (100, 1000, and 8000%/mm)

The curves have been offset on the ordinate in order to differentiate them properly

In our experiments, there was no significant variation of the load-deformation relationship with the various testing velocities for any of the braided polyester tapes tested to failure.

Synthetic tapes implanted as intra-articular CCL-substitutes become immersed in the joint fluid of the stifle. Immersion of the prostheses in physiological saline solution prior to tensile testing did not alter any of the biomechanical characteristics (data not shown).

Cyclic loading—We observed marked differences in the mechanical characteristics of the braided polyester tapes as a result of cyclic loading in the load-to-failure tests (Table 2). Cycling the prosthesis 25 times through 2000 cycles prior to the load-to-failure tests reduced the strength in the 4 mm polyester tapes ($p<0.05$), but we found no significant reduction in ultimate load for the 7 mm tapes.

Table 2. Load-to-failure tests and the effects of cyclic loading

	Precycled			Uncycled		
Parameter	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
4 mm polyester (n=3)						
Load at failure (N)	271.32*	7.71	2.84	317.46	9.64	3.04
Elongation at break (%)	9.470†	0.576	6.02	14.267	0.404	2.80
Stiffness (N/mm)						
at 50% of ultimate strength	44.50*	4.80	10.8	21.560	0.467	2.18
at ultimate strength	28.69†	0.923	3.21	22.251	0.123	0.539
Energy to failure (N.mm)	1586*	113	7.13	2372	142	6.00
Static modulus (N/mm)	34.56†	5.00	14.5	17.13	2.04	11.9
7 mm polyester (n=3)						
Load at failure (N)	663.41	20.2	3.05	678.22	41.45	6.11
Elongation at break (%)	14.400†	0.458	3.19	19.867	0.058	6.20
Stiffness (N/mm)						
at 50% of ultimate strength	54.92†	1.04	1.89	31.86	1.49	4.68
at ultimate strength	46.08*	1.35	2.93	34.13	2.04	5.98
Energy to failure (N.mm)	5707*	185	3.23	6847	112	1.64
Static modulus (N/mm)	55.30‡	1.93	3.49	21.169	0.852	4.01

Significantly (*$P<0.05$, †$P<0.01$, ‡$P<0.001$) different from value for the noncycled tape of the same width

Statistical analysis revealed that, for both widths of polyester tape, the energy absorbed was significantly decreased by precycling ($p<0.05$). At the time of load-to-failure testing, we encountered a relatively smaller increase in elongation of the cycled tapes ($p<0.05$). Typical load-elongation curves for the paired polyester tapes are shown in Fig 5. The two curves show that the changes in mechanical behavior of the synthetic prostheses were affected by the cycling experiment. At the beginning of the curve, there was a steeper slope in precycled baided polyester compared with uncycled polyester.

The stiffness at 50% of the failure force of precycled polyester tape was significantly superior to that of the uncycled material ($p<0.05$ for 4 mm and $p<0.001$ for 7 mm tapes). Also, we found a higher stiffness at the moment of failure (4 mm $p<0.01$, 7 mm $p<0.05$). Due to the cyclic loading, the material behaves more as a monofilament than as a woven material. Where there was no significant change in stiffness from 50% to 100% of the failure load in uncycled ligaments, we found differences for both widths when precycled. The precycled prostheses were significantly stiffer at 50% (paired t-test, $p<0.05$). This difference might be due to the incomplete recovery of the prostheses between the different sets of load cycles and due to contraction of the braided structure.

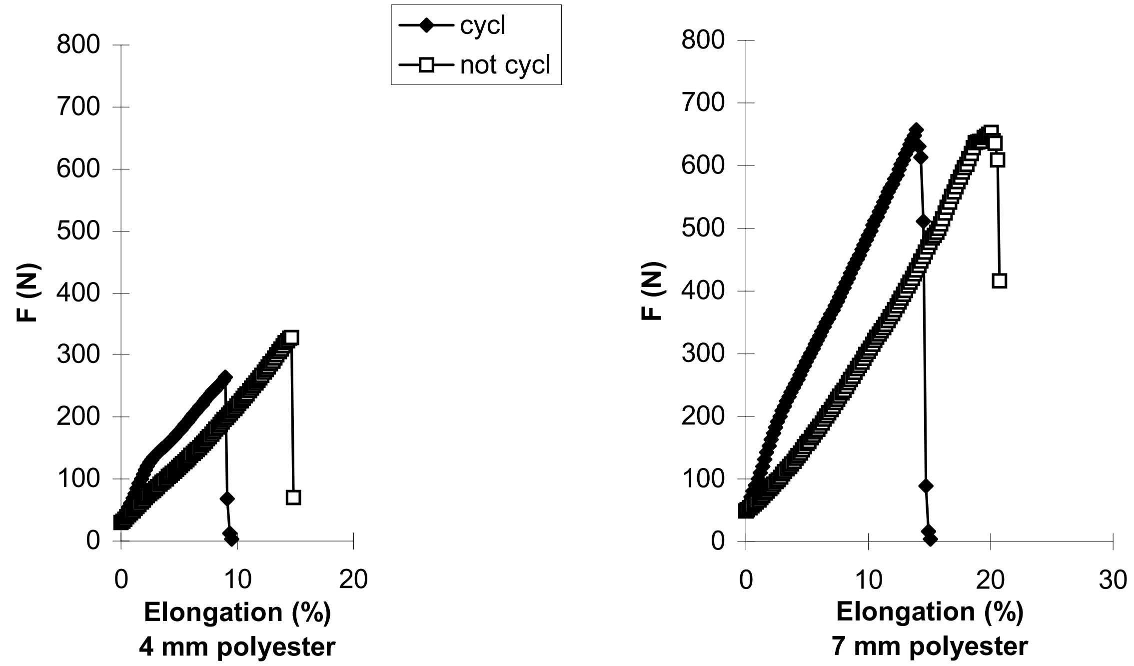

Fig 5. Approximate load-deformation relation of 4 mm and 7 mm polyester tapes tested after precycling and without precycling at a deformation rate of 1000%/min

Deformation at thelower force limit is set at zero

We determined the static modulus from the linear part between the lower and upper force limits of the load elongation curves. We encountered highly significant increases in this modulus after 25 sets of 2000 load cycles (4 mm $p<0.01$; 7 mm $p<0.001$).

In addition, we recorded data on the dynamic modulus and on residual elongation during the successive cyclic loading runs. There was hardly any change in modulus with an increased number of load cycles. As with natural ligaments, synthetic prostheses also exhibit viscoelastic behavior. There was insufficient time for complete length recovery between each cycle, and the implants progressively elongated under repetitive load cycles (Fig 6). A real CCL should be able to completely regain its original length after up to 14% elongation.[13] Residual elongation after dynamic loading is a measure of the permanent elongation when no stress is applied. After the first round of 2000 cycles, we found a residual elongation of 0.282% for the 4 mm braided polyester but only 0.253% for the 7 mm tapes (Fig 6). At the start of the 25th round, the 4 mm material was 0.405% longer than its original; by this time the 7 mm ligament was 0.333% longer.

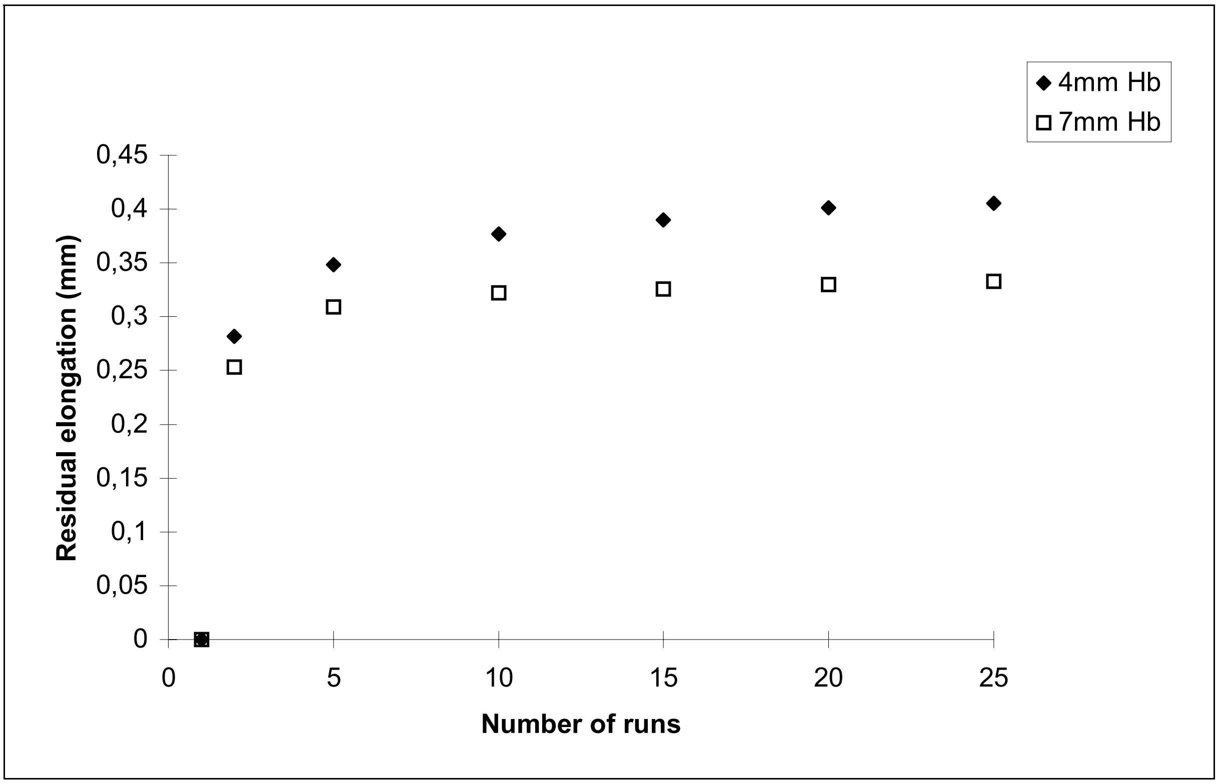

Fig 6. Residual elongation of 4 mm and 7 mm braided polyester after cycling

The *in vitro* material properties of braided polyester meet the mechanical requirements of a CCL prosthesis. Direct extrapolation of these experimental results, nevertheless, is inadvisable. *In vivo* assessment further concentrates on biocompatibility and the clinical efficacy of braided polyester as a CCL substitute in dogs.

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[a] Textechno-Herbert Stein, Germany

[b] Mersilene, distributed by Ethicon Ltd

[c] Distributed by Davies & Geck

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3.2.2. Biomechanical properties of braided polyester tapes intended for use as intra-articular cranial cruciate ligament prostheses in dogs

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SUMMARY

In vitro structural and material properties of braided, multifilament, nonabsorbable polyester tapes, used for intra-articular stabilization of cranial cruciate ligament (CCL)-deficient stifle joints were determined and compared with properties of multifilament polyamide tapes. Thirty polyester tapes (width, 4 mm), 10 polyester tapes (width, 7 mm), and 30 polyamide tapes (width, 4 mm) were tested to failure at 1,000 mm/min. Cyclic loading experiments between physiologic limits of force were also performed, using 3 polyester tapes of each widths.

Ultimate loads and corresponding stiffnesses of the polyester and the polyamide tapes were measured. Failure properties of polyester tapes were affected by previous precycling. Polyester tapes of 4-mm or 7-mm widths should be able to resist forces resulting from weight bearing in dogs, suggesting that these tapes will be effective for stabilization of the stifle joint in dogs with ruptured CCL.

INTRODUCTION

Rupture of the cranial cruciate ligament (CCL) is a common clinical problem in dogs.[1,2] Instability of the stifle joint results in lameness and rapid development of degenerative joint disease (DJD).[3] The major goal of surgical repair of a ruptured CCL is to improve functional performance of the stifle joint.[3] A number of procedures have been developed and evaluated.[4] It is believed that intra-articular implantation of a prosthesis can better mimic the original position and function of the CCL, compared with extracapsular placement of stabilization sutures.[5] Presently, regardless of the surgical procedure performed, consistent restoration of normal stifle joint biomechanics and complete arrest of the progression of DJD is still not possible.[6]

Numerous autografts and synthetic materials have been used for reconstructive surgery of the CCL.[4] In the early 1980's there was considerable interest in the development and use of synthetic prostheses for repair of human cruciate ligaments.[7] Although surgical management of a ruptured CCL in dogs, using various artificial prostheses, has been reported, there have only been a few reports describing the mechanical behavior of synthetic exra-articular CCL substitutes.[8,9] Any replacement material should behave in a manner similar to the natural ligament in the expected range of loading and should have load-elongation characteristics that closely resemble those of the original ligament during ultimate loading. However, the suitability of a prosthesis does not depend solely on tensile behavior. The recoverable elastic characteristics of the synthetic material are equally important for clinical use. Joint stability can not be guaranteed should the implant become severely elongated and stretched.[4]

Braided polyester sutures are often used in humans where a strong nonabsorbable suture is needed to help permanently repair tissue. The intra-articular use of braided, multifilament, nonabsorbable polyester suture material to repair ruptured CCL in dogs was described in 1986.[10] This technique has been used clinically ever since. The purpose of the study reported here was to determine the *in vitro* structural and material properties of a braided, multifilament, nonabsorbable polyester tape commonly used for intra-articular stabilization of CCL-deficient stifle joints in dogs and compare those with properties of a multifilament polyamide tape.

MATERIALS AND METHODS

Sample population—Thirty 4-mm wide tapes and ten 7-mm wide tapes of a braided, multifilament, nonabsorbable, polyester suture material[a], commonly used as CCL prostheses in dogs, and thirty 4-mm wide tapes of multifilament polyamide material[b] were used to determine structural and material properties in a load-to-failure test. Because of the inferior material properties of polyamide in the simple load-to-failure test, the effects of cyclic loading on structural and material properties were determined, using 3 sets of each width of polyester tapes only.

Experimental protocol—Tests were performed in standard climate conditions (ie, relative humidity, 65 ± 2%; temperature, 20 ± 2 C). Load-to-failure tests were used to simulate traumatic overload conditions, whereas cyclic loading tests mimicked physiologic loading during daily activities.

Behavior of polyester and polyamide tapes in a simple load-to-failure test was characterized by determining the structural variables of stiffness, load, and energy absorbed, and the material properties of static modulus and elongation.

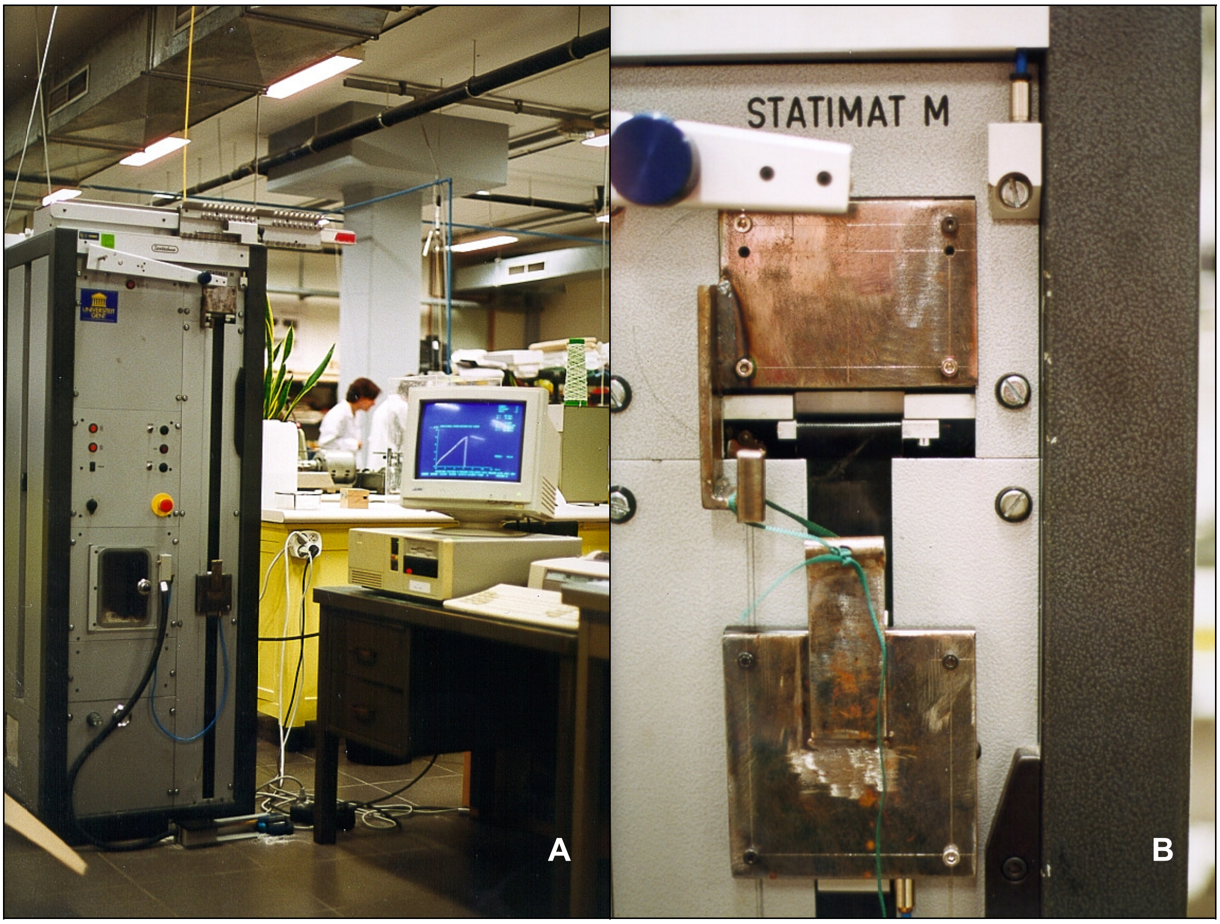

Fig 1. Statimat M tesile tester
A. A personal computer with specialized software programs was connected to the microprocessor of the tensile tester
B. Polyester specimens were mounted in clamping devices mimicking the bony anchorages in the stifle joint of the dog

Tensile tester—Polyester and polyamide tapes were mounted as loops in a tensile tester (Fig 1).[c] A personal computer with specialized software programs was connected to the microprocessor of the tensile tester. Data were collected via a built-in load cell and a displacement transducer.

Special clamping devices were designed by the principal investigator (HdR) to simulate *in vivo* fixation points of a CCL prosthesis; the proximal and distal clamps mimicked the femoral and tibial anchor points, respectively. The upper hook was rigidly mounted on a 1,000-N load cell. The lower clamp was attached to the moving cross head. The direction of loading was along the same orientation as would be used in a clinical setting. To simulate intra-operative conditions, the tapes were tied around the metal devices such that the knot was close to the distal anchor point. One person (HdR) tied all tapes; 4 throws were used and tightened securely as square knots. The knotted tapes had a constant original length of 100 mm.

The standard available computer programs for dynamic loading and relaxation did not meet the requirements for this study. Therefore, new software programs were written to set interclamp distance, lower and upper force limits, and rate of extension for both load-to-failure and cyclic loading tests. Data were translated and stored in files on the personal computer connected to the tensile tester. To determine increases in length of the synthetic tapes, direct calculations were made from the displacement of the clamps. Material elongation was zeroed at the lower force limit. Data were written to a file, and test results were further analyzed, using commercially available software[d] on a remote computer.

Load-to-failure tests—To determine load at material failure, 4-mm wide polyester and polyamide tapes and 7-mm wide polyester tapes were loaded at a constant rate of elongation (1,000 mm/min) until they failed (ie, broke). The fast extension rate was used to more closely approximate loading conditions *in vivo*. Load and displacement data were recorded simultaneously by the testing machine and transferred to a remote computer for analysis. Load versus elongation curves were computed, and the following structural and material variables were obtained: ultimate load, elongation at 20, 50, and 100% of ultimate load, strain, stiffness at 50 and 100% of ultimate load, energy absorbed to failure, and static modulus for the physiologic range of forces.

To assess the influence of loading rate on load versus elongation curves, the polyester tapes were also tested at elongation rates ranging from 100 to 8,000 mm/min. Each polyester tape was divided into 3 equal pieces to minimize the effect of material variability on the elongation versus rate tests. Load versus elongation curves were determined.

Because intra-articular CCL prostheses will be in permanent contact with the synovial fluid of the stifle joint, additional load-to-failure tests were conducted, using 4-mm wide polyester tapes that had been immersed in saline (0.9% NaCl) solution.

Cyclic loading tests—The effects of cyclic loading on 3 tapes of each width of polyester tape were determined in an attempt to reflect biomechanical conditions and abrasions resulting from daily activities. The test method was similar to that used previously to evaluate yarns.[11] The ideal resting time between sets of cyclic loading was determined in a preliminary study. Lower and upper force limits were calculated from the weight bearing forces determined by use of force plate analysis, using dogs weighing approximately 12 and

25 kg, respectively.[12] The force limits were thus set at 25 and 87 N for the 4-mm wide tapes and 42 and 137 N for the 7-mm wide tapes.

Each polyester tape was cut in half. One half was repetitively loaded for 25 sets of 2,000 cycles between the 2 force limits at an elongation rate of 500 mm/min. This extension rate resulted in approximately 2 cycles per second; the hind limb stride frequency in healthy dogs at the trot approaches 2 Hz.[13] Between each set of 2,000 cycles, the synthetic material was allowed to recover for 20 minutes. During each cyclic loading test, residual elongation and the dynamic modulus were determined. A load-to-failure test was performed on each precycled tape at an elongation rate of 1,000 mm/min. For comparison, the other half of the same tape was elongated without cycling at the same rate until it failed. To facilitate comparison of load versus elongation curves, several variables were defined, including ultimate load, elongation at failure, stiffness at 50 and 100% of ultimate load, energy to failure, and static modulus.

Statistical analyses—Data were analyzed, using a commercially available software package.[e] Descriptive statistics were used to test for normality. Structural variables determined in the load-to-failure tests were compared between the 4-mm wide polyester and polyamide tapes by use of nonparametric Kruskal-Wallis rank tests. Differences in stiffness at 50 and 100% of ultimate load were compared among groups by use of a parametric 2-sample t-test. Mechanical data were compared between precycled and noncycled polyester tapes by use of paired t-tests. Differences were considered significant when $P < 0.05$.

RESULTS

Load at failure—Ultimate load (ie, the force acting on the tested material at the moment of failure) and maximal linear load to failure (ie, to first sign of rupture) were not significantly different among any of the synthetic materials. At the moment of failure, the synthetic material most often immediately and almost completely ruptured. Mean (± SD) ultimate loads were 301.78 ± 16.92 N and 726.40 ± 37.74 N for the 4-mm and 7-mm wide polyester tapes, respectively. The 4-mm wide polyamide tape was significantly ($P < 0.001$) weaker than the 4-mm wide polyester tape (Table 1).

Table 1. *In vitro* biomechanical properties of synthetic materials intended for use as cranial cruciate ligament prostheses in dogs

Property	4-mm wide polyamide tape (n=30)	4-mm wide polyester tape (n=30)	7-mm wide polyester tape (n=10)
Ultimate load (N)	266.48 +/- 13.19‡	301.78 +/- 16.92	726.40 +/- 37.74
Elongation♠ (mm)			
at 20% of ultimate load	3.02 +/- 0.32‡	2.02 +/- 0.32	4.36 +/- 0.46
at 50% of ultimate load	9.73 +/- 0.58‡	7.22 +/- 0.77	10.82 +/- 1.07
at 100% of ultimate load	17.10 +/- 0.72‡	14.03 +/- 1.05	20.60 +/- 1.66
Stiffness (N/mm)			
at 50% of ultimate load	27.37 +/- 0.87‡	21.12 +/- 2.57	33.25 +/- 2.94
at 100% of ultimate load	15.57 +/- 0.49‡	21.63 +/- 2.19	34.85 +/- 2.66

♠Increase in length of tape from length at lower force limit
Significantly (*P<0.05, †P<0.01, ‡P<0.001) different from value for 4-mm wide polyester tape

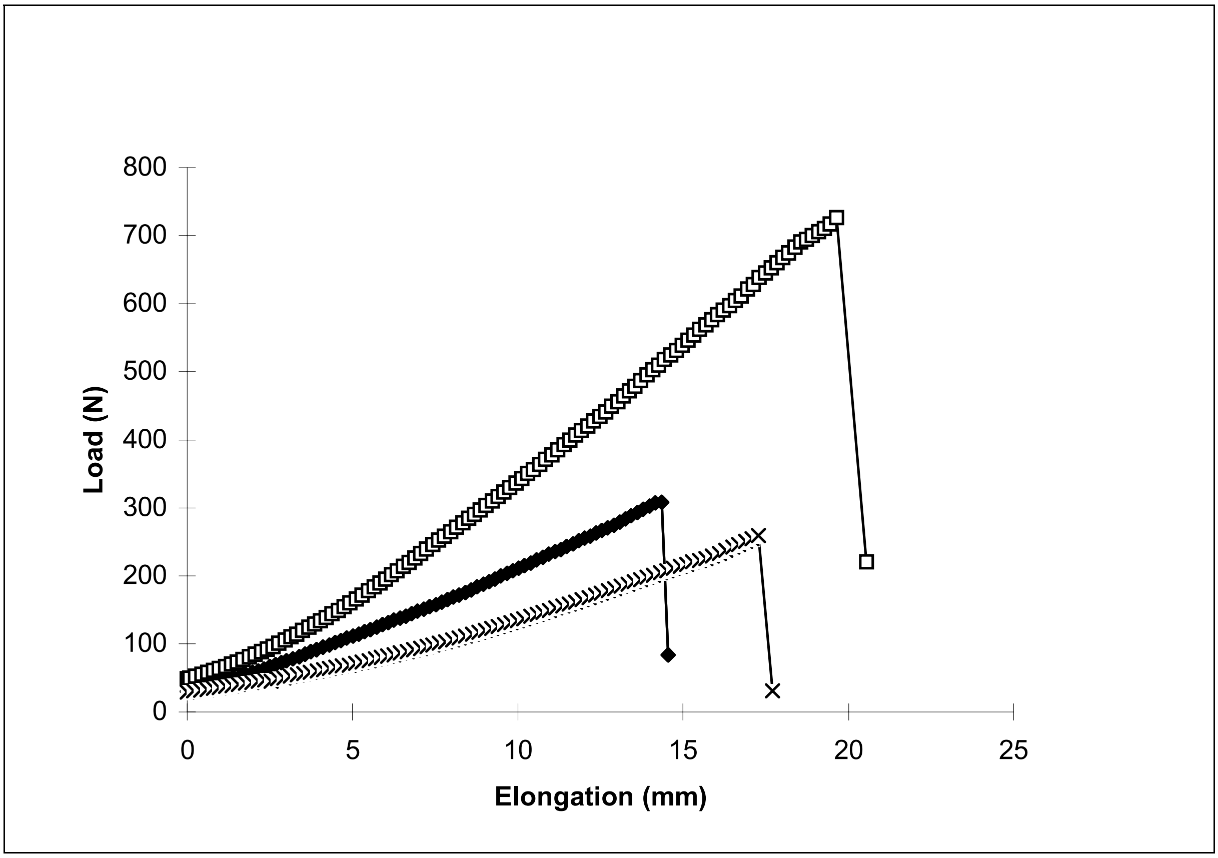

Fig 2. Representative load versus elongation curves obtained during load-to-failure testing of 4-mm wide polyestre tapes (♦), 7-mm wide polyester tapes ( ), and 4-mm wide polyamide tapes (x)

All relations between load and elongation during loading were expressed by the load versus elongation curves (Fig 2). The initial toe region, which was not present in all curves, was not expressed. In that area, extension occurred with only a slight increase in load. All curves had a fairly linear pattern until failure. Only one mode of failure was observed during the load-to-failure tests, and the site of rupture was always located near the knot.

During load-to-failure tests, elongation was defined as the increase in length at any moment during the test. Elongation of the material at the lower force limit was considered the baseline elongation measurement. Change in length was measured relative to this reference point. Elongation prior to this point was attributable to knot tightening. At failure, mean elongation of the 4-mm polyester tape was 14.03 ± 1.05 mm, whereas elongation of the 7-mm wide tape was 20.60 ± 1.66 mm. Mean elongation at failure was significantly ($P < 0.001$) greater for the 4-mm wide polyamide tape, compared with the 4-mm polyester tape (Table 1). Elongation at 20 and 50% of the ultimate load accounted for 14 and 51% of the ultimate elongation of the 4-mm wide polyester tape, 21 and 52% of the elongation of the 7-mm wide polyester tape, and 17 and 57% of the elongation of the 4-mm wide polyamide tape.

To provide a better expression of real specimen elongation, strain to ultimate load was calculated and expressed as a percentage of elongation (ie, elongation at failure divided by mean initial length of the synthetic tape). The mean strain to ultimate load was 14.03 ± 1.05% for the 4-mm wide polyester tape, 20.60 ± 1.66% for the 7-mm wide polyester tape, and 17.10 ± 0.72% for the 4-mm wide polyamide tape. Strain was significantly ($P < 0.001$) greater for the 4-mm wide polyamide tape, compared with the 4-mm wide polyester tape.

Mean stiffness, which characterizes the rigidity of the material, at 50% of ultimate load was 21.12 ± 2.57 N/mm and 33.25 ± 2.94 N/mm for the 4- and 7-mm wide polyester tapes, respectively. The 4-mm wide polyamide tape was significantly ($P < 0.001$) stiffer at 50% of the ultimate load than the 4-mm wide polyester tape (Table 1). Stiffness of either width of polyester tape at 100% of ultimate load was not significantly different from stiffness at 50% of ultimate load. Both polyester tapes resisted loading in a similar manner throughout the entire test, as indicated by the linear pattern of the load versus elongation curves. In contrast, stiffness of the 4-mm wide polyamide tape at 100% of ultimate load was significantly ($P < 0.001$) decreased, compared with its stiffness at 50% of ultimate load. Mean stiffness at failure of the 4-mm wide polyester tape was significantly ($P < 0.001$) greater than that of the polyamide tape.

The amount of energy required to rupture the tested materials was represented by the area under the load versus elongation curves. For the 4- and 7-mm wide polyester tapes, mean energy to failure was 2,252 ± 170 N.mm and 7,877 ± 736 N.mm, respectively. Energy to failure of the 4-mm wide polyamide tape (2,212 ± 157 N.mm) was not significantly different, compared with the 4-mm wide polyester tape.

The modulus was also determined as the ratio of increase in force to the corresponding increase in length. The static modulus between the lower and upper force limits was 15.47 ± 1.48 N/mm and 20.01 ±2.26 N/mm for the 4- and 7-mm wide polyester tapes, respectively. The static modulus of the 4-mm wide polyamide tape (8.83 ± 0.38 N/mm) was significantly ($P < 0.001$) less, compared with the 4-mm wide polyester tape.

Effects of extension rate on elastic and failure characteristics were determined for both widths of polyester tape. The lower force limits (25 and 42 N for the 4- and 7-mm wide tapes, respectively) were chosen as the first Y-value recorded. Extension rate did not significantly affect load versus elongation relationships. Immersion of the polyester tapes in saline solution prior to tensile testing also did not significantly alter any biomechanical characteristic measured.

Effects of cyclic loading—Pronounced differences were detected in the mechanical characteristics of the braided polyester tape as a result of cyclic loading (Table 2). Cyclic loading significantly reduced the strength of the 4-mm wide tape. However, no significant reduction in ultimate load was detected for the 7-mm wide tape. For both widths of polyester tape, energy to failure was significantly affected by precycling.

A significant decrease in further elongation at failure was detected for precycled tapes, compared with noncycled tapes. In addition, the load versus elongation curves for precycled and noncycled tapes revealed that the change in mechanical behavior of polyester tape was affected by cyclic loading (Fig 3). The initial slope of the curve for precycled tape was steeper, compared with noncycled tape. Stiffness at 50 and 100% of ultimate load for both widths of precycled tape was significantly greater, compared with noncycled tape (Table 2). Moreover, for both widths of precycled tapes, stiffness at 50% of ultimate load was significantly greater than that at 100%. Differences in stiffness were not detected for noncycled tapes.

The static modulus was determined from the linear part of the load versus elongation curves between the lower and upper force limits. Significant increases in this modulus were detected for both widths of tape after 25 sets of 2,000 cycles (Table 2). In addition, dynamic modulus and residual elongation data were recorded during the successive sets of cyclic loading. Dynamic modulus did not significantly change as the number of cycles increased.

Table 2. Effects of precycling on *in vitro* biomechanical properties of synthetic materials intended for use as CCL prostheses in dogs

	4-mm wide polyester tape		**7-mm wide polyester tape**	
Property	**Precycled[♣] (n=3)**	**Uncycled (n=3)**	**Precycled[♣] (n=3)**	**Uncycled (n=3)**
Ultimate load (N)	271.32 +/- 7.71*	317.46 +/- 9.64	663.41 +/- 20.25	678.22 +/- 41.45
Elongation[♠] (mm)	9.47 +/- 0.57†	14.27 +/- 0.40	14.40 +/- 0.46†	19.87 +/- 0.06
Stiffness (N/mm)				
at 50% of ultimate load	44.50 +/- 4.80*	21.56 +/- 0.47	54.92 +/- 1.04†	31.86 +/- 1.49
at 100% of ultimate load	28.69 +/- 0.92†	22.25 +/- 0.12	46.08 +/- 1.35*	34.13 +/- 2.04
Energy to failure (N.mm)	1586.39 +/- 113.1*	2372.79 +/- 142.3	5707.19 +/- 184.6*	6847.76 +/- 112.1
Static modulus (N/mm)	34.56 +/- 5.00†	17.13 +/- 2.04	55.30 +/- 1.93‡	21.17 +/- 0.85

[♣] Precycled tapes were subjected to 25 sets of 2000 cycles between the lower and upper force limits (4-mm wide tape, 25 and 87 N; 7-mm wide tape, 42 and 137 N, respectively) before load-to-failure testing

[♠] Increase in length of tape from length at lower force limit

Significantly (*P<0.05, †P<0.01, ‡P<0.001) different from value for the noncycled tape of the same width

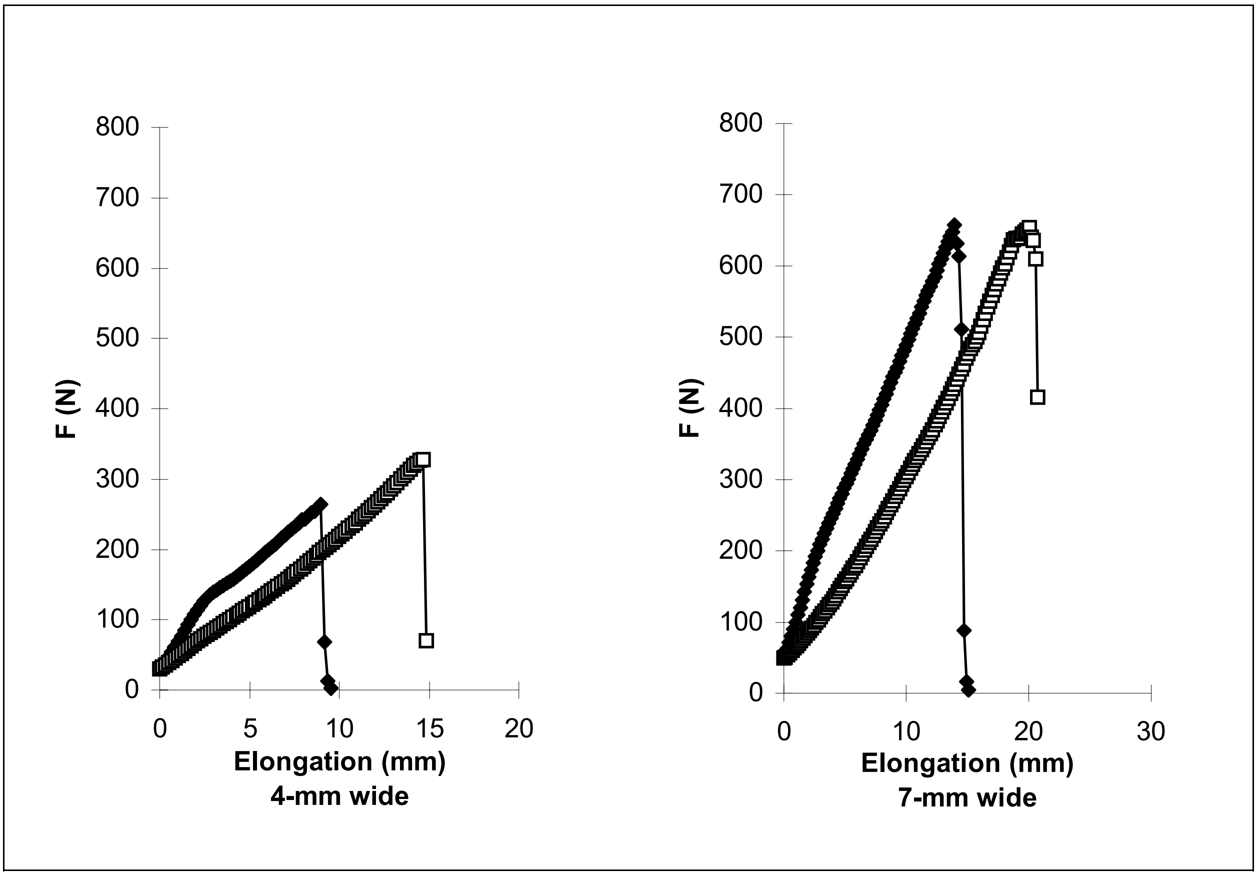

Fig 3. Representative load versus elongation curves obtained during load-to-failure testing of polyester tapes. The tapes were either subjected to cyclic loading (♦) before load-to-failure tests or were tested without prior cyclic loading ( )

Because of the viscoelastic properties of the polyester tape, there was insufficient time for complete recovery of length between cycles. Residual elongation after each cycle thus accumulated, resulting in a gradual increase in length of the tape throughout the experiment. Elongation of the tapes at the lower force limit was set at zero. Further elongation was measured relative to this reference point. Residual elongation after dynamic loading is a measure of the permanent elongation when no stress is applied. After the first set of 2,000 cycles, mean residual elongation of the 4- and 7-mm wide tapes was 0.282 ± 0.07 mm and 0.253 ± 0.03 mm, respectively. At the start of the 25th set, elongation of the 4- and 7-mm wide tapes was 0.405 ± 0.147 mm and 0.333 ± 0.014 mm, respectively.

DISCUSSION

Biomechanically matched prostheses that provide full joint stability after cruciate ligament surgery in humans or dogs are not yet available. The present study focused on the biomechanical properties of a material commonly used for CCL prostheses in dogs. This prosthesis, made of braided, nonabsorbable polyester tape, was compared with a polyamide tape because of the great similarity of the braiding structure and size of the implants. Unfortunately, we could not directly compare the synthetic materials with the CCL from a healthy dog.

Simple load versus elongation curves are particularly well suited for characterization of material behavior during loading. These curves can provide information on biomechanical properties that occur at the time of acute overload. The mean strength of the CCL from dogs, measured *in vitro*, is 46 N/kg of body weight.[14-16] A fast elongation rate was chosen for the load-to-failure tests in our study to mimic the *in vivo* loading conditions of acute overload. To assess synthetic materials intended for use as CCL prostheses, it is imperative to know the forces that the CCL must endure *in vivo*. Under physiological weight-bearing conditions, ligaments from humans are subjected to loads ranging from only 10 to 25% of their ultimate load.[17] Accurate predictions of the functional demands of the CCL in dogs would aid in the search for the ideal prosthesis. However, the structural properties of CCL prostheses do not depend solely on the strength of the material. Results of cyclic loading tests can provide more data on mechanical variables than simple load-to-failure tests. The extension rates and force limits for the cyclic loading experiments in our study were chosen to be comparable with those encountered during normal activity. The loading of a particular limb and the stride frequency can be accurately determined by use of force plate analysis.[12,13] The polyester and polyamide tapes in our study were tested, using *in vitro* conditions that simulated the intra-articular stabilizing technique of Lieben.[10] The bony anchorages were mimicked by the design of the clamps, and a surgical knot was applied close to the distal tunnel.

Load versus elongation curves obtained with natural ligaments reveal an initial concave and a final convex region.[18] In contrast, we found a fairly linear relationship between load and elongation of the polyester tapes. These results suggest that polyester tapes may not be as strong as the CCL during *in vitro* testing, but these tapes should easily be able to resist the forces of weight bearing when used as a prosthesis in dogs. We found that all characteristics of the polyester tapes were superior to those of the polyamide tapes of the same size.

Inclusion of a knot in the test procedure decreases the load at failure for most materials.[9] Additionally, testing a longer length of material will result in a decrease in the final load (weak link theory).[19] For technical reasons, the original length of the synthetic tapes was 100 mm, whereas the CCL in dogs is typically only 13.5- to 17.5-mm long.[16,20] Even when results of tensile loading experiments reveal that a synthetic material has superior strength, compared with the original CCL, there is no guarantee that such strength can be maintained for the rest of a dog's life. As do natural ligaments, synthetic prostheses have viscoelastic properties. However, a prosthesis is not able to elongate and recover to the same extent as the natural ligament. In dogs, the CCL should completely regain its original length following as much as a 14% increase in length.[20] Prostheses also are not able to repair microlesions and are susceptible to abrasion.[7] An inevitable decrease in biomechanical properties will thus occur.

Knot slide did not appear to be a notable problem in this study. By using knotted tapes, we were able to evaluate both the prosthetic material and knot properties. Elongation under loading is a measure of elasticity and knot tightening.[21] During tying of knots, a considerable loss in tension may occur.[8,22] We are not aware of data that describes the correct tension for grafts intended to restore joint stability.

We observed a fairly linear elongation to failure for both widths of polyester tapes. Elongation of the 7-mm wide tape was greater, compared with the 4-mm wide tape, especially during the first part of the test. Macroscopically, both widths are braided with an even number of fiber bundles. The 7-mm wide tapes, however, contain a higher number of filaments within each bundle. Because of the braided nature of the material, the filaments within the fiber bundles first stretch during loading. This effect will initially be more pronounced in the 7-mm wide tape, because its width can be reduced to a greater extent.

Because of the periarticular structures *in vivo*, it is unlikely that this difference in elongation will have any clinical repercussion within the normal range of motion following surgical placement of the prosthesis.

The stiffness of the 100-mm long polyester tape loops only amounted to approximately 10% of the stiffness of a natural CCL.[6] A greater stiffness is expected for shorter loops.[23] The 7-mm wide polyester tape had more resistance to loading than the 4-mm wide tape. A CCL prosthesis should be stiff enough to avoid micromotion that may delay ingrowth of autogenous tissue during the early recovery period.[21] However, complications, such as rapid progression of DJD, are associated with prostheses that are too stiff.[24] The multifilamentous nature of the synthetic tapes may allow or promote ingrowth of autogenous tissue.[25-28] This tissue matures into collagen aligned parallel to the long axis of the prosthesis and will form an adequate neoligament.[26,28] A lack of ingrowth may be related to a chronic inflammatory response.[29] In contrast to autografts,[16,30] we found that the braided polyester tape absorbed a great amount of energy to failure, suggesting that this material may withstand vigorous trauma immediately after surgery.

The static modulus between 2 force limits indicates the amount of load necessary to increase the length of the prosthesis. In the present study, static modulus was low for both widths of polyester tape.

The rate of elongation used during load-to-failure testing of femur-CCL-tibia preparations significantly influences all failure characteristics.[18] However, rate of elongation has no effect on such preparations within the recoverable range of load and elongation.[20] Likewise, we did not detect any effect of elongation rate on the behavior of the polyester tape in the load-to-failure tests.

To properly reflect biomechanical conditions and abrasions resulting from daily activities, a special test procedure was designed in which the lower and upper force limits were load-controlled. During walking, the CCL is subjected to a rapid application and removal of force.[17] With no forces applied, visco-elastic recovery occurs. Cyclic loading between 2 force limits that are within physiologic range is intended to simulate the loading of a limb during normal ambulation. The lower and upper force limits that we used were derived from data on vertical weight-bearing forces in walking dogs that weighed 12 and 25 kg, respectively. The extension rate was representative of the loading conditions to which the stifle joint is subjected in a trotting dog. After cycling, the mechanical response of the polyester tapes was significantly different than that of the noncycled tapes. The 4-mm wide precycled tape failed at a lower ultimate load, but the ultimate strength of the 7-mm wide tape was not affected by precycling. Both widths of polyester tape progressively elongated under repetitive load cycles. Elastic deformations will disappear when the load is removed and when sufficient time is allowed for the material to return to its original length. However, we found that the precycled polyester tapes became permanently elongated; mean elongation of these tapes in the load-to-failure test was less, compared with that of the noncycled tapes. Both widths of precycled polyester tapes absorbed far less energy prior to failure than noncycled tapes. However, precycled tapes were still capable of absorbing the shock of traumatic overload.

A qualification of the data from the present study relates to the number of tapes tested during the cyclic loading experiment. Insufficient numbers of tapes were tested to allow for accurate determination of the dynamic modulus. Testing a larger number of tapes was impractical because of the duration of a single cyclic loading test.

Results of our study provide information on material properties of polyester and polyamide tapes under loading conditions. Direct extrapolation of the results to *in vivo* situations, nevertheless, is inadvisable. *In vivo* assessment is required to determine the biocompatibility and clinical efficacy of the braided polyester tape as CCL prosthesis in dogs.

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[a] Mersilene®, Ethicon Ltd, distributed by Johnson & Johnson Medical bv, Dilbeek, Belgium.

[b] Lacs suspenseurs®, Davis & Geck, distributed by Sherwood Benelux nv, Mechelen, Belgium.

[c] Statimat®, Textechno-Herbert Stein, München Gladbach, Germany.

[d] Excel, Microsoft nv, Brussels, Belgium.

[e] Statistix®, Analytical Software, Tallahassee, FL.

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CHAPTER 3

BIOMECHANICAL BEHAVIOUR OF THE CANINE CRANIAL CRUCIATE LIGAMENT AND ITS SYNTHETIC SUBSTITUTES

3.1. Load-controlled tensile tests

3.2. Displacement-controlled tensile tests

- 3.2.1. Biomechanical properties of artificial cranial cruciate ligaments
- 3.2.2. Biomechanical properties of braided polyester tapes intended for use as intra-articular cranial cruciate ligament prostheses in dogs

3.1. Load-controlled tensile tests

SUMMARY

In dogs, braided polyester is used as intra-articular substitute material in dogs with injury to the cranial cruciate ligament (CCL). The breaking strength of the prosthesis should at least approximate the strength of the original CCL as determined under identical loading conditions.

The breaking strength of normal CCL was determined in 44 canine cadavers, elongated at a loading rate of 0.1 kN/s. The *in vitro* breaking load of the canine CCL approximated 3 times the body weight. A significant correlation existed between the body weight of the dogs tested and the ultimate breaking strength of their CCL.

The breaking strength of flat braided polyester tapes of 4 and 8 mm, mounted as knotted loops, was determined under similar testing conditions as the cadaver preparations. The 4 mm polyester loops broke at a mean load of 440 N, whereas 860 N was needed to break the 8 mm loops. Ethylene oxide gas sterilisation did not decrease the breaking strength of braided polyester.

Based on the experimental results, a 4 mm polyester tape would be a valuable choice for replacing a torn CCL in dogs up to 15 kg of body weight.

INTRODUCTION

The cranial cruciate ligament (CCL) is a unique ligamentous structure, hidden in the center of the stifle joint in all terrestrial mammals, important for maintaining stifle joint stability.[1,2] Injury to the ligament is detrimental for the joint.[3] CCL replacement techniques have become popular as surgeons strive to restore normal stifle kinetics after CCL rupture.[4]

The behaviour of the CCL in the physiologic range of loading mainly relies on assumptions. *In vivo* loading of the CCL encountered in normal use is likely much smaller than the load required to rupture the ligament under test conditions.[5-7] *In vitro* observations on breaking strength of the CCL have been documented in various species. The results of single traction experiments in the absence of surrounding soft tissues have been published in man[7-13], monkeys[9,14], horses[15], cattle[6], rabbits[16,17], goats[18,19], sheep[20], and dogs[8,13,21-24]. On the other hand, direct measurement of *in vivo* forces remains tricky. Only in the goat, *in vivo* loading experiments of the CCL during spontaneous activity has been reported hitherto.[25]

The search for an ideal substitute for the successful management of a torn CCL has attracted the attention of human and veterinary surgeons for the last decades. Inspired by a publication on the intra-articular use of polyester in cruciate-deficient dogs[26], veterinary surgeons in Belgium started to use this material to stabilise canine stifle joints after CCL rupture. At that point, mechanical *in vitro* studies on the material properties of braided polyester tapes were totally lacking. To deal with the urgent need of biomechanical data on this polyester substitute, load-controlled tensile test protocol was instituted.

The paper reports preliminary results on the breaking strength of the natural CCL related to the body weight of the cadaver dogs and on the strength of polyester prostheses of various sizes. Meanwhile, the effect of ethylene oxide gassterilisation on the strength properties of braided polyester was assessed.

MATERIALS AND METHODS

Cadavera—All specimens were obtained from fresh cadavera from adult dogs of various breeds and ages. None was destroyed for this specific purpose. Forty-four hind limbs were harvested (21 pairs and 2 individual legs). The body weight of each donor cadaver was registrated and ranged from 7.5 kg to 50 kg (mean 24 kg). No data on the ages of the dogs tested were available. All stifles were considered normal, based on the absence of radiological signs of DJD on lateral radiographs.

The cadaver limbs had their skin removed and were disarticulated at the coxofemoral joint. The shafts of tibia and femur were cleared of soft tissues. The hind legs were shortened by a saw cut through the femur and the tibia, leaving about 15 cm bone proximally and distally to the stifle joint. Two parallel bone tunnels were drilled lateromedially perpendicular to the long axis of the femur and the tibia, while the stifle specimen was fixed under the physiological angle of 140°. The stifle joint was left unopened until just before the test. All soft tissue surrounding the stifle joint, femorotibial attachments and joint structures were carefully transected to isolate the CCL and the menisci. The preparation was only executed at the last moment before mounting the bone-ligament-bone specimen into the testing instrument, to avoid dessication of the CCL.

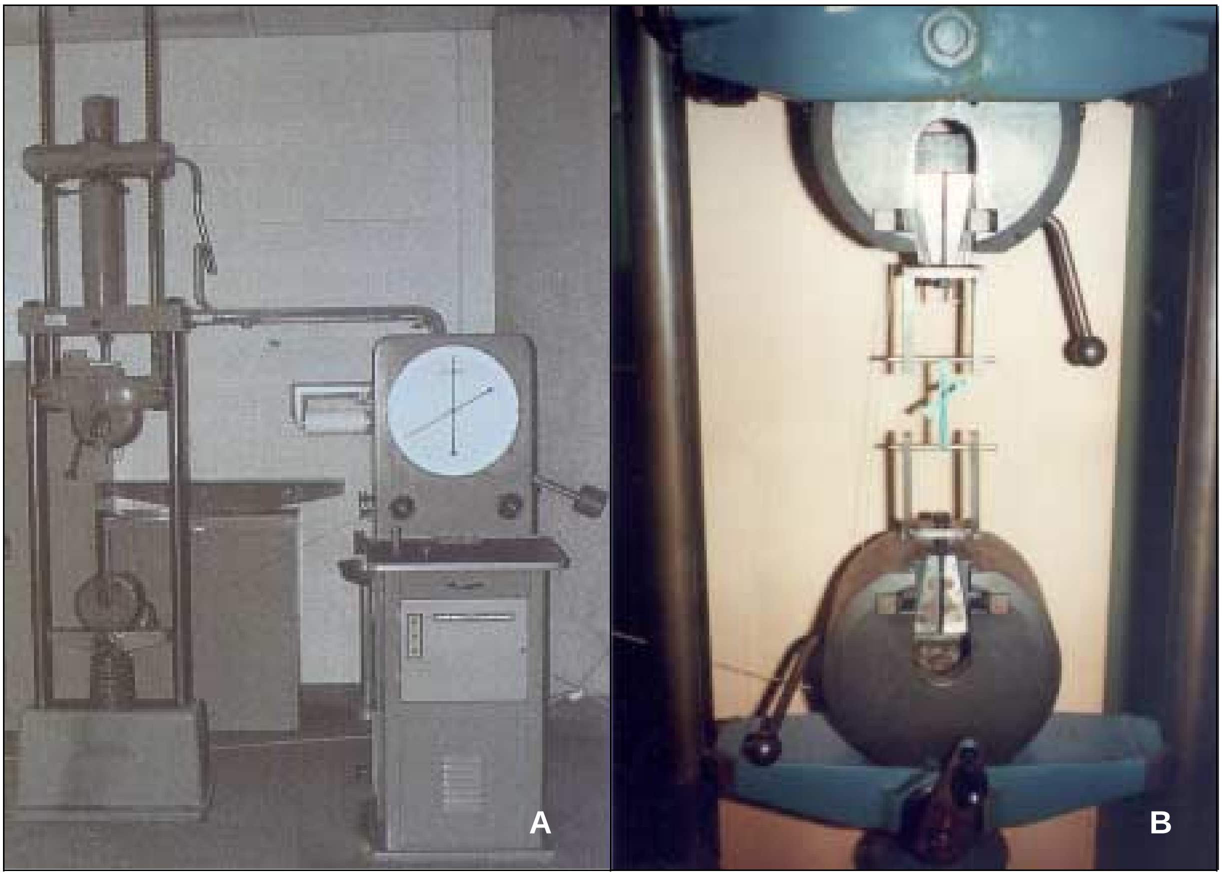

Fig 1. Amsler Bodson electro-hydraulic universal test machine
A. Load and displacement data are drawn on a calibrated strip-chart which is connected to the tensile tester
B. Polyester specimens were mounted around smooth-surfaced steel bars

The specimens were mounted in an electro-hydraulic universal test machine[a] (Fig 1 A). Smooth-surfaced steel bars were driven through the created bone tunnels. The test specimens were elongated to failure at a constant loading rate of 0.1 kN/s. Load and displacement data were drawn simultaneously in a graph on a calibrated strip-chart. The maximum linear load to failure (first significant sign of rupture) could be deduced from the graph as the first recorded peak value.

Polyester—The polyester prostheses are made of green-dyed polyethylene terephtalate[b]. They are braided structures, with a flat cross-sectional configuration, available in various widths. The synthetic prostheses are sterilised in their package by irradiation by the manufacturer. In this series of preliminary tests, polyester tapes with a width of 4 and 8 mm were used. For technical reasons, the samples were all tied around a 170 mm diameter cylinder to create loops. A surgeon's knot was used for the first throw with 4 subsequent single throws placed.

The specimens were mounted around smooth-surfaced steel bars in the electro-hydraulic universal test machine (Fig 1 B). The position of the knot was always choosen midway between the two bars.

With the specimen in a vertical position, a steady and constant vertical pull was applied until the graft failed. The test specimens were elongated to failure at a constant loading rate of 0.1 kN/s. Load and displacement data were drawn simultaneously in a graph on a calibrated strip-chart. The load at which the suture brook was recorded, and the strain due to distraction was determined.

Four 4 mm and four 8 mm polyester samples were tested as single loops. An equal number of each was submitted to the tensile tests as double strand loops, with only one overall knot.

In addition, four samples of 4 mm width were sterilised by ethylene oxide prior to loading to failure. The sterilisation was carried out in a gas steriliser[c], using clingas-118 LG-1, a mixture of 12% ethylene oxide and 88% freon (dichlorodifluoromethane) at a temperature of 40°C and under 1.4 bar (140kPa) of pressure during 6 hours. The completeness of the sterilisation was proved by the coloured indicator on the Steri-Dual package that changed from pink to brown.

Statistical analysis—All data were analysed using the statistical software package Statistix 4.1.

The Pearson correlation test was used to assess the association between the body weight of the cadavera and the load at failure of the CCL. A paired t-test was applied to compare the breaking strength of the left and right CCL in the 21 pairs. Data on the breaking strength of the polyester tapes were analysed using two-sample t-tests. A significance level of 0.05 was chosen.

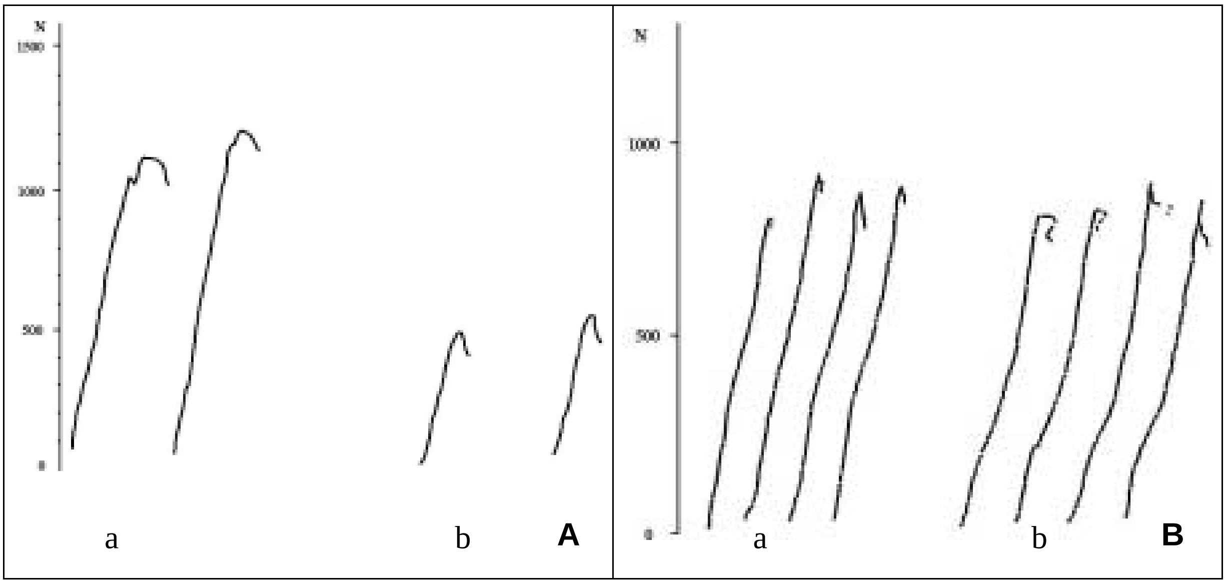

Fig 2. Typical recordings of successful load-controlled tensile tests
A. Load-to-failure curves of right and left cranial cruciate ligaments from the same dog (a) Bouvier de Flandres, 50 kg, breaking load of 1130N and 1210N respectively and (b) Mixed breed, 15 kg, breaking load of 490N and 530N respectively
B. Load-to-failure curves of 4mm double loops (a) and 8mm single loops (b) of the polyester prostheses

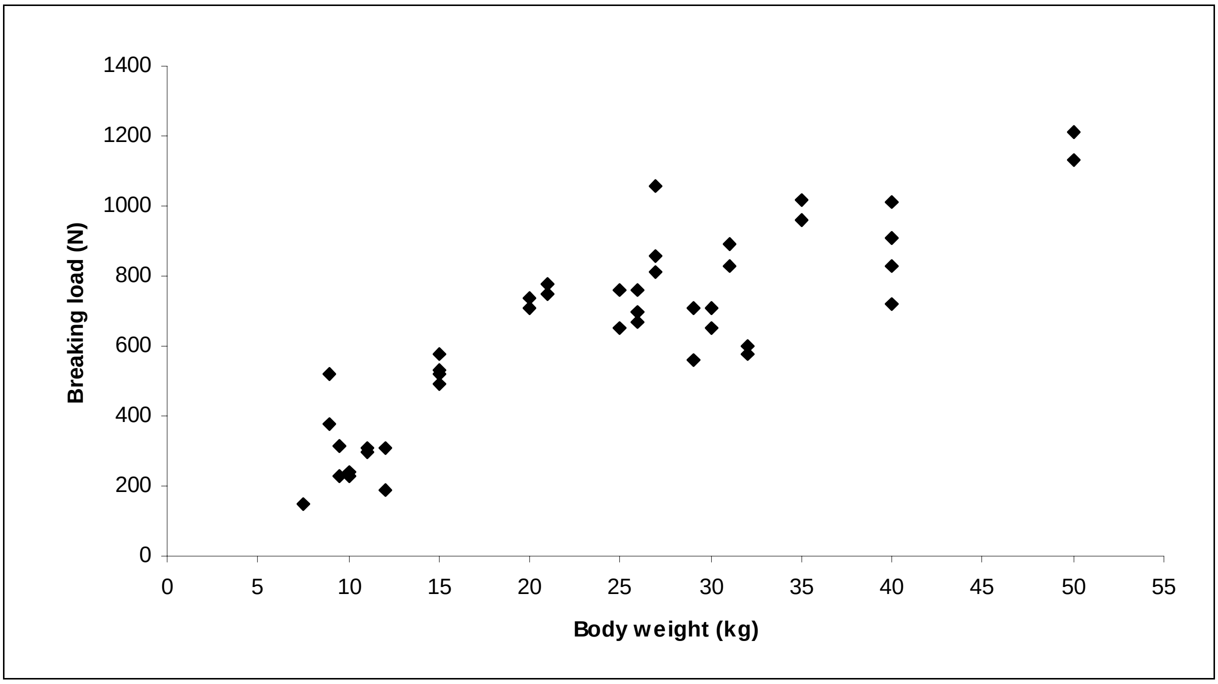

Fig 3. The breaking load of the cranial cruciate ligament of cadaver specimens of various body weights

RESULTS

Cadavera—Typical recordings of successful tests on the left and right CCLs from the same animals are shown in Fig 2 A. The breaking load of the CCL varied from 150 N to 1230 N. A highly significant correlation (r=0.86) was found between the body weight of the donor cadaver and the ultimate breaking strength of the particular CCL, which is also clearly shown in the plotted data (Fig 3).

Statistical comparison showed no difference in breaking load values between both stifles of the same dog. A correlation between lefts and rights as high as 0.95 was calculated.

Polyester— Typical load-to-failure curves are shown in Fig 2 B. In all of the samples, the material failure was situated adjacent to the knot. The mean load at failure for the single loop specimens of 4 mm was 440 N while an average of 860 N was necessary to break the 8 mm tape. Tested as a double strand 870 N and 1580 N respectively were recorded as mean breaking loads for both sizes. Statistical significant differences in the load at failure between the double loops of 4 mm and the single loops of 8 mm width were not observed.

The strain was determined for the single loop knotted materials and amounted to 8.1% and 4.4% for the 4 and 8 mm test specimens respectively. This decrease in plastic deformation with an increasing sample width is statistically significant.

The gross appearance and colour of the polyester tape sterilised by ethylene oxide did not differ from the untreated samples. The mean ultimate breaking value of the sterilised implants was 455 N as compared to 440 N found as average for non-ethylene oxide sterilised specimens. Statistically, there was no significant difference in load at failure. An increase in elongation of the test material was associated with this pretreatment. A mean strain of 11.1% was found after ethylene oxide sterilisation, while only 8.1% was noted for the untreated 4 mm polyester tapes. However, the difference was not statistically significant for the sample sizes used.

DISCUSSION

The ultimate breaking strength of the canine CCL, expressed in kg, under load-controlled tensile testing conditions appeared to approximate 3 times the body weight in dogs of all sizes. Increased body weight was consistently accompagnied by a gradual decrease in the load per kg needed to break the CCL. Others investigators found a factor 4 in dogs weighing 6 to 10 kg.[21] Factors such as age, size, and body constitution may all influence the ultimate strength of the CCL based on the body weight.[23] The results of tested pairs of stifles were consistent with previous studies in which was stated that the mechanical values of right and left sides can be averaged.[6,8,21-23]

Simple load versus elongation curves are also suited for characterisation of synthetic material behaviour during loading. Under constant loading, the polyester prostheses gradually elongated. Failure of individual fibres in the prosthesis at lower than ultimate force levels, prior to complete rupture of the polyester tape was also seen. Including a knot in the test procedure increased the amount of elongation under loading because of the influence of knot tightening.[27] Elongation decreased with an increased width of the polyester tape. The presence of a knot also decreased the ultimate breaking strength of a prosthesis.[28] However, the knotted loops mimicked to a greater extent the clinical use of the ligament. Doubling the width of the polyester prostheses, also doubled the ultimate breaking strength.

Ethylene oxide is a superior gas for sterilisation because of its excellent penetration while causing little to no damage to the material.[29] In a previous clinical study using polyester strands, the prosthesis was pre-operatively woven and sterilised with ethylene oxide.[26] No reference to strength parameters was given. In our tests, ethylene oxide was not found to have any detrimental effect on the appearance nor on the ultimate breaking strength of the polyester tapes. Our preliminary data were recently confirmed in the literature in an article on the mechanical characteristics of extra-articular stabilisation materials.[28] The investigators found no adverse effects on the material characteristics other than a small decrease in stiffness. An increased strain of the gassterilised tested specimens was seen in our studies but could not be proven to be statistically significant.

Based on the ultimate breaking strength data of both the natural CCL and the polyester, a polyester tape of 4 mm width would be a valuable choice for replacing a ruptured CCL in dogs weighing up the 15 kg. An 8 mm tape should be used in heavier dogs.

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[a] Amsler Bodson, Liège, Belgium

[b] Mersilene, distributed by Ethicon Ltd, Belgium

[c] Matachana 118 LG-1, C/Hierro, Barcelona, Spain

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3.2. Displacement-controlled tensile tests

3.2.1. Biomechanical properties of artificial cranial cruciate ligaments

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SUMMARY

In dogs, injury to the cranial cruciate ligament (CCL) is commonly repaired with artificial textile materials. The dynamic mechanical behaviour of this textile product must be similar to the natural CCL of the dog. Therefore, a test method has been developed to analyze the mechanical properties of the CCL substitute in a realistic way. Modulus, elongation and failure properties are assessed for braided polyester of 4- and 7-mm widths and braided polyamide of 4-mm width potential CCL substitutes.

Braided polyester tape loops are strong and superior to polyamide, although not as strong as the original CCL. Nevertheless, the polyester prostheses should easily be able to resist normal weight bearing forces in all sizes of dogs.

Both sizes of polyester tapes also proved to be able to absorb the shock of traumatic overload, even after cycling, when the amount of energy absorbed prior to failure is reduced. They are not able to elongate and recover to the same extent throughout their entire lifetime as the original structure does.

INTRODUCTION

In dogs, rupture of the cranial cruciate ligament (CCL) is an injury frequently sustained by the stifle, resulting in joint instability (Fig 1).[1] Numerous autologous and synthetic materials have been used for surgical reconstruction of the CCL. A prosthesis should be strong enough and not too elastic in order to restore and also maintain stifle joint stability. Although various artificial prostheses have been reported (e.g., stainless steel, monofilament nylon, multifilament polyester), there is little published information on the mechanical properties of the grafts used,[2,3] nor has a sufficient test method to simulate loading in practice been published. Any replacement material should behave, as closely as possible, like the natural ligament in the normal range of loading and should closely resemble the load-deformation characteristics of the original structure during ultimate loading. According to the literature, the average measured strength of the canine CCL *in vitro* is 46 N/kg body weight.[4-6] Physiological loading of the CCL in the dog has been estimated to be 10% to 20% of its ultimate breaking load only.[7] At the time of traumatic injury, these ligaments are subjected to a sudden load that exceeds their ultimate strength. To simulate this condition, tensile tests at a high extension rate have to be used. During walking or trotting, the cruciate ligaments or their substitutes are subjected to a rapid application and removal of force.[7] This situation can be mimicked by cyclic loading experiments between two force levels.

In this paper, we present data on the material properties of 4 and 7 mm braided multifilament non-absorbable polyester suture materials. Both sizes are commonly used clinically for intra-articular stabilization of CCL-deficient stifle joints in dogs. We compare these with braided polyamide because of the great similarity of the braiding structure and size of the material. We test fast load-to-failure, and we have also designed a test method to match the dynamic loading conditions of the CCL of a walking dog as closely as possible. We determine the behavior of the braided polyester prostheses during cyclic loading and the effects of cycling on the failure properties of braided polyester.

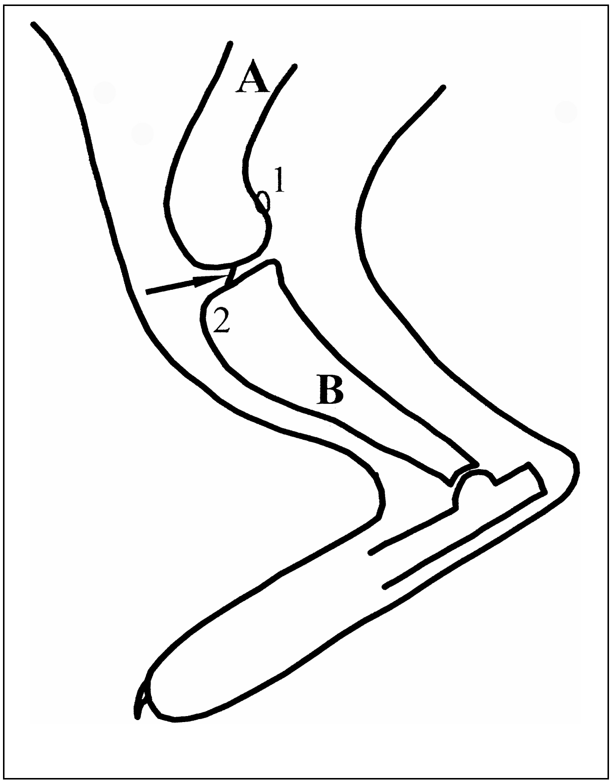

Fig 1. Stifle joint of the dog

Arrow indicates cranial cruciate ligament
A. Upper leg
B. Shinbone
1. Small smooth bony structure around which the CCL substitute is anchored during stabilizing surgery,
2. Tunnel perpendicular to the bony crest through which the CCL substitute is passed during stabilizing surgery

MATERIALS AND METHODS

Our principal author Hilde de Rooster designed special clamping devices to simulate *in vivo* fixation of the CCL substitute, and fabricated proximal and distal clamps to mimic the anatomical anchorage points during stabilizing surgery (Fig 1 and 2).[8] The upper hook consisted of a vertical bar rigidly mounted on a 1000 N loadcell. The lower clamp had a tunnel drilled through a metal bar, oriented perpendicular to the clamp itself and attached to the moving crosshead. The tested prostheses were mounted as loops tied around the upstanding metal device of the upper clamp and through the distal tunnel, the knot being close to the distal anchorage as it would be intra-operatively. A surgical knot was tied and three additional throws were used and tightened securely to square knots, always by the principal author. During surgery, the same knotting is used. Grasping the free ends with needle holders allowed firm tension to be exerted and a tight loop to be formed. The knotted loops had a constant original length of 100 mm.

We used control programs written for the Statimat M tensile tester[a]. A personal computer, working under MS-DOS© was connected to the microprocessor of the displacement-controlled testing machine. Through software programs, appropriate instructions to execute sudden overload and dynamic loading between two force levels could be sent to the Statimat. The data were collected by a built-in load cell and a displacement transducer. Material elongation was zeroed at the lower force limit, since it corresponds to the situation in a moving dog. All tests involved standard climate conditions (65% +/- 2% RH and 20°C +/- 2°C).

We tested flat braided 4 and 7 mm green-dyed tapes made of non-absorbable polyester (polyethylene terephtalate)[b]. For comparison, we also tested 4 mm polyamide[c] blue-dyed tapes.

The study was divided into two major parts. The first section of this investigation characterized the behavior of braided polyester and polyamide in simple load-to-failure tests. To determine the load at failure, the synthetic prostheses were loaded at a constant rate of elongation of 1000%/min until breakage. From the load-displacement data of each set, we obtain structural and material parameters: load at failure (N), strain (%), stiffness (N/mm), energy absorbed to failure (N.mm), and static modulus for the physiologic range of forces (N/mm). To assess the influence of the loading rate on the load-deformation curves, we also tested the polyester prostheses at crosshead velocities of 100, 250, 500, 1000, 2000, 4000, and

8000%/min. Each polyester tape was divided into three equal pieces to minimize the effect of material variability on the deformation rate tests.

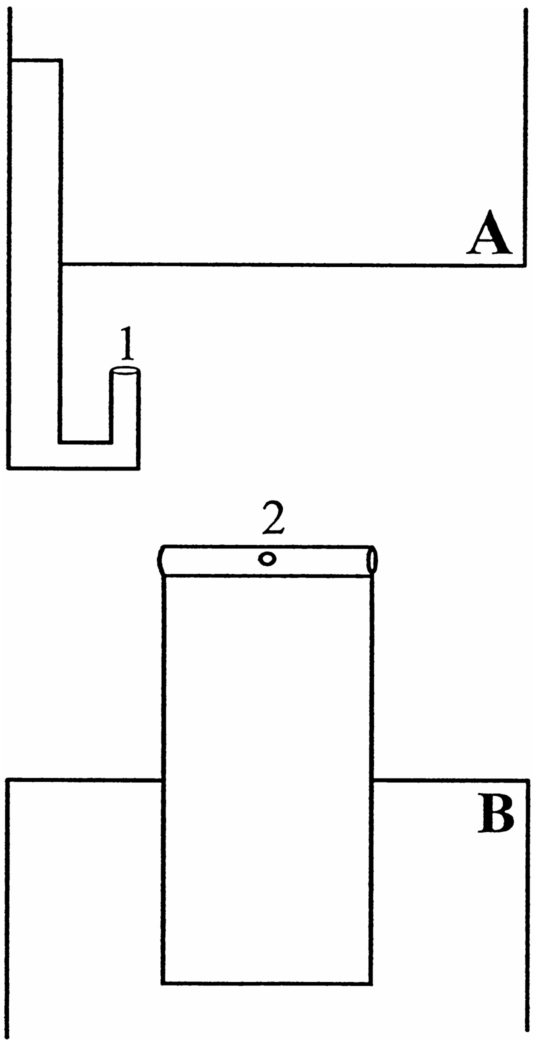

Fig 2. Clamping devices mimicking the bony anchorages in the stifle joint of the dog

A. Upper clamp
B. Lower clamp
1. Round vertical bar around which the CCL substitute is anchored during the loading experiments
2. Tunnel perpendicular to the clamp through which the CCL substitute is passsed during the loading experiments

The second portion of the study investigated the effects of cyclic loading of braided polyester prior to load-to-failure tests to properly reflect biomechanical conditions and abrasion by daily activity. We deduced the test method from previous dynamic loading experiments between two force levels on yarns.[9] Preliminary relaxation studies were set up to determine the resting time between the different cyclic loading sets. The lower and upper force levels were calculated from the weight bearing forces in dogs of about 12 and 25 kg of body weight, respectively.[10] The force limits were thus set at 25 N and 87 N for the 4 mm polyester prostheses, and 42 N and 137 N for the 7 mm tapes. Each polyester tape was cut in half. One strap was repetitively loaded between the two force limits through 25 sets of 2000 cycles at a rate of elongation of 500%/min, representing a dog trotting at 2 Hz.[11] Between each round of 2000 cycles, the synthetic material was allowed to recover for 20 minutes, representing a rest period of the dog. Three loops of each size were tied, cycled, and finally elongated to failure at a rate of 1000%/min. A larger number of experiments was impractical at this stage of the investigations because of the duration of one single test. The other halves of the tapes served as controls and were elongated till break at the same rate without previous cycling.

Analysis of data—Data were analysed using the software package Statistix (Analytical software, Tallahassee, USA), the two-sample t-test or, where appropriate, the paired t-test. Differences were considered significant when $p<0.05$.

RESULTS AND DISCUSSION

Information on biomechanical properties under loading conditions occurring at the time of acute overload are provided in Table 1. The average loads at failure were 302 and 726 N for the 4 and 7 mm polyester tapes, respectively. The 4 mm polyamide tapes were significantly weaker than the 4 mm polyester ($p<0.001$).

Table 1. Simple load-to-failure tests

	4 mm polyamide (n=30)			4 mm polyester (n=30)			7 mm polyester (n=10)		
Parameter	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
Load at failure (N)	266.5‡	13.2	4.95	301.8	16.9	5.61	726.4	37.7	5.19
Elongation (%)									
at 20% of failure force	3.016‡	0.321	10.5	2.022	0.325	16.2	4.359	0.461	10.5
at break	17.100‡	0.724	4.23	14.03	1.09	7.46	20.60	1.66	8.06
Stiffness (N/mm)									
at 50% of ultimate strength	27.368‡	0.871	3.18	21.12	2.58	12.19	33.25	2.94	8.84
Energy to failure (N.mm)	2212	157	7.10	2252	170	7.54	7877	736	9.35
Static modulus (N/mm)	8.830‡	0.380	4.30	15.47	1.49	9.62	20.01	2.26	11.3

Significantly (*$P<0.05$, †$P<0.01$, ‡$P<0.001$) different from value for 4 mm polyester

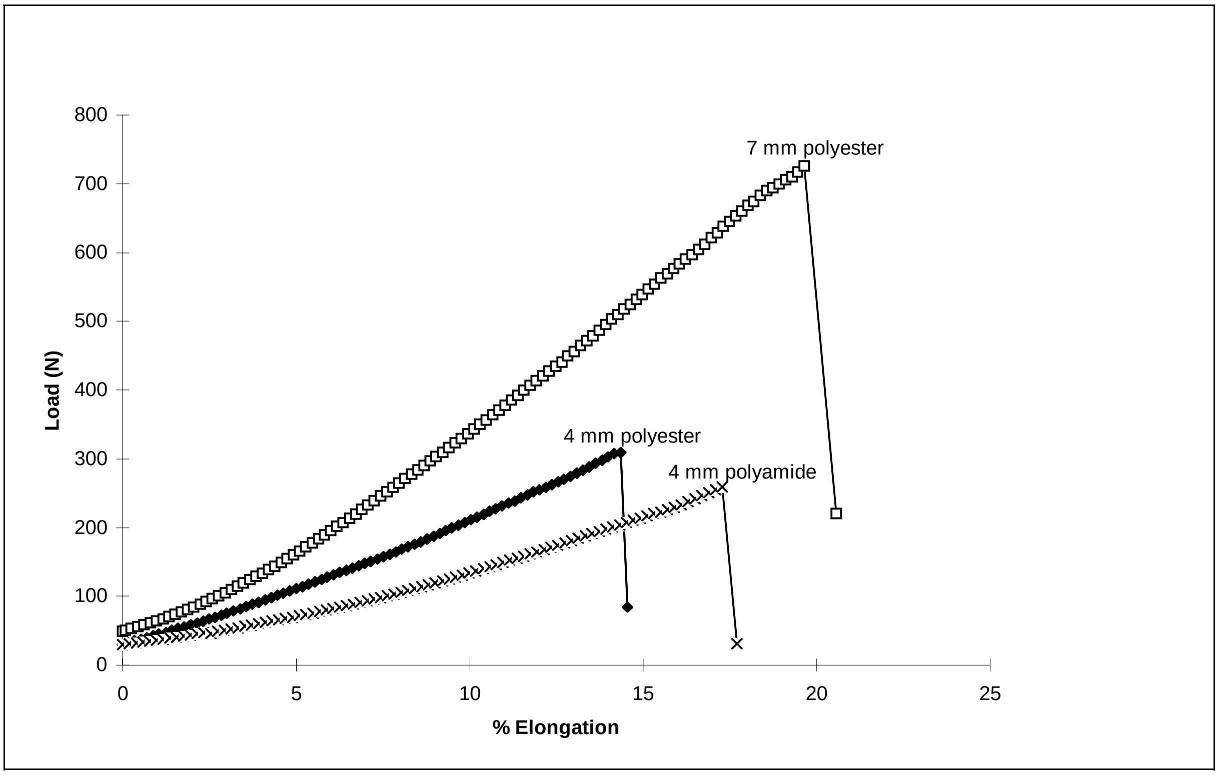

Fig 3. Approximate load-elongation curve of 4 mm and 7 mm polyester tapes and 4 mm polyamide tapes

Typical load behavior curves for the 4 mm polyester, the 7 mm polyester, and the 4 mm polyamide tapes at an extension rate of 1000%/min are plotted in Fig 3. All characteristics of the polyester tapes were superior to the behavior of the polyamide tapes. The initial toe region, under the lower force limits as set for the cyclic loading tests, was not expressed. All curves exhibited a fairly linear pattern up to failure, in contrast with curves obtained with natural ligament specimens, which showed an initial concave and a final convex region.[12] The site of rupture was always located near the knot. We chose a high testing rate for the load-to-failure tests in this study to mimic the loading conditions of acute overload. The extension rates and force limits for the cyclic loading experiments were comparable to those encountered in normal activity. The prostheses were tested in conditions that simulated intra-articular stabilizing surgery. The bony anchorages were mimicked by the design of the clamps, and a surgical knot was tied close to the tunnel of the distal clamp (Fig 2). Including a knot in the test procedure, as would be done intra-operatively, decreases the load at failure for most materials.[3] For technical reasons, the original length of the synthetic loop had to be

100 mm, while the natural CCL in dogs has an average length of only 13.5 to 17.5 mm.[4,13] Testing a longer length of material may result in a decreased ultimate load (weak link theory).

Studying loops provided an evaluation of both the prosthetic material and knot properties. Elongation under loading is a measure of elasticity in combination with knot tightening.[14] The elongation of the material at the lower force level is considered to be the base level for the elongation measurement during the experiments. We measured further length changes relative to this reference point. Elongation prior to this point was completely due to knot tightening. We calculated the strain to failure, expressed as percent elongation since it provides a better expression of real specimen elongation. Strain is the elongation at failure, divided by the mean initial length of the prosthetic loop. Due to the braided nature of the synthetic implants, the composing fibre bundles first stretch in their composition. Braided polyester tapes 7 mm wide elongated to a greater extent than the smaller tape, especially in the first part of the test. Width reduction of the braided material could possibly explain this difference: the 7 mm polyester braids had a higher number of filaments per bundle. The 4 mm braided polyester gave an approximate strain of 14%, whereas the average strain was 21% for the 7 mm tapes. Strain was 17% for the 4 mm braided polyamide tapes, significantly greater than for the 4 mm polyester ($p<0.001$).

The stiffness of the braided polyester tapes only amounted to about 10% of the stiffness in lineair loading described for the real CCL (Table 1).[4] The stiffness at failure of 4 mm polyamide was inferior to the stiffness of 4 mm polyester ($p<0.001$). The 7 mm polyester tapes, being broader, obviously had more resistance to loading than the 4 mm tapes.

In contrast to autografts (biological substitute tissues),[4] the braided synthetic tapes seem to be able to withstand vigorous trauma postoperatively, since they can absorb a great amount of energy up to failure. For the 4 mm polyester as well as the 4 mm polyamide, the energy up to failure amounted to about 2200 N.mm. More than 7000 N.mm of energy could be absorbed by the 7 mm broad polyester implants.

The static modulus indicates the amount of load which is necessary to increase the length of the prosthesis between two force levels. Values were relatively low for both graft widths of the polyester tapes. The modulus for the 4 mm polyamide tape was even smaller ($p<0.001$).

When studying femur-CCL-tibia preparations, the loading rate used during load-to-failure testing significantly influences all failure characteristics.[12] We tested the effect of the extension rate on the load-deformation curve for both 4 and 7 mm braided polyester tapes. The results at 100, 1000, and 8000%/mm are presented in Fig 4.

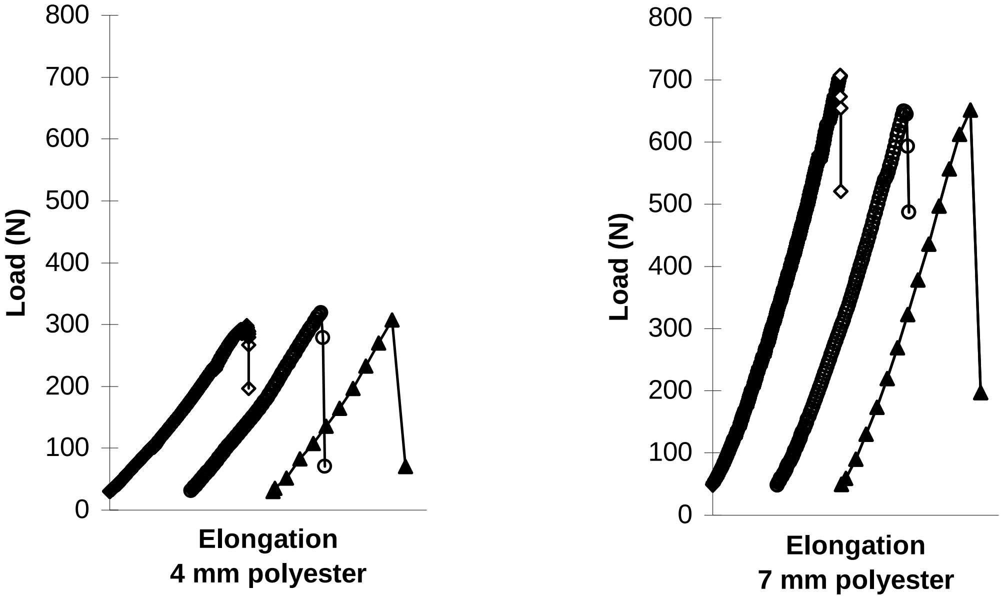

Fig 4. Load-elongation curves of braided polyester tapes at various extension rates (100, 1000, and 8000%/mm)

The curves have been offset on the ordinate in order to differentiate them properly

In our experiments, there was no significant variation of the load-deformation relationship with the various testing velocities for any of the braided polyester tapes tested to failure.

Synthetic tapes implanted as intra-articular CCL-substitutes become immersed in the joint fluid of the stifle. Immersion of the prostheses in physiological saline solution prior to tensile testing did not alter any of the biomechanical characteristics (data not shown).

Cyclic loading—We observed marked differences in the mechanical characteristics of the braided polyester tapes as a result of cyclic loading in the load-to-failure tests (Table 2). Cycling the prosthesis 25 times through 2000 cycles prior to the load-to-failure tests reduced the strength in the 4 mm polyester tapes ($p<0.05$), but we found no significant reduction in ultimate load for the 7 mm tapes.

Table 2. Load-to-failure tests and the effects of cyclic loading

	Precycled			Uncycled		
Parameter	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
4 mm polyester (n=3)						
Load at failure (N)	271.32*	7.71	2.84	317.46	9.64	3.04
Elongation at break (%)	9.470†	0.576	6.02	14.267	0.404	2.80
Stiffness (N/mm)						
at 50% of ultimate strength	44.50*	4.80	10.8	21.560	0.467	2.18
at ultimate strength	28.69†	0.923	3.21	22.251	0.123	0.539
Energy to failure (N.mm)	1586*	113	7.13	2372	142	6.00
Static modulus (N/mm)	34.56†	5.00	14.5	17.13	2.04	11.9
7 mm polyester (n=3)						
Load at failure (N)	663.41	20.2	3.05	678.22	41.45	6.11
Elongation at break (%)	14.400†	0.458	3.19	19.867	0.058	6.20
Stiffness (N/mm)						
at 50% of ultimate strength	54.92†	1.04	1.89	31.86	1.49	4.68
at ultimate strength	46.08*	1.35	2.93	34.13	2.04	5.98
Energy to failure (N.mm)	5707*	185	3.23	6847	112	1.64
Static modulus (N/mm)	55.30‡	1.93	3.49	21.169	0.852	4.01

Significantly (*P<0.05, †P<0.01, ‡P<0.001) different from value for the noncycled tape of the same width

Statistical analysis revealed that, for both widths of polyester tape, the energy absorbed was significantly decreased by precycling ($p<0.05$). At the time of load-to-failure testing, we encountered a relatively smaller increase in elongation of the cycled tapes ($p<0.05$). Typical load-elongation curves for the paired polyester tapes are shown in Fig 5. The two curves show that the changes in mechanical behavior of the synthetic prostheses were affected by the cycling experiment. At the beginning of the curve, there was a steeper slope in precycled baided polyester compared with uncycled polyester.

The stiffness at 50% of the failure force of precycled polyester tape was significantly superior to that of the uncycled material ($p<0.05$ for 4 mm and $p<0.001$ for 7 mm tapes). Also, we found a higher stiffness at the moment of failure (4 mm $p<0.01$, 7 mm $p<0.05$). Due to the cyclic loading, the material behaves more as a monofilament than as a woven material. Where there was no significant change in stiffness from 50% to 100% of the failure load in uncycled ligaments, we found differences for both widths when precycled. The precycled prostheses were significantly stiffer at 50% (paired t-test, $p<0.05$). This difference might be due to the incomplete recovery of the prostheses between the different sets of load cycles and due to contraction of the braided structure.

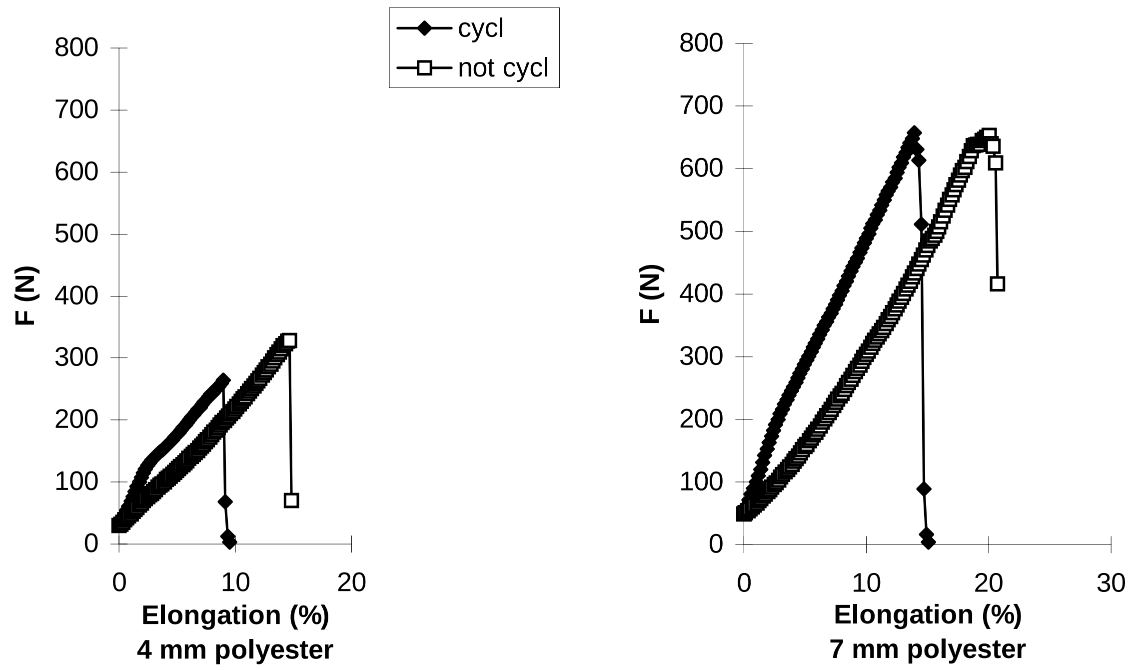

Fig 5. Approximate load-deformation relation of 4 mm and 7 mm polyester tapes tested after precycling and without precycling at a deformation rate of 1000%/min

Deformation at thelower force limit is set at zero

We determined the static modulus from the linear part between the lower and upper force limits of the load elongation curves. We encountered highly significant increases in this modulus after 25 sets of 2000 load cycles (4 mm $p<0.01$; 7 mm $p<0.001$).

In addition, we recorded data on the dynamic modulus and on residual elongation during the successive cyclic loading runs. There was hardly any change in modulus with an increased number of load cycles. As with natural ligaments, synthetic prostheses also exhibit viscoelastic behavior. There was insufficient time for complete length recovery between each cycle, and the implants progressively elongated under repetitive load cycles (Fig 6). A real CCL should be able to completely regain its original length after up to 14% elongation.[13] Residual elongation after dynamic loading is a measure of the permanent elongation when no stress is applied. After the first round of 2000 cycles, we found a residual elongation of 0.282% for the 4 mm braided polyester but only 0.253% for the 7 mm tapes (Fig 6). At the start of the 25th round, the 4 mm material was 0.405% longer than its original; by this time the 7 mm ligament was 0.333% longer.

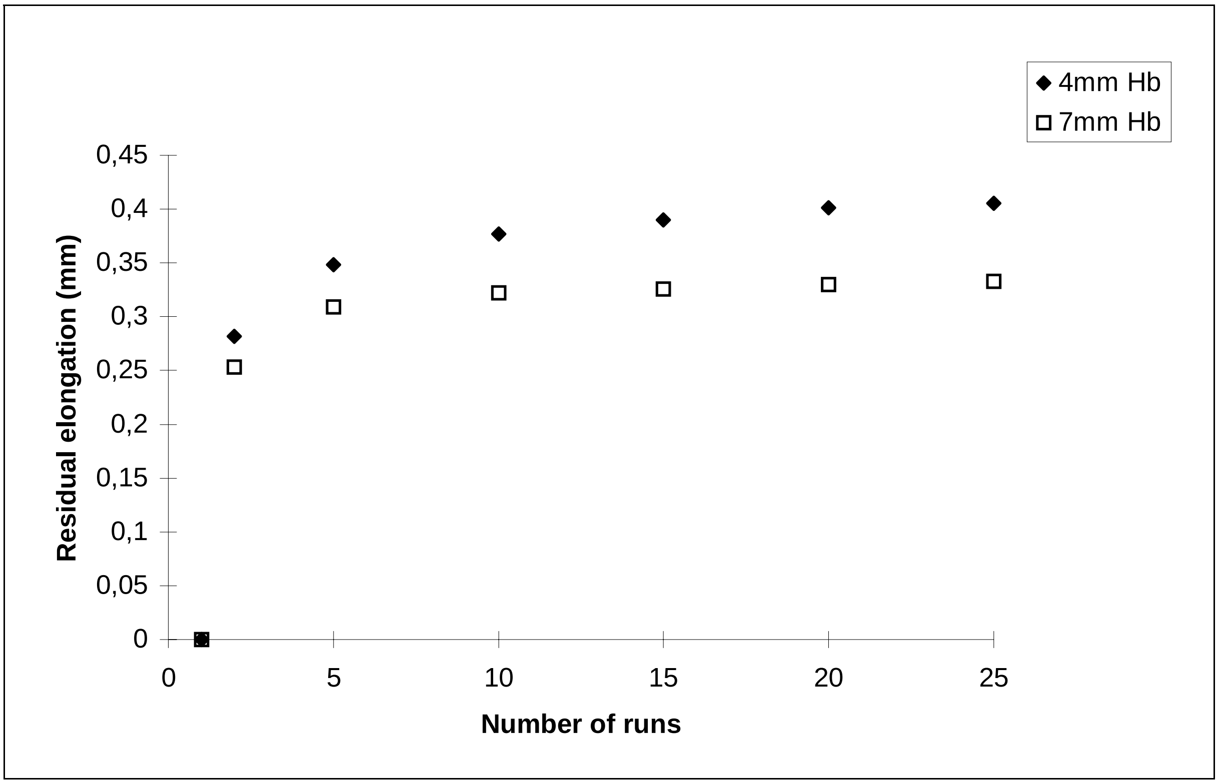

Fig 6. Residual elongation of 4 mm and 7 mm braided polyester after cycling

The *in vitro* material properties of braided polyester meet the mechanical requirements of a CCL prosthesis. Direct extrapolation of these experimental results, nevertheless, is inadvisable. *In vivo* assessment further concentrates on biocompatibility and the clinical efficacy of braided polyester as a CCL substitute in dogs.

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[a] Textechno-Herbert Stein, Germany

[b] Mersilene, distributed by Ethicon Ltd

[c] Distributed by Davies & Geck

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3.2.2. Biomechanical properties of braided polyester tapes intended for use as intra-articular cranial cruciate ligament prostheses in dogs

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SUMMARY

In vitro structural and material properties of braided, multifilament, nonabsorbable polyester tapes, used for intra-articular stabilization of cranial cruciate ligament (CCL)-deficient stifle joints were determined and compared with properties of multifilament polyamide tapes. Thirty polyester tapes (width, 4 mm), 10 polyester tapes (width, 7 mm), and 30 polyamide tapes (width, 4 mm) were tested to failure at 1,000 mm/min. Cyclic loading experiments between physiologic limits of force were also performed, using 3 polyester tapes of each widths.

Ultimate loads and corresponding stiffnesses of the polyester and the polyamide tapes were measured. Failure properties of polyester tapes were affected by previous precycling. Polyester tapes of 4-mm or 7-mm widths should be able to resist forces resulting from weight bearing in dogs, suggesting that these tapes will be effective for stabilization of the stifle joint in dogs with ruptured CCL.

INTRODUCTION

Rupture of the cranial cruciate ligament (CCL) is a common clinical problem in dogs.[1,2] Instability of the stifle joint results in lameness and rapid development of degenerative joint disease (DJD).[3] The major goal of surgical repair of a ruptured CCL is to improve functional performance of the stifle joint.[3] A number of procedures have been developed and evaluated.[4] It is believed that intra-articular implantation of a prosthesis can better mimic the original position and function of the CCL, compared with extracapsular placement of stabilization sutures.[5] Presently, regardless of the surgical procedure performed, consistent restoration of normal stifle joint biomechanics and complete arrest of the progression of DJD is still not possible.[6]

Numerous autografts and synthetic materials have been used for reconstructive surgery of the CCL.[4] In the early 1980’s there was considerable interest in the development and use of synthetic prostheses for repair of human cruciate ligaments.[7] Although surgical management of a ruptured CCL in dogs, using various artificial prostheses, has been reported, there have only been a few reports describing the mechanical behavior of synthetic exra-articular CCL substitutes.[8,9] Any replacement material should behave in a manner similar to the natural ligament in the expected range of loading and should have load-elongation characteristics that closely resemble those of the original ligament during ultimate loading. However, the suitability of a prosthesis does not depend solely on tensile behavior. The recoverable elastic characteristics of the synthetic material are equally important for clinical use. Joint stability can not be guaranteed should the implant become severely elongated and stretched.[4]

Braided polyester sutures are often used in humans where a strong nonabsorbable suture is needed to help permanently repair tissue. The intra-articular use of braided, multifilament, nonabsorbable polyester suture material to repair ruptured CCL in dogs was described in 1986.[10] This technique has been used clinically ever since. The purpose of the study reported here was to determine the *in vitro* structural and material properties of a braided, multifilament, nonabsorbable polyester tape commonly used for intra-articular stabilization of CCL-deficient stifle joints in dogs and compare those with properties of a multifilament polyamide tape.

MATERIALS AND METHODS

Sample population—Thirty 4-mm wide tapes and ten 7-mm wide tapes of a braided, multifilament, nonabsorbable, polyester suture material[a], commonly used as CCL prostheses in dogs, and thirty 4-mm wide tapes of multifilament polyamide material[b] were used to determine structural and material properties in a load-to-failure test. Because of the inferior material properties of polyamide in the simple load-to-failure test, the effects of cyclic loading on structural and material properties were determined, using 3 sets of each width of polyester tapes only.

Experimental protocol—Tests were performed in standard climate conditions (ie, relative humidity, 65 ± 2%; temperature, 20 ± 2 C). Load-to-failure tests were used to simulate traumatic overload conditions, whereas cyclic loading tests mimicked physiologic loading during daily activities.

Behavior of polyester and polyamide tapes in a simple load-to-failure test was characterized by determining the structural variables of stiffness, load, and energy absorbed, and the material properties of static modulus and elongation.

Fig 1. Statimat M tesile tester
A. A personal computer with specialized software programs was connected to the microprocessor of the tensile tester
B. Polyester specimens were mounted in clamping devices mimicking the bony anchorages in the stifle joint of the dog

Tensile tester—Polyester and polyamide tapes were mounted as loops in a tensile tester (Fig 1).[c] A personal computer with specialized software programs was connected to the microprocessor of the tensile tester. Data were collected via a built-in load cell and a displacement transducer.

Special clamping devices were designed by the principal investigator (HdR) to simulate *in vivo* fixation points of a CCL prosthesis; the proximal and distal clamps mimicked the femoral and tibial anchor points, respectively. The upper hook was rigidly mounted on a 1,000-N load cell. The lower clamp was attached to the moving cross head. The direction of loading was along the same orientation as would be used in a clinical setting. To simulate intra-operative conditions, the tapes were tied around the metal devices such that the knot was close to the distal anchor point. One person (HdR) tied all tapes; 4 throws were used and tightened securely as square knots. The knotted tapes had a constant original length of 100 mm.

The standard available computer programs for dynamic loading and relaxation did not meet the requirements for this study. Therefore, new software programs were written to set interclamp distance, lower and upper force limits, and rate of extension for both load-to-failure and cyclic loading tests. Data were translated and stored in files on the personal computer connected to the tensile tester. To determine increases in length of the synthetic tapes, direct calculations were made from the displacement of the clamps. Material elongation was zeroed at the lower force limit. Data were written to a file, and test results were further analyzed, using commercially available software[d] on a remote computer.

Load-to-failure tests—To determine load at material failure, 4-mm wide polyester and polyamide tapes and 7-mm wide polyester tapes were loaded at a constant rate of elongation (1,000 mm/min) until they failed (ie, broke). The fast extension rate was used to more closely approximate loading conditions *in vivo*. Load and displacement data were recorded simultaneously by the testing machine and transferred to a remote computer for analysis. Load versus elongation curves were computed, and the following structural and material variables were obtained: ultimate load, elongation at 20, 50, and 100% of ultimate load, strain, stiffness at 50 and 100% of ultimate load, energy absorbed to failure, and static modulus for the physiologic range of forces.

To assess the influence of loading rate on load versus elongation curves, the polyester tapes were also tested at elongation rates ranging from 100 to 8,000 mm/min. Each polyester tape was divided into 3 equal pieces to minimize the effect of material variability on the elongation versus rate tests. Load versus elongation curves were determined.

Because intra-articular CCL prostheses will be in permanent contact with the synovial fluid of the stifle joint, additional load-to-failure tests were conducted, using 4-mm wide polyester tapes that had been immersed in saline (0.9% NaCl) solution.

Cyclic loading tests—The effects of cyclic loading on 3 tapes of each width of polyester tape were determined in an attempt to reflect biomechanical conditions and abrasions resulting from daily activities. The test method was similar to that used previously to evaluate yarns.[11] The ideal resting time between sets of cyclic loading was determined in a preliminary study. Lower and upper force limits were calculated from the weight bearing forces determined by use of force plate analysis, using dogs weighing approximately 12 and

25 kg, respectively.[12] The force limits were thus set at 25 and 87 N for the 4-mm wide tapes and 42 and 137 N for the 7-mm wide tapes.

Each polyester tape was cut in half. One half was repetitively loaded for 25 sets of 2,000 cycles between the 2 force limits at an elongation rate of 500 mm/min. This extension rate resulted in approximately 2 cycles per second; the hind limb stride frequency in healthy dogs at the trot approaches 2 Hz.[13] Between each set of 2,000 cycles, the synthetic material was allowed to recover for 20 minutes. During each cyclic loading test, residual elongation and the dynamic modulus were determined. A load-to-failure test was performed on each precycled tape at an elongation rate of 1,000 mm/min. For comparison, the other half of the same tape was elongated without cycling at the same rate until it failed. To facilitate comparison of load versus elongation curves, several variables were defined, including ultimate load, elongation at failure, stiffness at 50 and 100% of ultimate load, energy to failure, and static modulus.

Statistical analyses—Data were analyzed, using a commercially available software package.[e] Descriptive statistics were used to test for normality. Structural variables determined in the load-to-failure tests were compared between the 4-mm wide polyester and polyamide tapes by use of nonparametric Kruskal-Wallis rank tests. Differences in stiffness at 50 and 100% of ultimate load were compared among groups by use of a parametric 2-sample t-test. Mechanical data were compared between precycled and noncycled polyester tapes by use of paired t-tests. Differences were considered significant when $P < 0.05$.

RESULTS

Load at failure—Ultimate load (ie, the force acting on the tested material at the moment of failure) and maximal linear load to failure (ie, to first sign of rupture) were not significantly different among any of the synthetic materials. At the moment of failure, the synthetic material most often immediately and almost completely ruptured. Mean (± SD) ultimate loads were 301.78 ± 16.92 N and 726.40 ± 37.74 N for the 4-mm and 7-mm wide polyester tapes, respectively. The 4-mm wide polyamide tape was significantly ($P < 0.001$) weaker than the 4-mm wide polyester tape (Table 1).

Table 1. *In vitro* biomechanical properties of synthetic materials intended for use as cranial cruciate ligament prostheses in dogs

Property	4-mm wide polyamide tape (n=30)	4-mm wide polyester tape (n=30)	7-mm wide polyester tape (n=10)
Ultimate load (N)	266.48 +/- 13.19‡	301.78 +/- 16.92	726.40 +/- 37.74
Elongation♠ (mm)			
at 20% of ultimate load	3.02 +/- 0.32‡	2.02 +/- 0.32	4.36 +/- 0.46
at 50% of ultimate load	9.73 +/- 0.58‡	7.22 +/- 0.77	10.82 +/- 1.07
at 100% of ultimate load	17.10 +/- 0.72‡	14.03 +/- 1.05	20.60 +/- 1.66
Stiffness (N/mm)			
at 50% of ultimate load	27.37 +/- 0.87‡	21.12 +/- 2.57	33.25 +/- 2.94
at 100% of ultimate load	15.57 +/- 0.49‡	21.63 +/- 2.19	34.85 +/- 2.66

♠Increase in length of tape from length at lower force limit

Significantly (*P<0.05, †P<0.01, ‡P<0.001) different from value for 4-mm wide polyester tape

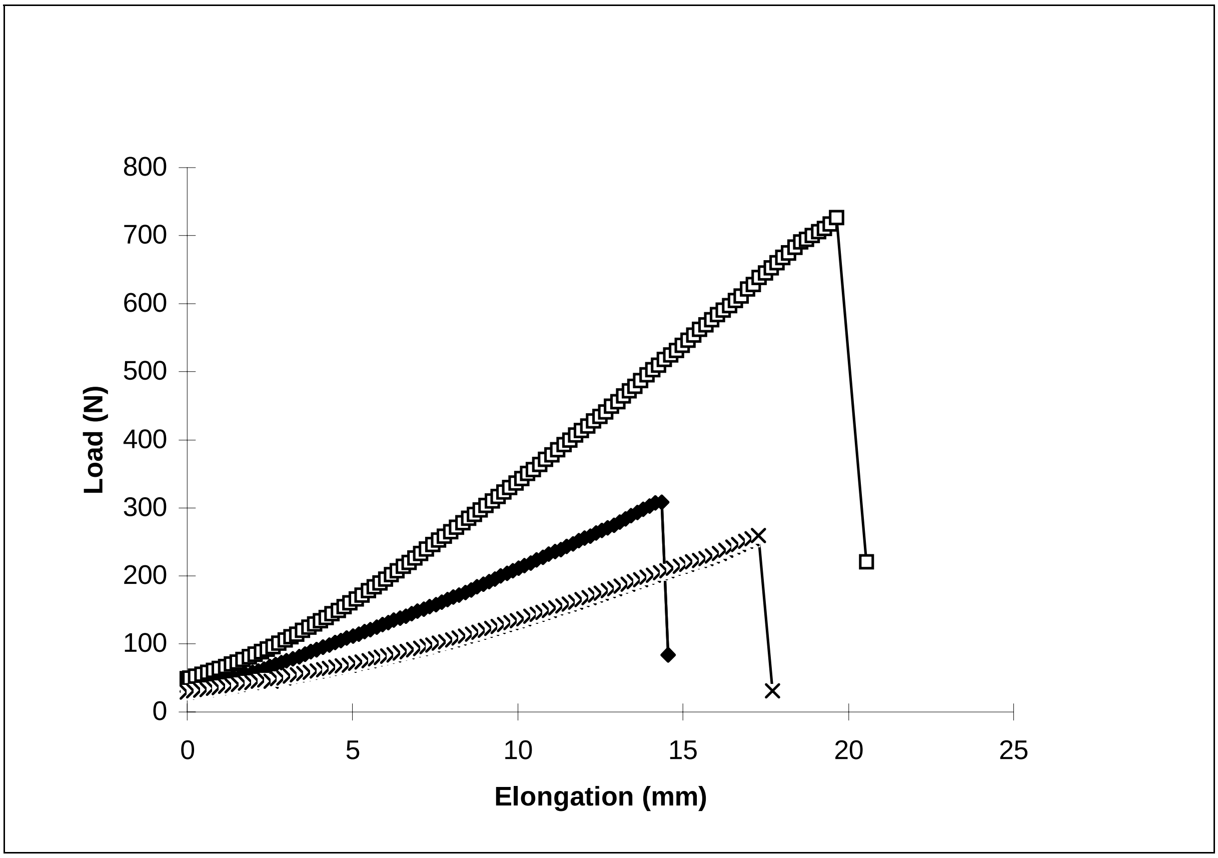

Fig 2. Representative load versus elongation curves obtained during load-to-failure testing of 4-mm wide polyestre tapes (♦), 7-mm wide polyester tapes ( ), and 4-mm wide polyamide tapes (x)

All relations between load and elongation during loading were expressed by the load versus elongation curves (Fig 2). The initial toe region, which was not present in all curves, was not expressed. In that area, extension occurred with only a slight increase in load. All curves had a fairly linear pattern until failure. Only one mode of failure was observed during the load-to-failure tests, and the site of rupture was always located near the knot.

During load-to-failure tests, elongation was defined as the increase in length at any moment during the test. Elongation of the material at the lower force limit was considered the baseline elongation measurement. Change in length was measured relative to this reference point. Elongation prior to this point was attributable to knot tightening. At failure, mean elongation of the 4-mm polyester tape was 14.03 ± 1.05 mm, whereas elongation of the 7-mm wide tape was 20.60 ± 1.66 mm. Mean elongation at failure was significantly ($P < 0.001$) greater for the 4-mm wide polyamide tape, compared with the 4-mm polyester tape (Table 1). Elongation at 20 and 50% of the ultimate load accounted for 14 and 51% of the ultimate elongation of the 4-mm wide polyester tape, 21 and 52% of the elongation of the 7-mm wide polyester tape, and 17 and 57% of the elongation of the 4-mm wide polyamide tape.

To provide a better expression of real specimen elongation, strain to ultimate load was calculated and expressed as a percentage of elongation (ie, elongation at failure divided by mean initial length of the synthetic tape). The mean strain to ultimate load was 14.03 ± 1.05% for the 4-mm wide polyester tape, 20.60 ± 1.66% for the 7-mm wide polyester tape, and 17.10 ± 0.72% for the 4-mm wide polyamide tape. Strain was significantly ($P < 0.001$) greater for the 4-mm wide polyamide tape, compared with the 4-mm wide polyester tape.

Mean stiffness, which characterizes the rigidity of the material, at 50% of ultimate load was 21.12 ± 2.57 N/mm and 33.25 ± 2.94 N/mm for the 4- and 7-mm wide polyester tapes, respectively. The 4-mm wide polyamide tape was significantly ($P < 0.001$) stiffer at 50% of the ultimate load than the 4-mm wide polyester tape (Table 1). Stiffness of either width of polyester tape at 100% of ultimate load was not significantly different from stiffness at 50% of ultimate load. Both polyester tapes resisted loading in a similar manner throughout the entire test, as indicated by the linear pattern of the load versus elongation curves. In contrast, stiffness of the 4-mm wide polyamide tape at 100% of ultimate load was significantly ($P < 0.001$) decreased, compared with its stiffness at 50% of ultimate load. Mean stiffness at failure of the 4-mm wide polyester tape was significantly ($P < 0.001$) greater than that of the polyamide tape.

The amount of energy required to rupture the tested materials was represented by the area under the load versus elongation curves. For the 4- and 7-mm wide polyester tapes, mean energy to failure was 2,252 ± 170 N.mm and 7,877 ± 736 N.mm, respectively. Energy to failure of the 4-mm wide polyamide tape (2,212 ± 157 N.mm) was not significantly different, compared with the 4-mm wide polyester tape.

The modulus was also determined as the ratio of increase in force to the corresponding increase in length. The static modulus between the lower and upper force limits was 15.47 ± 1.48 N/mm and 20.01 ±2.26 N/mm for the 4- and 7-mm wide polyester tapes, respectively. The static modulus of the 4-mm wide polyamide tape (8.83 ± 0.38 N/mm) was significantly ($P < 0.001$) less, compared with the 4-mm wide polyester tape.

Effects of extension rate on elastic and failure characteristics were determined for both widths of polyester tape. The lower force limits (25 and 42 N for the 4- and 7-mm wide tapes, respectively) were chosen as the first Y-value recorded. Extension rate did not significantly affect load versus elongation relationships. Immersion of the polyester tapes in saline solution prior to tensile testing also did not significantly alter any biomechanical characteristic measured.

Effects of cyclic loading—Pronounced differences were detected in the mechanical characteristics of the braided polyester tape as a result of cyclic loading (Table 2). Cyclic loading significantly reduced the strength of the 4-mm wide tape. However, no significant reduction in ultimate load was detected for the 7-mm wide tape. For both widths of polyester tape, energy to failure was significantly affected by precycling.

A significant decrease in further elongation at failure was detected for precycled tapes, compared with noncycled tapes. In addition, the load versus elongation curves for precycled and noncycled tapes revealed that the change in mechanical behavior of polyester tape was affected by cyclic loading (Fig 3). The initial slope of the curve for precycled tape was steeper, compared with noncycled tape. Stiffness at 50 and 100% of ultimate load for both widths of precycled tape was significantly greater, compared with noncycled tape (Table 2). Moreover, for both widths of precycled tapes, stiffness at 50% of ultimate load was significantly greater than that at 100%. Differences in stiffness were not detected for noncycled tapes.

The static modulus was determined from the linear part of the load versus elongation curves between the lower and upper force limits. Significant increases in this modulus were detected for both widths of tape after 25 sets of 2,000 cycles (Table 2). In addition, dynamic modulus and residual elongation data were recorded during the successive sets of cyclic loading. Dynamic modulus did not significantly change as the number of cycles increased.

Table 2. Effects of precycling on *in vitro* biomechanical properties of synthetic materials intended for use as CCL prostheses in dogs

	4-mm wide polyester tape		7-mm wide polyester tape	
Property	**Precycled♣ (n=3)**	**Uncycled (n=3)**	**Precycled♣ (n=3)**	**Uncycled (n=3)**
Ultimate load (N)	271.32 +/- 7.71*	317.46 +/- 9.64	663.41 +/- 20.25	678.22 +/- 41.45
Elongation♠ (mm)	9.47 +/- 0.57†	14.27 +/- 0.40	14.40 +/- 0.46†	19.87 +/- 0.06
Stiffness (N/mm)				
at 50% of ultimate load	44.50 +/- 4.80*	21.56 +/- 0.47	54.92 +/- 1.04†	31.86 +/- 1.49
at 100% of ultimate load	28.69 +/- 0.92†	22.25 +/- 0.12	46.08 +/- 1.35*	34.13 +/- 2.04
Energy to failure (N.mm)	1586.39 +/- 113.1*	2372.79 +/- 142.3	5707.19 +/- 184.6*	6847.76 +/- 112.1
Static modulus (N/mm)	34.56 +/- 5.00†	17.13 +/- 2.04	55.30 +/- 1.93‡	21.17 +/- 0.85

♣Precycled tapes were subjected to 25 sets of 2000 cycles between the lower and upper force limits (4-mm wide tape, 25 and 87 N; 7-mm wide tape, 42 and 137 N, respectively) before load-to-failure testing

♠Increase in length of tape from length at lower force limit

Significantly (*P<0.05, †P<0.01, ‡P<0.001) different from value for the noncycled tape of the same width

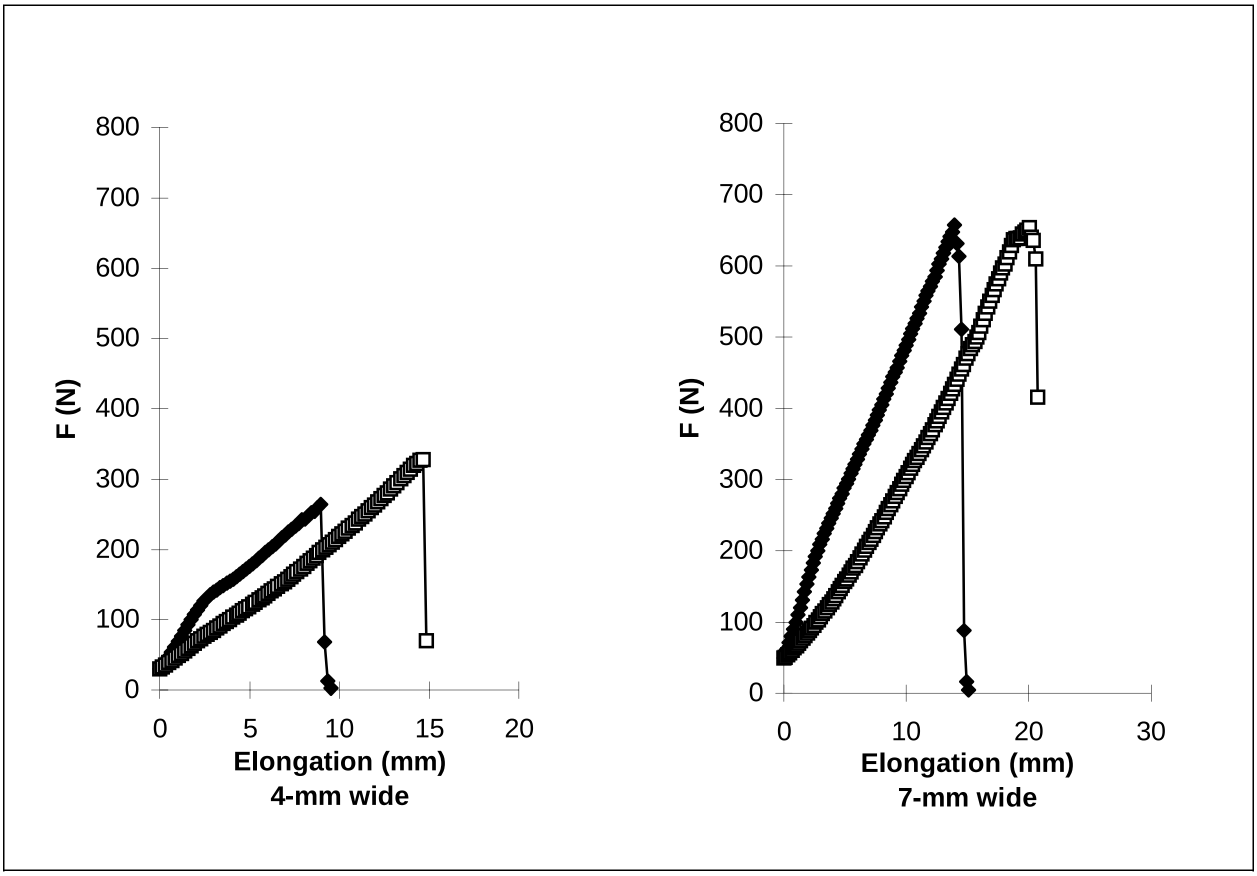

Fig 3. Representative load versus elongation curves obtained during load-to-failure testing of polyester tapes. The tapes were either subjected to cyclic loading (♦) before load-to-failure tests or were tested without prior cyclic loading ( )

Because of the viscoelastic properties of the polyester tape, there was insufficient time for complete recovery of length between cycles. Residual elongation after each cycle thus accumulated, resulting in a gradual increase in length of the tape throughout the experiment. Elongation of the tapes at the lower force limit was set at zero. Further elongation was measured relative to this reference point. Residual elongation after dynamic loading is a measure of the permanent elongation when no stress is applied. After the first set of 2,000 cycles, mean residual elongation of the 4- and 7-mm wide tapes was 0.282 ± 0.07 mm and 0.253 ± 0.03 mm, respectively. At the start of the 25th set, elongation of the 4- and 7-mm wide tapes was 0.405 ± 0.147 mm and 0.333 ± 0.014 mm, respectively.

DISCUSSION

Biomechanically matched prostheses that provide full joint stability after cruciate ligament surgery in humans or dogs are not yet available. The present study focused on the biomechanical properties of a material commonly used for CCL prostheses in dogs. This prosthesis, made of braided, nonabsorbable polyester tape, was compared with a polyamide tape because of the great similarity of the braiding structure and size of the implants. Unfortunately, we could not directly compare the synthetic materials with the CCL from a healthy dog.

Simple load versus elongation curves are particularly well suited for characterization of material behavior during loading. These curves can provide information on biomechanical properties that occur at the time of acute overload. The mean strength of the CCL from dogs, measured *in vitro*, is 46 N/kg of body weight.[14-16] A fast elongation rate was chosen for the load-to-failure tests in our study to mimic the *in vivo* loading conditions of acute overload. To assess synthetic materials intended for use as CCL prostheses, it is imperative to know the forces that the CCL must endure *in vivo*. Under physiological weight-bearing conditions, ligaments from humans are subjected to loads ranging from only 10 to 25% of their ultimate load.[17] Accurate predictions of the functional demands of the CCL in dogs would aid in the search for the ideal prosthesis. However, the structural properties of CCL prostheses do not depend solely on the strength of the material. Results of cyclic loading tests can provide more data on mechanical variables than simple load-to-failure tests. The extension rates and force limits for the cyclic loading experiments in our study were chosen to be comparable with those encountered during normal activity. The loading of a particular limb and the stride frequency can be accurately determined by use of force plate analysis.[12,13] The polyester and polyamide tapes in our study were tested, using *in vitro* conditions that simulated the intra-articular stabilizing technique of Lieben.[10] The bony anchorages were mimicked by the design of the clamps, and a surgical knot was applied close to the distal tunnel.

Load versus elongation curves obtained with natural ligaments reveal an initial concave and a final convex region.[18] In contrast, we found a fairly linear relationship between load and elongation of the polyester tapes. These results suggest that polyester tapes may not be as strong as the CCL during *in vitro* testing, but these tapes should easily be able to resist the forces of weight bearing when used as a prosthesis in dogs. We found that all characteristics of the polyester tapes were superior to those of the polyamide tapes of the same size.

Inclusion of a knot in the test procedure decreases the load at failure for most materials.[9] Additionally, testing a longer length of material will result in a decrease in the final load (weak link theory).[19] For technical reasons, the original length of the synthetic tapes was 100 mm, whereas the CCL in dogs is typically only 13.5- to 17.5-mm long.[16,20] Even when results of tensile loading experiments reveal that a synthetic material has superior strength, compared with the original CCL, there is no guarantee that such strength can be maintained for the rest of a dog's life. As do natural ligaments, synthetic prostheses have viscoelastic properties. However, a prosthesis is not able to elongate and recover to the same extent as the natural ligament. In dogs, the CCL should completely regain its original length following as much as a 14% increase in length.[20] Prostheses also are not able to repair microlesions and are susceptible to abrasion.[7] An inevitable decrease in biomechanical properties will thus occur.

Knot slide did not appear to be a notable problem in this study. By using knotted tapes, we were able to evaluate both the prosthetic material and knot properties. Elongation under loading is a measure of elasticity and knot tightening.[21] During tying of knots, a considerable loss in tension may occur.[8,22] We are not aware of data that describes the correct tension for grafts intended to restore joint stability.

We observed a fairly linear elongation to failure for both widths of polyester tapes. Elongation of the 7-mm wide tape was greater, compared with the 4-mm wide tape, especially during the first part of the test. Macroscopically, both widths are braided with an even number of fiber bundles. The 7-mm wide tapes, however, contain a higher number of filaments within each bundle. Because of the braided nature of the material, the filaments within the fiber bundles first stretch during loading. This effect will initially be more pronounced in the 7-mm wide tape, because its width can be reduced to a greater extent.

Because of the periarticular structures *in vivo*, it is unlikely that this difference in elongation will have any clinical repercussion within the normal range of motion following surgical placement of the prosthesis.

The stiffness of the 100-mm long polyester tape loops only amounted to approximately 10% of the stiffness of a natural CCL.[6] A greater stiffness is expected for shorter loops.[23] The 7-mm wide polyester tape had more resistance to loading than the 4-mm wide tape. A CCL prosthesis should be stiff enough to avoid micromotion that may delay ingrowth of autogenous tissue during the early recovery period.[21] However, complications, such as rapid progression of DJD, are associated with prostheses that are too stiff.[24] The multifilamentous nature of the synthetic tapes may allow or promote ingrowth of autogenous tissue.[25-28] This tissue matures into collagen aligned parallel to the long axis of the prosthesis and will form an adequate neoligament.[26,28] A lack of ingrowth may be related to a chronic inflammatory response.[29] In contrast to autografts,[16,30] we found that the braided polyester tape absorbed a great amount of energy to failure, suggesting that this material may withstand vigorous trauma immediately after surgery.

The static modulus between 2 force limits indicates the amount of load necessary to increase the length of the prosthesis. In the present study, static modulus was low for both widths of polyester tape.

The rate of elongation used during load-to-failure testing of femur-CCL-tibia preparations significantly influences all failure characteristics.[18] However, rate of elongation has no effect on such preparations within the recoverable range of load and elongation.[20] Likewise, we did not detect any effect of elongation rate on the behavior of the polyester tape in the load-to-failure tests.

To properly reflect biomechanical conditions and abrasions resulting from daily activities, a special test procedure was designed in which the lower and upper force limits were load-controlled. During walking, the CCL is subjected to a rapid application and removal of force.[17] With no forces applied, visco-elastic recovery occurs. Cyclic loading between 2 force limits that are within physiologic range is intended to simulate the loading of a limb during normal ambulation. The lower and upper force limits that we used were derived from data on vertical weight-bearing forces in walking dogs that weighed 12 and 25 kg, respectively. The extension rate was representative of the loading conditions to which the stifle joint is subjected in a trotting dog. After cycling, the mechanical response of the polyester tapes was significantly different than that of the noncycled tapes. The 4-mm wide precycled tape failed at a lower ultimate load, but the ultimate strength of the 7-mm wide tape was not affected by precycling. Both widths of polyester tape progressively elongated under repetitive load cycles. Elastic deformations will disappear when the load is removed and when sufficient time is allowed for the material to return to its original length. However, we found that the precycled polyester tapes became permanently elongated; mean elongation of these tapes in the load-to-failure test was less, compared with that of the noncycled tapes. Both widths of precycled polyester tapes absorbed far less energy prior to failure than noncycled tapes. However, precycled tapes were still capable of absorbing the shock of traumatic overload.

A qualification of the data from the present study relates to the number of tapes tested during the cyclic loading experiment. Insufficient numbers of tapes were tested to allow for accurate determination of the dynamic modulus. Testing a larger number of tapes was impractical because of the duration of a single cyclic loading test.

Results of our study provide information on material properties of polyester and polyamide tapes under loading conditions. Direct extrapolation of the results to *in vivo* situations, nevertheless, is inadvisable. *In vivo* assessment is required to determine the biocompatibility and clinical efficacy of the braided polyester tape as CCL prosthesis in dogs.

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[a] Mersilene®, Ethicon Ltd, distributed by Johnson & Johnson Medical bv, Dilbeek, Belgium.

[b] Lacs suspenseurs®, Davis & Geck, distributed by Sherwood Benelux nv, Mechelen, Belgium.

[c] Statimat®, Textechno-Herbert Stein, München Gladbach, Germany.

[d] Excel, Microsoft nv, Brussels, Belgium.

[e] Statistix®, Analytical Software, Tallahassee, FL.

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CHAPTER 4

TREATMENT OF CRANIAL CRUCIATE LIGAMENT RUPTURE IN DOGS USING AN INTRA-ARTICULAR POLYESTER PROSTHESIS

4.1. Retrospective study evaluating patient data and clinical features in dogs affected by cranial cruciate ligament disease

4.2. Intra-articular treatment of cranial cruciate ligament rupture with a polyester prosthesis. Surgical technique

4.3. Intra-articular treatment of cranial cruciate ligament rupture with a polyester prosthesis. Longterm follow-up

4.1. Retrospective study evaluating patient data and clinical features in dogs affected by cranial cruciate ligament disease

SUMMARY

Data of dogs presented with rupture of the cranial cruciate ligament (CCL) may contribute further to a clarification of the etiopathogenesis of canine CCL disease.

Twohundred-twenty dogs (240 joints) surgically treated for CCL rupture were reviewed for patient data and clinical observations.

An overrepresentation with regard to the hospital population was found for the Rottweiler, the Maltese and the Boxer. Two-third of the dogs which sustained CCL rupture were weighing 22 kg or more. Slightly more female than male dogs were presented. The mean age for spontaneous CCL rupture was situated around 5 years of age, small dogs were generally presented at an older age whereas large breed dogs were mostly affected at a younger age.

INTRODUCTION

Cranial cruciate ligament (CCL) injury is a relatively frequent acquired disorder in dogs.[1-9] Traditionally, injury to the CCL in dogs has been classified in a degenerative syndrome in middle-aged to older, small to medium-sized dogs and a traumatic condition in young large breed dogs. Current observations have challenged these traditional views of CCL disease.[10,11] Literature reports of an increased frequency of spontaneous cruciate injury in large breed dogs.[10-12] Patient groups are incontestably interrelated and various causes of CCL damage are not mutually exclusive.

This study is aimed at determining the type of dog affected by cranial cruciate disease and the clinical features through a retrospective study of cases surgically treated for CCL-deficiency at Ghent University Veterinary Hospital during a 5-year period.

MATERIALS AND METHODS

Records of dogs affected by cranial cruciate disease presented to the University of Ghent, Department of Medical Imaging from January 1996 through December 2000 were searched. Diagnosis of CCL rupture was based on orthopaedic examination including specific tests for craniocaudal stifle joint instability (cranial drawer test and tibial compression test), and radiographic findings including tibial compression radiographs. Only dogs with completely filled out records having no concurrent orthopaedic abnormalities at the stifle joint and in which the CCL rupture was documented by direct visualisation during stifle joint arthrotomy were considered for inclusion in the study. Twohundred-twenty dogs (240 stifle joints) met these criteria.

Data from each dog were recorded onto standardised survey sheets. Breed, body weight, body constitution, age at time of hospital admission, gender, and limb affected were reviewed. We could not consistently extract from the data whether the dogs had been neutered. Information obtained from the owner included time elapsed from onset of lameness until diagnosis, evolution of degree of lameness, current medical treatment, and function and activity level of the dog. General and specific clinical features were carefully recorded. Lameness was subjectively scored on a scale of 0 (not detectable at the moment of presentation) to 3 (non-weight bearing). Muscle atrophy, stifle joint effusion, decrease in flexion, pain, and ligamentous instability were assessed and graded on a 3-point scale (0 {normal} to 2 {severe}). Crepitus and the presence of a click on passive manipulation of the stifle joint were recorded as present (1) or absent (0).

Radiographic views from both stifles were evaluated to determine the degree of osteoarthrosis (OA) before surgery and craniocaudal instability. The radiographs were evaluated to determine the degree of degenerative changes on a 4-point scale from 0 (absent) to 3 (extreme), according the criteria of Brünnberg and others (Chapter 2.2., Fig 1).[13] Grade 1 was attributed to those cases with only a small spur on the distal pole of the patella and a small area of irregular bony proliferation on the proximal aspect of the distal femoral articular surface. Also, a minute exosthosis might be seen on the tibial head at the site where the CCL had been inserted. In grade 2 cases, additional bony proliferations are encountered on the proximal margin of the patella, along the ridges of the femoral trochlea, at the periphery of the tibial plateau, and around the fabellae. Radiographic changes were graded as 3 when the above described signs were more pronounced, with areas of irregular bony proliferations along the entire length of the ridges of the femoral trochlea, extensive osteophytes on the tibial plateau and on the fibular head fusing both bones to each other, irregular densities at the groove of the long digital extensor muscle, and fabellae almost completely enveloped in new bone. Each set of radiographs was also screened to evaluate radiographic tibial compression (0 {negative}, 1 {positive} or 2 {suggestive}).

A random sampling of files from the corresponding at-risk population presented to the Department of Medical Imaging, Ghent University Veterinary Hospital during the same period of time was screened for breed and gender.

Statistical Analysis—Patient data were analysed using the statistical software package Statistix 4.1.

Breed prevalence values were calculated by dividing the number of dogs with cruciate deficiency of that particular breed by the total number of individuals of the corresponding breed presented at the Department of Medical Imaging during the same period of time and multiplying by 100. These values were determined for all breeds that were represented by at least five individuals affected by CCL damage. Each of these breed prevalences for CCL rupture were compared with the mean prevalence of rupture for all other breeds in the total population, using Chi-square test for independence at a level of significance of at least 5%.

Relations between background variables and disease features were investigated by Spearman's rank correlation tests (concordance between two non-parametric, ordinal variables such as age, body weight, duration of the clinical signs of lameness) or Chi-square tests (gender), and by Kruskal-Wallis one-way non-parametric analysis of variance (association between variables such as body weight and chronicity and grade of pre-operative OA). The relationships between clinical symptoms and surgical observations were analysed using the non-parametric rank sum two-sample (Mann-Whitney) test for dichotomised variables such as the presence or absence of damage to the medial meniscus and the detection of a click.

RESULTS

During the 5-year period, data on 240 cases of surgically treated CCL rupture were reviewed. Cruciate surgery has been carried out on 114 right and 126 left stifle joints. Complete CCL rupture was diagnosed in 164 cases, partial tearing in 66 stifle joints, and in 10 cases grossly intact CCLs with interstitial tearing were found during surgery. Thirthy-two dogs ruptured their contralateral CCL after surgical repair of the first. Only those dogs which had both cruciate surgeries (20/32) done at Ghent University Veterinary School within the studied period were included twice in this study.

Of the operated dogs, 85 were male and 135 were female (ratio 1:1.6). In the total hospital population of dogs presented during the same period, both genders were rather equally represented (male:female ratio 1:1.1). We found an increased prevalence of CCL rupture in the female dog (Chi-square; $p<0.05$). In the bilaterally affected dogs, 23/32 were bitches.

Fifty-five different breeds were represented in the survey. The Rottweiler was the most commonly affected breed (n=47, 19.6%) with, in decreasing order of frequency: the mixed breed dogs (n=22, 9.2%), the Labrador Retriever (n=20, 8.3%), the Golden Retriever, the Maltese, the Yorkshire terrier (each n=14, 5.8%), the Bernese Mountain dog, the Boxer (both n=11, 4.6%), the Poodle (n=9, 3.7%) and the Bouvier des Flandres (n=5, 2.1%) being the other commonly presented breeds. The risk of CCL rupture was significantly higher compared with the mean prevalence of rupture for all other breeds in the total population in the following breeds only: Boxer (Chi-square; $p<0.05$), and Maltese and Rottweiler (both $p<0.01$). A similar breed distribution was reflected in the bilaterally affected cases, with 25 per cent being Rottweiler. Most dogs were house pets; four dogs were used as show animals where 9 others were working dogs.

The median age at the time of diagnosis of CCL rupture was 5 years (mean 5.2 years, range 0.8 - 12 years). The body weight of patients varied from 2.5 to 72 kg with a mean value of 29.1 kg and a median weight of 30.6 kg. Data on body constitution were recorded in 165 of the 220 dogs with cranial cruciate problems. Fifty-five (33%) were overweight. When the age at presentation and the body weight are plotted against each other, there appeared to be a tendency of heavier dogs to rupture their CCL at an earlier age than most smaller dogs do (Fig 1) (R_s=0.31).

Owners reported in nearly half of the reviewed cases minor trauma such as jumping in or out a car or a sofa as the probable cause of onset of the lameness. In only 7 dogs, high-energy trauma was recorded; none of these developed contralateral CCL rupture during the studied period. Hundred fifty-nine of the 167 dogs in which the activity level prior to the cruciate problems was recorded (95%) were graded to be normally active in daily life by their owners.

Lameness due to the CCL rupture was present for a variable duration before owners seeked veterinary intervention. The mean interval between clinical onset and the moment of diagnosis amounted to just over 10 weeks, although the majority of dogs is presented with a one month-old lameness. The degree of lameness had not changed in 140 (58.4%) of the 240 affected cases. Amelioration of the clinical signs was reported in 26 (10.8%), and in 74 cases (30.8%) the problems got worse over time. A non-weight bearing lameness at the time of presentation was recorded in 34 of the 240 cases (14.1%).

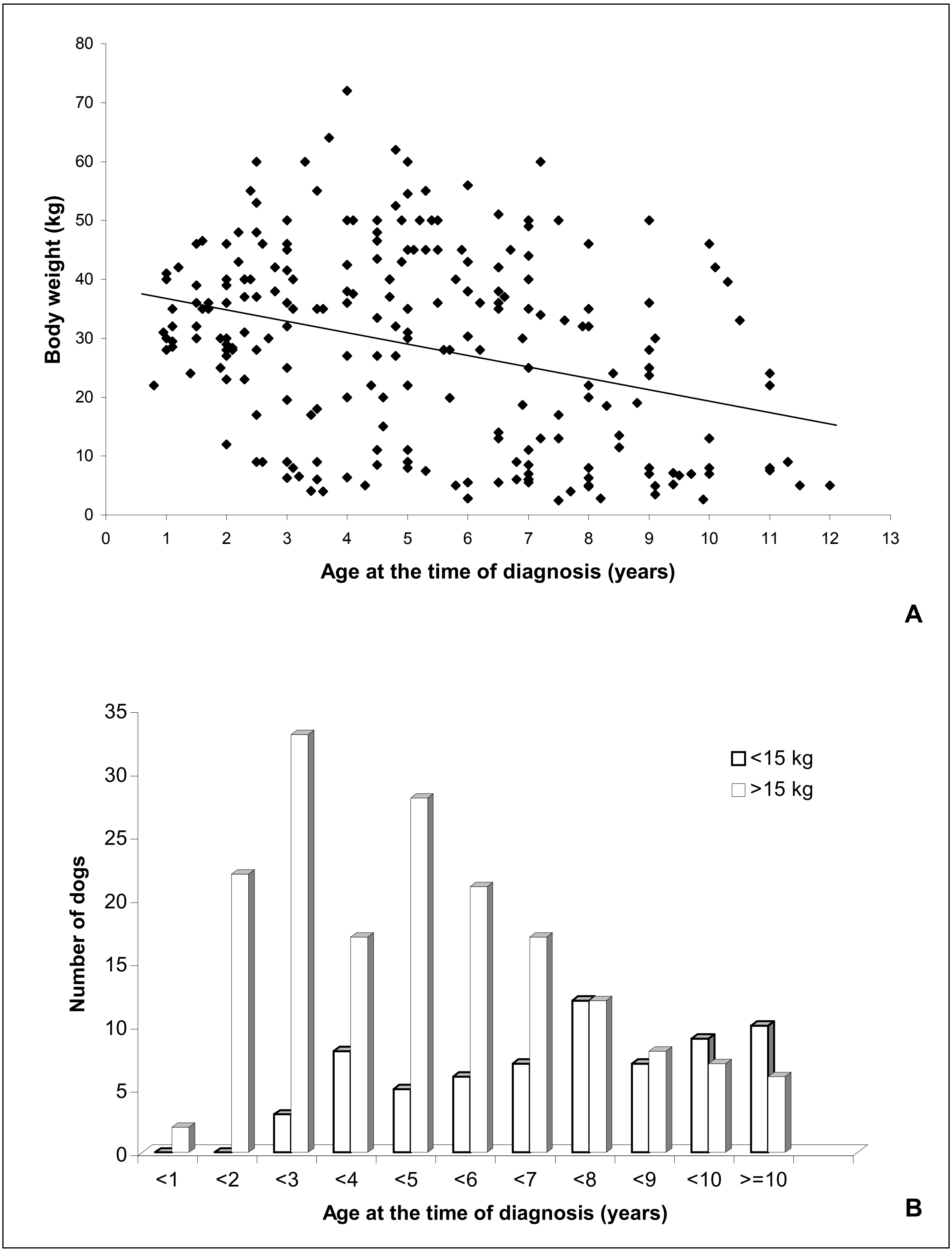

Fig 1. The age at the time of diagnosis of cranial cruciate ligament disease in relation to the body weight of the affected dogs

Joint swelling was appreciated in all but 6 affected stifle joints (97.5%). A normal range of motion was recorded in 168 of the cruciate-deficient stifle joints (70.4%). In all but 36 cases (85%), atrophy of the thigh or crural muscles was appreciated. The degree of muscle atrophy tended to increase as chronicity of the lameness increased (R_s=0.33).

Crepitation was present in 43 affected stifles (17.9%). An audible click or a palpable snap could be produced in 45 of the cruciate-deficient joints (18.7%). In 17 of these cases (37.8%), the click could be permanently detected during passive manipulation. At surgery, medial meniscal damage was found in 15 of these 17 stifles. In the remaining 28 cases (66.2%), the click was inconsistently producable. Intraoperatively, only 19 of those 28 stifles seemed to have a meniscal tear. On the other hand, 84 of the 118 joints (71.2%) showing a meniscal tear at surgery did not produce a click or snap at clinical examination.

Clinically, ligamentous instability could not be tested in the concious patient in 29 cases. Craniocaudal instability during the cranial drawer test and/or the tibial compression test was present in 139 of the 164 cases with complete CCL rupture (84.8%) and in 45 of the 66 partial rupture cases (68.2%). Instability was also appreciated in 4 of the cases with grossly intact CCLs.

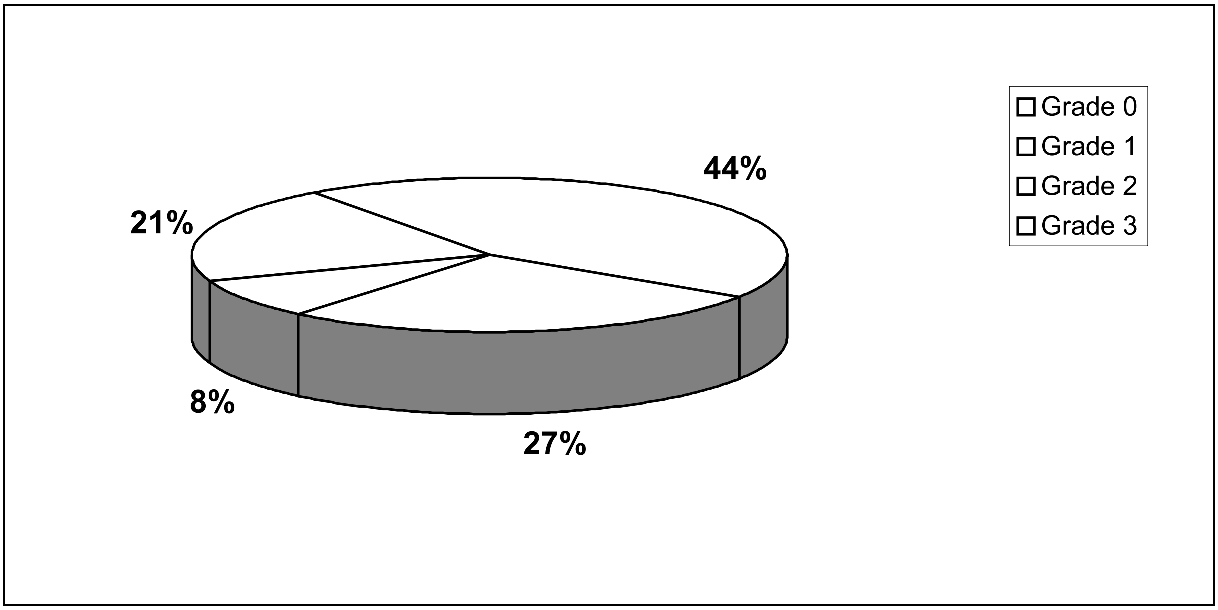

Fig 2. Pre-operative degree of osteoarthritis in cruciate-deficient stifle joints

The grade of OA could not be determined in 2 affected stifle joints, because no pre-operative radiographs were available. Only 49 of the 238 screened stifle joints (20.6%) were radiographically free of arthrosis prior to surgery (Fig 2). There appears to be a tendency of increased radiographic signs of OA when the lameness persisted for a longer period of time (Kruskall-Wallis, $p<0.01$). The grade of OA also seemed to be increasing with increased body weight (Kruskall-Wallis, $p<0.05$). The contralateral stifle joint was not radiographed at the time of initial injury in 9 cases. In 77 of the 231 radiographically screened opposite stifle joints (33.3%) some degree of arthrosis was present. Four joints even showed OA while the affected side was radiographically free of degenerative changes. None of those contralateral stifles had had previous surgery.

Tibial compression stress radiographs were available for 232 of the 240 affected stifle joints (96.7%). A false negative result was obtained in only 4 cruciate-deficient stifle joints, one was a case of interstitial tearing and the 3 others were partial CCL tears. A sensitivity of 98.3 per cent was reached for the radiographic tibial compression test, compared with 89.1 per cent for the clinical instability tests (cranial drawer test and/or tibial compression test). In 22 cases (9.5%), the tibial compression view of the affected stifle was suggestive for craniocaudal instability rather than conclusive. Mostly, imperfect positioning made the comparison of the bony landmarks difficult. During surgery of these cases, interstitial tears were appreciated in 3 cases, 9 had a partial tear while 10 had a complete tear of the CCL. Positive radiographs with an obvious craniocaudal displacement of the proximal tibia under tibial compression stress were obtained in 5 of the 10 cases of interstitial cruciate pathology (50%), in 53 of the 66 stifle joints with partial damage to the CCL (80.3%), and in 148 of the 164 cases of complete tearing (90.2%). Stress views were also routinely taken from the contralateral stifle joints, but in 22 cases they were missing. On 39 of the 218 contralateral stress radiographs (17.9%), positive compression was obtained. Eleven of these cases had an history of previous cruciate ligament surgery, while 16 suffered from an undiagnosed lameness at that stifle. In the remaining 12 cases, no orthopaedic stifle problems were known.

DISCUSSION

Various authors have already reported on populations of dogs that have had CCL rupture in an attempt to evaluate risk factors. Our studied population revealed several results which were most of the time consistent with previously published results.

In several studies on CCL rupture in dogs, females predominate.[12,14-21] In others, a rather equally represention of both genders was found.[9,11] In our sample of dogs with cruciate disease, slightly more (61.4%) females were present. There is also a temptation to suggest that bilateral CCL rupture is more common in female dogs. This overrepresentation was also confirmed when the percentage of contralateral rupture was considered in both gender categories. It is unclear whether this increased incidence is due to true predisposition or rather a coincidence because of the relatively small number of cases preventing accurate assessment. No differences in gender distribution were detected in a group of 42 bilateral cases by Doverspike and colleagues.[22] Data on spaying were not consistently recorded on our sheets. Previous reports indicated increased risk in neutered dogs of both sexes[11,18] or in neutered females only.[16,19,21] The latter group is considered to be more likely to become obese.[23]

Pure traumatic damage to the CCL is an incidental event in dogs.[18,22,24,25] It may occur in any breed at any age. For spontaneous CCL rupture, a difference in clinical frequency is seen in several breeds.[9,11,18,26] It might be questioned whether the breed incidence in the studied groups does not reflect the local popularity of particular breeds rather than indicate a genuine predisposition of the breed to rupture its CCL.[18,27] Our report supports other studies in that the 3 most commonly presented breeds diagnosed with CCL disease were the Rottweiler, the mixed breeds and the Labrador Retriever.[10,11,16,18,28,29] An overrepresentation with regard to our hospital population, however, was only found for the Rottweiler, the Maltese and the Boxer. We are aware of the fact that the breed prevalence based on the hospital population will not be the exactly true breed prevalence for the total dog population. The types of dogs presented to our Veterinary Clinic will somehow be influenced by the activities and specialities of our Department, but no correction factors to avoid this subtle generalisation are available.

Data from this study were similar to other patient data that indicated that the mean age for spontaneous CCL ruptures is situated around 5 years.[6,9,15,19,20,28,30-32] In the studied dogs, the age at the time of rupture seemed to be inversely related to the body weight, also a finding consistent with previously published results. Small dogs are generally much older before they develop cruciate problems.[6,16] In large breed dogs, there appears to be an increasing prevalence at a younger age.[10,11,18] Increased occurrence of CCL rupture is frequently reported in heavier dogs.[9,17] In the population studied here, two-third of the CCL patients which sustained an CCL rupture were weighing 22 kg or more. Only 2 of the dogs with overweight were represented for cruciate surgery at the contralateral stifle joint. It seems therefore unlikely that the higher incidence of CCL rupture found in heavier dogs will be directly related to excessive body weight.

It was not possible to distinguish dogs that had traumatic rupture of the CCL and dogs that suffered spontaneous CCL rupture. Several owners witnessed an acute but minor injury during routine physical activity. The vagueness of clients' histories makes certain distinctions unreliable and owner assessment of the duration of clinical signs is often not very accurate. One third of the dogs with extreme muscle atrophy had a recorded duration of clinical signs of maximum 4 weeks old. Originally, partial rupture of the CCL was considered to be rare in the dog.[33] The last years, diagnosis of partial tearing of the CCL has been increasing.[28,34,35] At the moment of the stabilising surgery, 68.3 per cent of the CCLs in this study were found to be completely ruptured. It is postulated that quite some cases of partial rupture are only presented to the veterinarian once the damage has become already complete.[13] It is therefore impossible to assess the exact number of cases that begun as partial tears and progressed to complete CCL rupture prior to presentation.

During passive manipulation of cruciate-deficient stifle joints, an audible click or a palpable snap can sometimes be produced in cases of concurrent meniscal damage. Not all clicks or snaps, however, mean a torn meniscus. They may be due to obvious femorotibial instability alone,[36] or to impingement of a cruciate stump.[37] Sometimes, there is confusion with crepitus from osteophytes or soft tissue.[37]

In the vast majority of cruciate-deficient stifles, radiographic signs of DJD are already present at the time of presentation. The OA changes often appear more advanced than could be directly related to the duration of the lameness. On the other hand, cases of partial tearing of the CCL tend to have more pronounced radiographic signs of DJD. Both findings are in keeping with other reports,[10,26] supporting the view that the problems at the stifle joint level are much older than expected from the history of lameness.

Tibial compression radiography is routinely performed to confirm the clinical diagnosis of CCL rupture in our canine patients and has a very high sensitivity irrespective the degree of cruciate damage. The specificity of the tibial compression stress radiographic test could not be deduced from the results of the contralateral stifle joints in the clinically affected dogs of the present study because bilateral cruciate problems are not uncommon. In an earlier study, however, the calculated specificity of the radiographic tibial compression test was 100 per cent.[38]

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4.2. Intra-articular treatment of cranial cruciate ligament rupture with a polyester prosthesis. Surgical technique

SUMMARY

An intra-articular treatment of cranial cruciate ligament (CCL) rupture using a polyester prosthesis is described. The graft is inserted behind the lateral fabella, guided through the centre of the joint lateral to the caudal cruciate ligament (CaCL), and pulled from medial to lateral through an horizontal bone tunnel in the tibial crest. The proximal part is passed underneath the tendon of the long digital extensor muscle. The polyester loop is tensioned by knotting.

INTRODUCTION

Methods for surgical stabilisation of the cranial cruciate ligament (CCL)-deficient stifle joint are very numerous. The purpose of CCL reconstruction is to restore stability and prevent further deterioration of the stifle joint. Autografts or synthetic prostheses can be applied to substitute the torn CCL.[1,2]

There has been recent interest in the use of prosthetic materials that promote fibrous tissue development and recolonisation.[3-7] Polyester fibre seems superior to carbon fibre as a scaffold for neo-ligamentous structures.[6,8] Several polyester implants have been used experimentally and clinically in animals and men. In 1986, Lieben published on an intra-articular stabilisation using a polyester tape after rupture of the CCL in dogs.[9]

A modification of the latter technique as it is routinely used at Ghent University Veterinary School is described.

MATERIALS AND METHODS

Material—The prostheses are flat braided green dyed tapes, made of nonabsorbable polyester (polyethylene terephtalate)[a]. The tapes have a length of 75 cm and are currently available in widths of 4 mm and 7 mm. The choice of width of the prosthesis depends on the patient's weight and activity level, and is based on the results of mechanical testing of both natural CCL's and polyester tapes as described in Chapter 3.

The patients are dogs presented at Ghent University Veterinary Hospital with CCL disease in which surgery is required. Over 240 dogs of various breeds and ages have been operated so far by intra-articular implantation of a polyester prosthesis into their cruciate-deficient stifle. The results will be reported on later (Chapter 4.3.).

Patient preparation—The dogs are sedated with IM Thalamonal® (0.1ml/kg). Meanwhile, a broad spectrum antibiotic (mostly amoxicilline) is administered. The dogs are further anaesthetised with IV Penthothal®, intubated and maintained on inhalation anaesthesia (halothane, oxygen, and nitrous oxide) throughout the procedure.

The affected limb is clipped from the trochanter major down to the hock, both laterally and medially. The patient is positioned in lateral recumbency with the affected leg uppermost and further prepared for surgery.

Operative technique—A curved parapatellar skin incision is made extending from the lateral condyle of the femur to the tibial tuberosity. The fascia overlying the cranial tibial muscle is incised parallel to the tibial crest. Enough fascia is left on the edge of the bone to receive sutures at closure. The muscle itself is bluntly freed from the crest by means of a periosteal elevator. An horizontal bone tunnel is drilled through the proximal tibial crest. The procedure continues by a standard lateral arthrotomy. Once the joint capsule is incised, the stifle is extended. The patella is luxated medially to expose the centre of the joint. The infrapatellar fat pad might obscure the visualisation. In such cases, a small part might be excised. The stifle is thoroughly explored for torn CCL fibres and possible concurrent tearing of the menisci. Ruptured CCL ends are carefully trimmed away. In cases of partial rupture of the CCL, the remaining bulk is also entirely excised. Pulling the tibia into cranial drawer position facilitates visualisation of the menisci. Drawering motion can be accomplished by placing a small Hohmann retractor[b] in back of the tibia and levering against the nonarticular femoral trochlea. Alternatively, the tibia can be pulled forwards by using a hook[c] which is anchored on the tibia caudal to the straight patellar ligament. Sometimes, it is useful to apply a self-retaining stifle distractor[d] to open up the joint space to inspect the menisci. A partial meniscectomy is performed whenever damage to the meniscus is appreciated. An arthroscopic smiley blade[e] is used to make a partial transverse cut just to the outside of the traumatised area. A curved hemostat is attached to retract the damaged part cranially. The incision is continued longitudinally to further isolated the torn piece.

After cleaning up the joint, a curved graft passer[e] is introduced intracapsularly proximal and medial to the lateral fabella (Fig 1). It is pushed along the caudal border of the femur and through the intercondylar sulcus until the eye of the graft passer emerges cranial and lateral to the CaCL. One side of the polyester tape is pulled through the eye of the graft passer and together they are gently retracted through the joint. The proximal end of the prosthesis is passed under the tendon of insertion of the long digital extensor muscle. Then, it is guided close to the bone, underneath the cranial tibial muscle towards the lateral opening of the tibial bone tunnel. The other end of the tape is pulled medially under the straight patellar ligament towards the medial opening of the tunnel through the tibial crest. A straight graft passer is used to pull this end from medial to lateral where it meets the other end of the prosthesis.

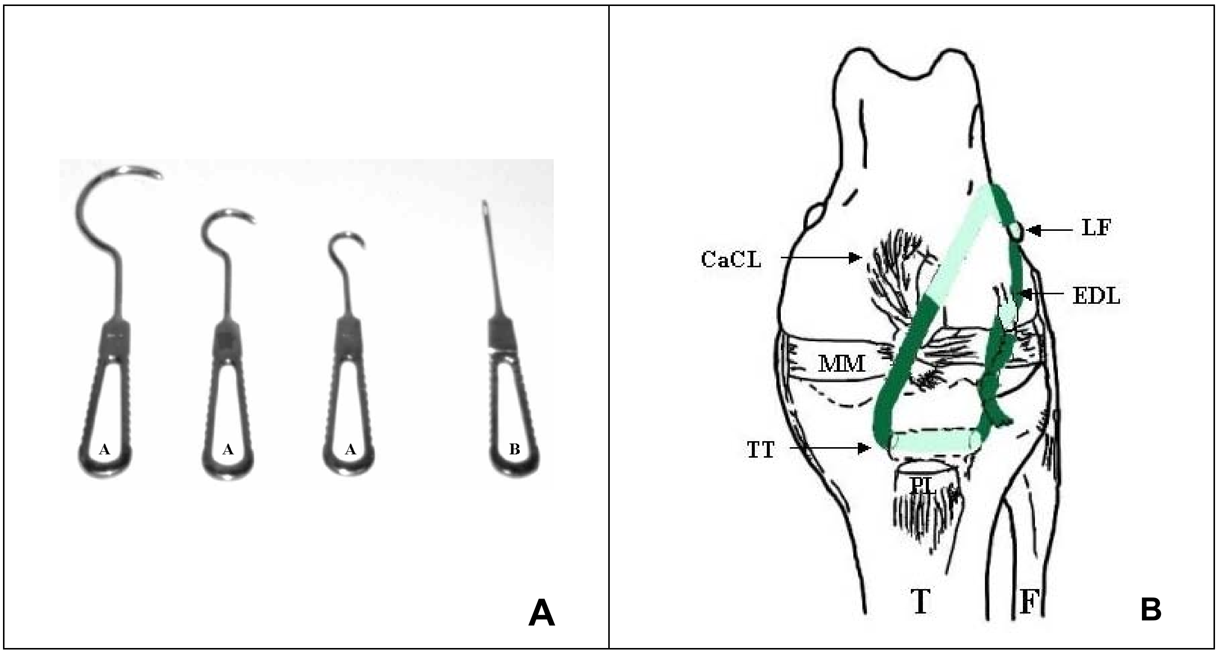

Fig 1. Graftpassers are used intra-operatively to pull the polyester prosthesis through the stifle joint of the cruciate-deficient dog
A. Curved (A) and straight (B) graftpassers
B. Intra-articular position of the prosthesis

CaCL Caudal cruciate ligament, EDL Tendon of the long digital extensor muscle, F Fibula, LF Lateral fabella, MM Medial meniscus, PL Patellar ligament, T Tibia, TT Tibial tubercle

The stifle joint is positioned in the normal standing angle of 140 degrees. Tension is applied on both sides of the prosthesis after which 4 to 5 square knots are made. The ends of the polyester tape are shortened and a Vicryl® suture is placed securing both ends of the tape together to ensure knot security. Without cutting the thread, a deep suture is placed as distally as possible deep to the belly of the cranial tibial muscle. By doing so, the stump is pulled under the muscle belly and any friction with the subcutaneous tissues is avoided. The overlying fascia is sutured in a continuous manner with Vicryl®. The retinacular tissue lateral to the stifle joint is imbricated with mattress sutures in PDS®. IV Temgesic® (0.03ml/kg) is administered before routine closure of the subcutis and skin.

An oral broad spectrum antibiotic is prescribed for the following 5 to 7 days.

DISCUSSION

Intra-articular reconstruction of the CCL by a polyester tape is a practically-oriented technique. The described operation is relatively easy to perform and the equipment required is inexpensive and useful for a variety of other orthopaedic procedures.

There has been a vogue in worldwide use of synthetic prostheses to replace ruptured CCLs in men and dogs.[1,10] Harvesting an autograft to reconstruct a CCL always compromises other anatomical structures, while autogenous CCL replacements under tension generally become weaker before they become stronger.[11-13] In order to reinforce autografts in this vulnerable postoperative phase, different augmentation devices have been developed, but the reported clinical results are variable.[14-17] When synthetic prostheses are inserted to substitute the CCL, no period of vulnerability is encountered, and surgical morbidity is dramatically decreased.[18-20] Synthetic materials are for these reasons considered potentially advantageous in reducing the rehabilitation time. Furthermore, polyester as well as carbon fibres are also claimed to promote fibrous tissue ingrowth in the prostheses, resulting in formation of a new ligamentous structure.[6,21] Although evidence of recolonisation by collagenous fibres can be proved histologically, it has been impossible so far to assess the strength of such neo-ligaments.[7,10]

It is extremely important that human and veterinary surgeons adhere to primary principles of ensuring sterile techniques to avoid introduction of bacteria when synthetic prostheses are implanted intra-articularly. The presence of foreign material makes tissues susceptible to both immediate and delayed infection, and prosthetic devices may act as an avenue for intra-articular spread of infection.[15,22] Even in the absence of infection, the introduction of foreign material in joints is associated with complications such as chronic reactive synovitis and effusions.[10,23-25] Histological examination of the synovial membrane in these cases often reveals areas of macrophage infiltration and foreign body giant cell reactions with engulfed synthetic wear particles.[26,27]

Although the polyester tapes has been used extensively as intra-articular cranial cruciate substitute in dogs, there is up to now scant experimental evidence of the biomechanical properties and the clinical efficacy in stabilising the cruciate-deficient stifle joint in dogs. In Chapter 3, a detailed study is presented on the *in vitro* structural and material properties of the braided, multifilament nonabsorbable polyester tapes. Further in this chapter, the clinical outcome after intra-articular implantation of this polyester in cruciate-deficient canine patients is treated at length.

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[a] Mersilene®, Ethicon Ltd, distributed by Johnson & Johnson Medical bv, Dilbeek, Belgium.

[b] distributed by Synthes-Mathys Medical Benelux, Brussels, Belgium

[c] distributed by Cantaert Medical Surplus bvba, St Denijs-Westrem, Belgium

[d] Wallace, distributed by Eickemeyer, Tuttlingen, Germany

[e] distributed by Endoscopie Richard Wolf Belgium sa, Drongen, Belgium

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4.3. Intra-articular treatment of cranial cruciate ligament rupture with a polyester prosthesis. Longterm follow-up

SUMMARY

Dogs that had intra-articular reconstruction of the cranial cruciate ligament (CCL) with a polyester prosthesis were followed-up at varying intervals. Six weeks after surgery, 64 affected stifle joints were assessed clinically of which 42 could be re-examined 3 to 49 months postoperatively. Clinical and radiographic variables were also assessed in another 33 cases at a longterm follow-up. Radiographic features that were evaluated included osteoarthritic (OA) changes and tibial compression.

The longterm functional outcome of treatment was also assessed by the owners in 65 cases of which 28 could be re-examined 10 to 49 months after the cruciate surgery. The owner-based assessments were compared to the results of the clinical and radiographic examination.

For most assessments made by a veterinary surgeon at 6 weeks and later postoperatively, no temporal profiles could be established. Nearly two-third of the cases showed a positive tibial compression radiograph at the longterm follow-up. No statistical association could be established between postoperative craniocaudal instability, OA changes, or functional use of the operated stifle joint.

The assessments made by owners of the clinical outcome of the intra-articular implantation of polyester do not appear to be accurate and they are not comparable to assessments made by a veterinary surgeon.

INTRODUCTION

Cranial cruciate ligament (CCL) disease is the most common condition to affect the stifle in dogs,[1,2] inevitably leading to osteoarthritis (OA) of the unstable joint.[3] There is a vast amount of literature available discussing CCL-deficiency.

Patient data and clinical features in the population of dogs affected by CCL disease presented to Ghent University Veterinary Hospital from January 1996 through December 2000 have been the subject of an earlier report (Chapter 4.1.).

The treatment of CCL rupture may be conservative or surgical. Fibrosis of the joint capsule and associated structures develops in chronic cases but only partially stabilises the joint.[4-6] Especially in heavier weight dogs, it is advocated to deal with the CCL-deficiency surgically at the earliest possible time following diagnosis to re-establish joint stability.[7-9]

The spectrum of methods for surgical stabilisation is enormous. More recently, several prosthetic ligament substitutions have been evaluated biomechanically. It is postulated that such a synthetic cruciate ligament offers relative advantages such as decreased surgical morbidity and faster rehabilitation.[10-12] The authors have experience with intra-articular implantation of a polyester tape, both experimentally and clinically.

The purpose of this study was to evaluate the functional outcome following stabilisation of the CCL-deficient stifle joint with an intra-articular polyester prosthesis by owner questionnaires, clinical examinations and stress radiography. The relationship between owner-based and veterinary surgeon-based assessments was studied as well as associations and correlations between individual clinical features.

MATERIALS AND METHODS

All dogs involved in this follow-up underwent, at the entry to the study, a full clinical examination including pre-operative radiographs at Ghent University Veterinary Hospital. A neutral and a stress radiographic view were taken from both the affected and the contralateral stifle joint. A polyester prosthesis was implanted intra-articularly in their cruciate-deficient stifle joint. The surgical method has been described previously (Chapter 4.2.). All surgeries were performed by the same orthopaedic staff surgeon in the period from January 1996 through February 2000. Dogs in which joint debridement during a diagnostic arthroscopic procedure delayed the intra-articular replacement of the ruptured CCL were omitted from follow-up study. Patients requiring additional surgical techniques due to concurrent patellar luxation were also discarded for this follow-up. Additional criteria for selection included the absence of concurrent hip problems. Not all dogs fulfilling the selection criteria were available for follow-up. A few dogs had died or were euthanatised for an unrelated problem, while some dog owners could no longer be contacted.

At the time of discharge from the Veterinary Hospital, all owners were requested to return their dogs for clinical examination at 6 weeks and at 3 months postoperatively.

Limb use at walk at the operated limb:
(0) excellent **(1)** good **(2)** fair **(3)** poor

Concurrent lameness at the contralateral limb:
(0) absent **(1)** present **(2)** previous surgery

Muscle atrophy at the operated side:
(0) none **(1)** slight **(2)** moderate **(3)** severe

Joint thickening of the operated stifle:
(0) absent **(1)** moderate effusion **(2)** severe effusion **(3)** peri-articular thickening

Pain on manipulation of the operated stifle:
(0) absent **(1)** moderate **(2)** severe

Decrease in joint flexion of the operated stifle:
(0) absent **(1)** moderate **(2)** severe

Craniocaudal instability of the operated stifle:
(0) absent **(1)** moderate **(2)** severe

Crepitus at the operated side:
(0) absent **(1)** present

Click on passive manipulation of the operated stifle joint:
(0) absent **(1)** present

Fig 1. Type of checklist filled out by the veterinary surgeon at the time of clinical re-examination at 6 weeks and at more than 3 months postoperatively

Lameness at walk at the operated limb:
(0) excellent **(1)** good **(2)** fair **(3)** poor

Lameness at the operated limb after excessive activity:
(0) unchanged **(1)** increased **(2)** not applicable

Stiffness at the operated limb after prolonged rest:
(0) unchanged **(1)** increased

Concurrent lameness at the contralateral limb:
(0) absent **(1)** present **(2)** previous surgery

Activity level as compared to the pre-injury level:
(0) unchanged **(1)** increased **(2)** decreased

Way of holding the operated limb while sitting:
(0) normal **(1)** aside the body

Thigh muscle mass at the operated side as compared to the contralateral side:
(0) similar **(1)** decreased **(2)** increased **(3)** uncertain

Fig 2. Type of questionnaire filled out by the dog owner more than 3 months postoperatively

Six weeks postoperatively—A total of 60 dogs (64 operated stifle joints) were re-presented at 6 weeks. The owners were carefully questioned regarding their dog's postoperative improvement. The period of non-weight bearing on the operated limb was categorised as less than a week, less than 2 weeks, less than 3 weeks or longer. They were questioned on the current limb function, and on the frequency and the type of lameness during daily activities.

All dogs were examined clinically by a veterinary surgeon (Fig 1). Limb use at walk at the operated side was subjectively scored on a scale of 0 (excellent) to 3 (poor). Excellent (0) implied no lameness at all, good (1) no lameness while walking although a slight gait abnormality, fair (2) any degree of intermittent lameness, and poor (3) continuous lameness. The impression of concurrent lameness at the contralateral limb was recorded. Physical examination was always carried out on the conscious dog. The patients were assessed for muscle atrophy on a 3-point scale (0{none} to 2 {severe}) and for stifle joint thickening (joint effusion or soft tissue joint thickening) on a 4-point scale (0{absent}, 1{moderate effusion}, 2{severe effusion}, 3{especially peri-articular thickening}). Attention was given to pain on manipulation, to a possible decrease in stifle joint flexion, and to craniocaudal instability (by the cranial drawer sign and/or tibial compression test in awake dogs), all scored as 0 (absent), 1 (moderate), or 2 (severe). Crepitus and the presence of a click on passive manipulation of the operated stifle joint were recorded as absent (0) or present (1). No radiographs were taken at 6 weeks postoperatively.

Longterm follow-up—Seventy-five dogs were represented at a variable time interval after surgery. Some owners spontaneously brought their dogs for a check-up after more than 3 months, the remaining were invited to do so by telephone.

Each dog was assessed clinically in an identical manner to that described above (Fig 1). Changes in body weight were recorded. Additionally, a standard lateral neutral radiograph and a tibial compression stress radiograph were taken from both stifle joints. The radiographs were evaluated to determine the degree of degenerative changes on a 4-point scale from 0 (absent) to 3 (extreme) according the criteria of Brünnberg and others as described previously (Chapter 2.2., Fig 1).[13] Grade 1 was attributed to those cases with only a small spur on the distal pole of the patella and a small area of irregular bony proliferation on the proximal aspect of the distal femoral articular surface. Also, a minute exostosis might be seen on the tibial head at the site where the CCL had been inserted. In grade 2 cases, additional bony proliferations are encountered on the proximal margin of the patella, along the ridges of the femoral trochlea, at the periphery of the tibial plateau, and around the fabellae. Radiographic changes were graded as 3 when the above described signs were more pronounced, with areas of irregular bony proliferations along the entire length of the ridges of the femoral trochlea, extensive osteophytes on the tibial plateau and on the fibular head fusing both bones to each other, irregular densities at the groove of the long digital extensor muscle, and fabellae almost completely enveloped in new bone. Each set of radiographs was also screened to evaluate radiographic tibial compression (0 {negative}, 1 {positive} or 2 {suggestive}).

All stifle joints were already graded for OA at the time of initial diagnosis of CCL deficiency which was used as a baseline for further evaluation. The same OA-scoring system was applied to the newly taken radiographs at the time of the follow-up evaluation. The evolution of the radiographic OA signs from the pre-operative to the postoperative situation was graded retrospectically on the radiographs as a set, independently from the already contributed OA-scores. In the cruciate-deficient stifle joint, it was determined whether the radiographic signs of OA had increased after surgical stabilisation. The opposite joint was assessed to account for changes that may have been due to age, systemic factors or cruciate disease developing in this limb.

Owner evaluation—Only a few owners spontaneously brougth their dogs for a check-up more than 3 months after the stabilising surgery at the CCL-deficient stifle joint. All other owners were contacted by telephone. At that occasion, they were asked a standard set of questions regarding the progress of their pet since surgery. A number of dogs had died meanwhile or were euthanatised for an unrelated problem. Some dog owners could no longer be reached by phone. An identical reply-paid questionnaire accompanied of a covering letter was sent to all such owners. A total of 65 complete questionnaires were obtained.

The questionnaire was deliberately kept simple and short to encourage response (Fig 2). The answers were multiple choice such that the subjective owner-assessment could somehow be categorised.

The dog owners were asked to grade the current function of the operated limb associated with activities of daily living. Lameness at walk was graded from 0 (excellent) to 3 (poor) as described above. Transient, intermittent lameness associated with exercise or unusual activity as well as stiffness after prolonged periods of rest had to be reported in the next questions. They were also asked whether there was a change in activity level as compared to the pre-injury level and if the dog had developed lameness in the contralateral limb. Further questions addressed the way their dog used to sit (physiologic or with the operated limb in a typical extended position aside the body), appreciable muscle atrophy, and the owner's overall satisfaction with the outcome of the surgical procedure. The change in body weight since the day of surgery was recorded as well.

All owners were re-invited to bring their dogs to the Department of Medical Imaging for a phycical and radiological re-examination. In this way, 28 of dogs had both veterinary and owner follow-up. The interval between owner evaluation and veterinary surgeon evaluation was never more than 2 weeks.

Statistical analysis—All findings were reduced to a numerical value and entered into a computer. The statistical software programme Statistix was used.

Statistical analysis included the Kruskall-Wallis test (one-way non-parametric analysis of variance) for comparisons of groups and the Mann-Whitney U-test (non-parametric 2-sample test for continuous variables). The Chi-square was used for differences in frequencies, using a level of significance of 5%. Scores at 6 weeks were compared to scores at follow-up using the Wilcoxon signed rank test (non-parametric paired test).

RESULTS

Apart from 7 dogs that required removal of the polyester prosthesis several months after implantation, no specific complications of the intra-articular implantation of a polyester prosthesis were seen during the studied period. This failure rate amounts to less than 3 per cent of all cruciate-deficient stifle joints operated on by intra-articular implantation of polyester.

Six weeks postoperatively—Sixty dogs were returned for clinical re-evaluation at 6 weeks after the cruciate surgery. Bilateral cases were assessed as two individual cases. A total of 64 treated stifles was available since 4 dogs were represented 6 weeks after a second surgical intervention because of contralateral CCL rupture.

Most dogs carried the operated limb for about 2 weeks after the surgical intervention. One third returned to weight bearing within the first week after surgery, while 10 per cent carried the leg for more than 3 weeks postoperatively. A period of gradual weight bearing ensued.

Only 14 of the 64 cases had a body weight of less than 15 kg. We were unable to deduce a significant difference in the recovery rate of small versus heavy dogs (Fig 3).

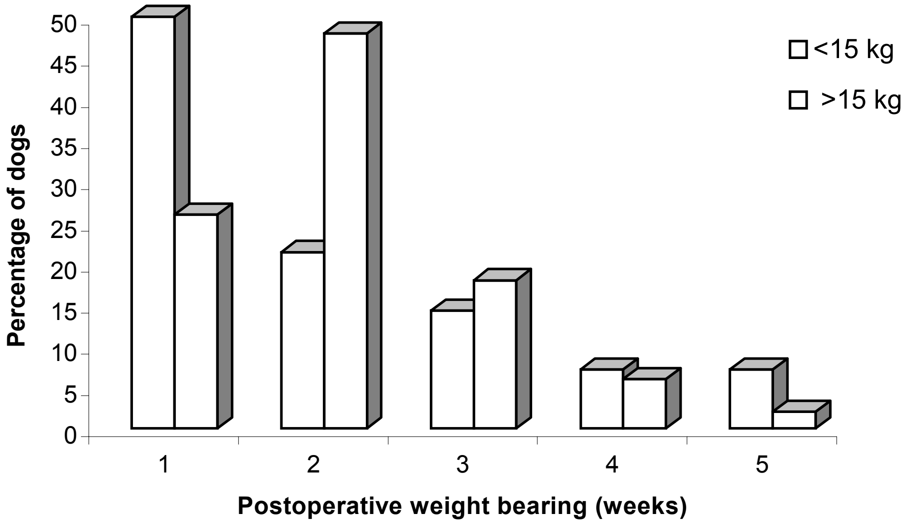

Fig 3. Early postoperative weight bearing in small (<15 kg) versus heavy (>15 kg) dogs

At 6 weeks, half of the cases (32/64) were reported to be still continuously lame during daily activities; in 6 of them, weight bearing on the operated leg was still poor. Nine of the dogs exhibited only infrequent lameness, being exercise-associated in most cases (6/9). Only 2 owners stated that their dogs were completely free of lameness at 6 weeks postoperatively. No relation was found between the reported early postoperative use of the leg and the reported frequency of lameness at 6 weeks postoperatively.

At the day of presentation at Ghent University Veterinary Hospital, 3 dogs did not exhibit any lameness during the examination. Half of the cases (32/64) showed a slight gait abnormality at walk at the recently operated side. Twenty-six dogs were still obviously limping on the operated leg, while the remaining 3 were almost only toe-touching. In 3 cases, lameness was now also detected at the contralateral non-operated side.

Muscle atrophy at the affected side was no longer detectable at 6 weeks postoperatively in 8 of the 64 cases, even though all of them except one had had slight atrophy at the time of cruciate surgery.

All stifle joints were thickened to a variable degree at 6 weeks. In 10 of the 64 stifles, joint enlargement seemed to be due to peri-articular soft tissue rather than due to joint effusion. The range of motion was normal in half of the cases (32/64), flexion was slightly reduced in 28 stifles, and extremely decreased in the remaining 4 joints. Mild pain during passive manipulation of the operated stifle joint was elicited in only 3 of the 64 cases.

Crepitation of the joint was only present in 8 of the 64 joints. A click was felt in 2 of the 64 operated stifles; in both cases the menisci were considered intact at the time of arthrotomy 6 weeks previously. Both dogs were only slightly lame at presentation. One of the two was again represented at 10 months postoperatively, showing a normal gait and no click at manipulation at that time. The other dog was lost for further follow-up.

At 6 weeks after surgery, craniocaudal instability could be elicited in 7 of the 64 surgically treated stifle joints during passive manipulation (cranial drawer and/or tibial compression) in awake dogs. Five of the dogs with passive cranial drawer motion were obviously limping; one other dog was still extremely lame on the operated leg. The remaining dog with stifle instability at 6 weeks only had a slight gait abnormality at presentation.

In 3 of the 7 dogs that required removal of the polyester prosthesis several months after implantation, clinical records of a routine re-evaluation at 6 weeks postoperatively were available. At 6 weeks, all 3 were moderately lame at walk, showing a slight muscle atrophy and only slight joint effusion. No alarming features were encountered at that time.

Longterm follow-up—The longterm postoperative responses for 75 operated stifle joints in 68 dogs were considered. Only 7 dogs were bilaterally included as two individual cases, although bilateral CCL problems were encountered in a total of 24 of the selected dogs in this follow-up (35.3%). In 2 cases, the first cruciate surgery was performed elsewhere and before entry of the dogs to this study. In both, the surgical method and the exact time of that operation could not be recalled by the owners. Their second stifle was stabilised at Ghent University Veterinary School by intra-articular implantation of a polyester prosthesis. During the follow-up period, 22 of the remaining 66 re-examined dogs ruptured the opposite cruciate ligament after repair of the earliest affected stifle joint. The diagnosis of contralateral CCL damage was made clinically and confirmed by a positive tibial compression radiograph in all cases. No relation was found between the postoperative recovery of the first stifle joint and the risk on contralateral CCL rupture. Eight of the bilaterally affected dogs were not subsequently operated on another time, whereas fourteen did undergo a cruciate surgery at the second stifle joint at Ghent University Veterinary School. Ten of them bilaterally received an intra-articular implantation of polyester, but only 7 were represented by their owners for a longterm follow-up after the second cruciate surgery. In the remaining 4 dogs, the first joint was stabilised by an intra-articular polyester prosthesis whereas the contralateral joint was treated by another surgical technique (imbrication). The postoperative follow-up data for the second stifles were obviously not included. The mean interval between the first and the second surgery in the 14 dogs in this study was 8 months (median interval, 7 months).

Twenty-one of the 66 dogs in which bilateral radiographs were made at the time of initial diagnosis of unilateral lameness due to CCL rupture and that did not already had previous cruciate surgery at the opposite joint (31.8%) also showed radiographic evidence of OA in their contralateral stifle joints. Eight of these 21 dogs with bilateral stifle OA (38.1%) were never represented for contralateral CCL damage during the follow-up period. The remaining thirteen (61.9%) did rupture their second CCL within the studied period. In contrast, only 9 of the 45 dogs (20%) with radiographically normal contralateral stifle joints subsequently ruptured their second CCL before conclusion of the study. The difference in frequency of contralateral CCL rupture in patients with and without pre-existing radiographic signs of OA was highly significant (Chi-square test, p<0.001).

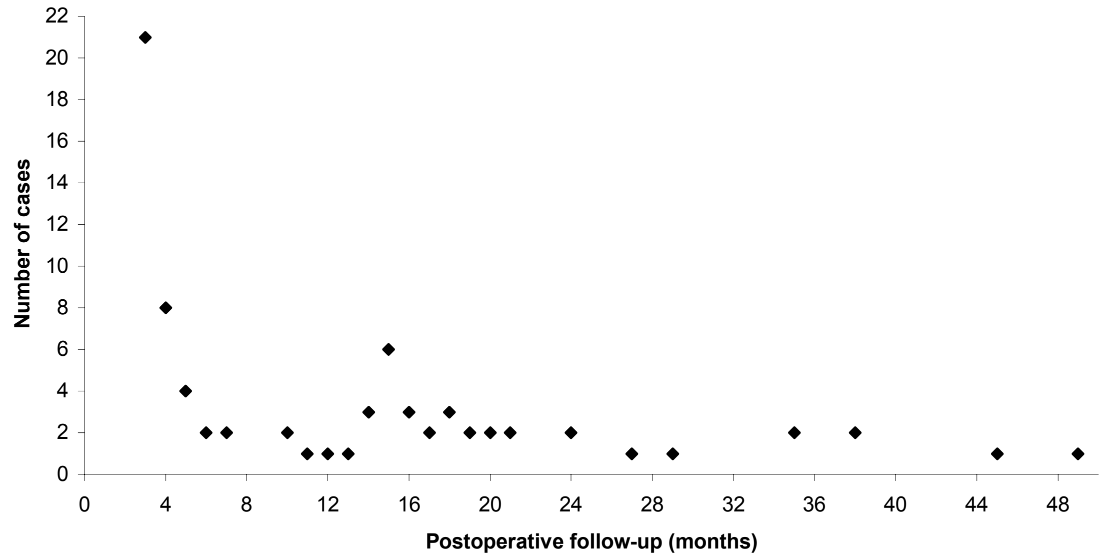

Fig 4. Time interval between surgery and follow-up

The dogs were re-examined at various time intervals after surgery (Fig 4). The cases were classified into 4 groups according to the follow-up length (less than 4 months: n=21, between 4 and 12 months: n=19, between 12 and 24 months: n=25, longer than 24 months: n=10) to determine if postoperative time had an effect on the various re-examination results.

At the time of follow-up, only 17 of the 75 operated legs (22.7%) were completely free of lameness. Another 44 cases (58.7%) showed a slight gait abnormality when walking. Thirteen dogs (17.3%) were limping on the operated side at the time of presentation while 1 (1.3%) was almost only toe-touching. A trend was noted which suggested that the gait of the patients gradually improved by an increase of the time interval between surgery and follow-up. A statistically significant difference was only found between the groups with a follow-up less than a year versus those with a longer follow-up (Kruskall-Wallis, $p<0.05$).

Forty-four of the 75 cases (58.7%) demonstrated some residual muscle atrophy of the affected side as compared to the opposite side. The atrophy was significantly more pronounced in the less than 4 months follow-up group compared to the longer follow-ups (Kruskall-Wallis, $p<0.05$).

Palpation of the operated stifle joints revealed the consistent presence of a firm, pain-free swelling on the medial aspect of the joint in all but 5 cases, and the range of stifle flexion was decreased in 30 of the 75 operated joints (40%). Without sedation, craniocaudal instability could be elicited in 21 of the operated joints (28%). Statistically, there were no differences in occurrence and degree of passive cranial drawer motion between the different follow-up groups.

A click was appreciated during passive manipulation in 2 of the 75 re-examined stifle joints. The first dog had poor limb use although it had been operated on 17 months earlier. At the time of surgery, a partial meniscectomy of the medial meniscus was also performed because of folding of the caudal horn. The second dog was obviously limping at presentation at 3 months postoperatively. The meniscus was considered normal at the moment of implantation of the polyester. The dog was lost for further follow-up.

Neutral and stress radiographs of both stifles were obtained at entry, and at the longterm re-examination. Pre- and postoperative radiographs were assessed for tibial compression and they were independently graded as to the degree of OA present. The evolution of the radiographic signs was graded on the pre- en postoperative radiographs as a set.

Nearly two-thirds of the surgically stabilised stifle joints (47/75) showed a positive tibial compression on the follow-up stress radiograph. It could not be determined statistically that the length of the interval between surgery and re-examination influenced the results of the tibial compression radiograph.

Plain radiographs of the operated stifle at follow-up revealed the following OA grades: grade 1 in 20 joints (26.7%); grade 2 in 37 joints (49.3%); grade 3 in 18 joints (24%). Of the 18 dogs in which a grade 3 degree of osteophyte formation was evident when re-examined postoperatively, 7 (39%) walked normally at the time of follow-up, and 9 (50%) were only slightly lame. The remaining 2 cases with this high degree of OA (11%) were obviously lame at walk.

Surgical treatment did not stop the development of OA in the majority of the cases. In only 9 of the 75 joints (12%), the radiographic signs had not worsened postoperatively. Four of them had the follow-up radiographs already taken as early as 3 months postoperatively. None of the 12 stifle joints which were radiographically free of OA at the time of initial diagnosis were again graded 0 when followed-up, 3 to 21 months postoperatively. Fifty-one cases (68%) worsenend by a score of one, 15 (20%) deteriorated by 2 points. Although the radiographs were taken at varying intervals postoperatively, no statistical difference could be determined in the progression of the OA between the different follow-up groups; nor was there a difference in the progression of OA between the radiographically stable and the tibial compression positive stifle joints.

There were also no statistically significant differences in the scores of OA nor in the progression of the radiographic signs between dogs that underwent meniscectomy and those that did not. Neither a correlation was found between the body weight of the operated dogs and the grade or progression of the postoperative radiographic signs of OA. Also weight loss or weight gain after the surgery did not seem to influence OA, although insufficient data might have been available to statistically determine a possible effect.

Plain radiographs of the 59 contralateral stifle joints without previous surgery at the time of follow-up revealed no OA in 37 cases (62.7 %), grade 1 in 10 (16.9%), grade 2 in 9 (15.3%), and grade 3 in 3 cases (5.1%). The overall incidence of degenerative changes in the operated stifle joints was increased compared to the opposite stifle.

The clinical data of the 7 dogs that required removal of the polyester prosthesis were not included in the longterm follow-up because these dogs were returned by their owners because of a sudden increase in ipsilateral lameness 1 to 14 months after surgery and thus not for a routine follow-up examination.

Three of the dogs all of a sudden developed a severe limp at the operated side, although they had become free of any lameness after the intra-articular implantation of the polyester tape. At the moment of re-operation (6, 7 and 9 months after the original surgical intervention), a broken polyester prosthesis was found in their joints (Fig 5). No foreign body response reactions were found histologically in any of the synovial biopsies.

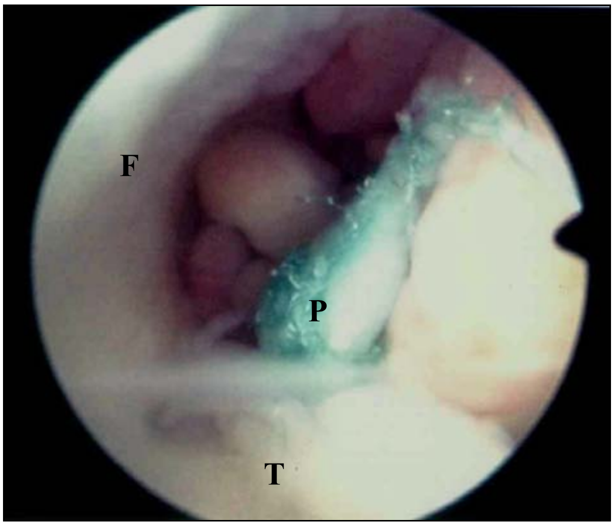

Fig 5. Arthroscopic view of a broken polyester prosthesis 7 months after implantation

F femoral notch
P polyester prosthesis
T tibial plateau

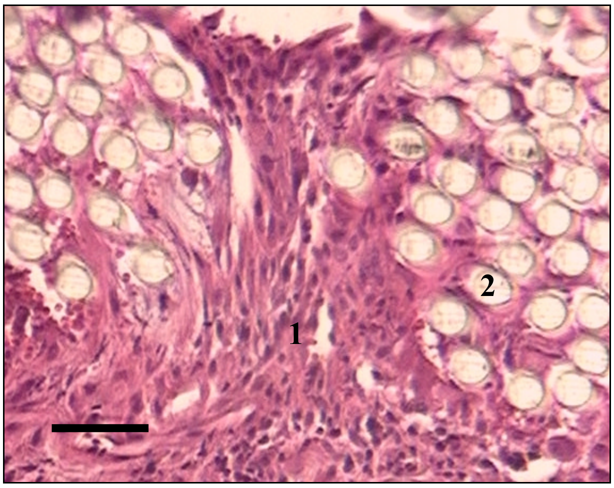

Fig 6. Ingrowth of fibroblasts (**1**) between the fibres (**2**) of the polyester prosthesis in a dog, 7 months after implantation
(H&E stain, bar=50µm)

The remaining 4 dogs became gradually more lame again and all had very swollen affected stifle joints. One dog had a chronic fistulating wound just below the level of the stifle joint at the lateral side 7 months postoperatively. A second dog suffered from a sinus tract at the medial aspect of the stifle which developed 14 months after surgery. At arthrotomy, the polyester prosthesis looked macroscopically intact in both cases. Histological examination of the prosthesis revealed fibroblast ingrowth between the fibers of the polyester in both cases (Fig 6). In the synovia of the first dog, giant cells were sporadically encountered while, in contrast, the biopsies of the second dog did not show any foreign body response. In the last 2 cases represented already at 1 and at 3 months postoperatively, the operated stifle was very painful while the dogs were at the same time systemically ill. Bacteriological culture revealed a pure culture of *Staphylococcus intermedius* in the first case. Unfortunately, no samples were taken in the second dog.

Six weeks versus longterm follow-up—Two-thirds of all cases re-examined at six weeks (a total of 42/64 operated stifle joints in 39/60 dogs) were again presented several months afterwards (range, 3 to 49 months).

Although there was an decrease in the overall scores for muscle atrophy from 6 weeks on, only 18 of the 42 operated limbs (42.9%) regained normal muscle mass by the time of re-examination.

Eight of the 42 affected stifle joints (19%) had a decrease in stifle joint swelling with time. There was an increase in periarticular thickening scores from 6 weeks to several months time points in 32 cases (76.2%) and an increase in joint effusion in the remaining 2 (4.8%). No significant differences in the range of flexion were encountered between both time points of re-examination. Also, no differences were noted for pain on manipulation or crepitus scores over time.

Data for longitudinal change in palpable instability were compared. Thirty-one of the 42 operated stifle joints (73.8%) were found to be stable on manipulation in the concious patient at 6 weeks as well as later on, while 5 cases (11.9%) were clinically unstable at both occasions. A further 2 joints (4.8%) were unstable at 6 weeks after surgery but were free of palpable instability several months later. The 4 remaining stifle joints (9.5%), in contrast, were first found to be stable but showed craniocaudal instability at later re-examination.

Owner evaluation—Completed questionnaires were available from 58 owners (a total of 65 operated stifle joints in 59 dogs), either by telephone or by post. Some of the other dogs were lost to follow-up because meanwhile they were deceased.

The interval between surgery and owner evaluation varied from 7 to 49 months. Owners noticed a vast improvement in the quality of gait of their pets in all but 2 cases in which the clients were dissatisfied with the surgical result.

Lameness was not observed by the owners in 46 of the 65 operated hindlegs (70.8%) during normal activity, although 7 of them were reported to have a mild stiffness on rising after prolonged rest and 9 were observed to be occasionally lame after strenuous exercise. A mild and infrequent limping was encountered in 17 (26.1%) cases and 2 (3.1%) more dogs were continuously lame on the operated stifle joint. The already present lameness was reported to be exacerbated by rest in 6 of the 19 cases and by both rest and exercise in a further 4 cases. Six dogs demonstrated decreased exercise tolerance.

Only 6 owners had the impression that the thigh was smaller at the operated side compared to the opposite leg. Three of these dogs were reported to show a limp during daily activities.

Twenty-six of the operated limbs (40%) were positioned abnormaly when the dog was sitting up. The patients used to hold their affected leg in a straightened position beside their bodies, not able to sit symmetrically in a full squat. In none of the cases, this condition seemed to bother any of them.

Thirty-seven of the 58 contacted clients were unwilling to return their dog for re-evaluation although data could be collected by telephone interview.

Owner versus veterinary surgeon evaluation—In 28 cases, the owner questionnaire was followed by a follow-up visit at the Department of Medical Imaging within the following 2 weeks. Because of the limited number of data, the results of comparisons between owner assessments of outcome and veterinary surgeon assessments could not be studied statistically.

Lameness was not observed by the owner in 10 of the evaluated operated hindlegs and also not in 3 of the opposite legs which, for the veterinary surgeon, clearly showed a mild limp at re-examination.

Atrophy of the thigh muscles was not appreciated by the owners in 10 cases while the veterinary surgeon noticed mild atrophy in 9 of those 10 and severe muscle loss in the remaining leg. In one case, the smaller thigh at the operated side as reported by the dog owner did seem to have a normal muscle mass at re-examination.

No relation was found between the way the dogs used to sit and the range of flexion as graded at re-examination.

DISCUSSION

Reported clinical improvement following cruciate surgery in dogs varies between 85 and 95 per cent, regardless of the surgical technique.[14-21] The goal of intra-articular implantation of polyester in the dog was restoration of craniocaudal stability of the CCL-deficient stifle joint and, in so doing, restoration of normal limb function. Like all other current surgical technique, a polyester prosthesis is not able to accomplish this goal completely. The aim of surgical intervention seems to be to palliate clinical signs rather than to attemp to return the stifle joint to normal. It can be argued intuitively that, to prevent additional injury and to minimise muscle atrophy and the duration of rehabilitation, surgery should be carried out immediately after the diagnosis of CCL damage is made.

The functional outcome after CCL surgery is commonly assessed by the dog owners. Although a recent study suggests that owner assessment is a useful and acceptable outcome measure in cruciate disease in dogs,[22] such assessments are fraught with error. Owners are in the best position to notice their dog's performance over time and client satisfaction is such an important aspect of veterinary medicine that it often becomes the treatment goal. It is clear, however, that owner-based assessment can never be accepted as a surrogate for evaluation by a clinician. A combined owner-based and veterinary surgeon-based judgement is to be preferred. The results of any follow-up study are biased because the studied dogs are never a random sample of the population of interest. We felt that, if the dogs were doing extremely well after the operation, a lot of the clients were not inclined to participate in the study because their dog would not benefit from the re-examination. Conversely, owners of dogs with persistent episodes of lameness or with contralateral lameness seemed to be more willing to return in order to pursue the reasons for the problem.

According to the dog owners, implantation of a polyester prosthesis improved limb function in about 90 per cent. Nevertheless, clinical examinations at follow-up revealed that less than one third of the dogs regained complete restoration of the stifle function. Grading a dog's gait at follow-up examination is a very subjective evaluation of lameness and it is sensitive to plenty of external factors. More objective measurements of limb function, however, require kinetic or kinematic gait analysis, and such tools were not available.

The range of longterm parameters of treatment results assessable by owners is rather small. Owners are in the best position to assess the exercise tolerance of their dog. They can accurately assess the ability to sit fully, providing an indication of fibrosis and flexibility of the operated stifle joint.[23,24] On the other hand, most of the owners did not seem to be able to correctly evaluate muscle atrophy of the thigh. It was a striking finding that more than half of the cases did not regain their original muscle mass by the time of follow-up. Rehabilitation protocols in humans[25,26] as well as in dogs with surgically treated CCL-deficient stifles[27-30] have shown decreased lameness scores at follow-up, and are therefore worthwhile considering.

Most of the assessments made by the veterinary surgeon did not change greatly with the length of follow-up so that no temporal profiles could be established. Capsular thickening or cranial drawer were unreliable indicators of the dog's performance and functional capabilities. Dogs are known to mount a massive fibrous tissue response in the joint capsule following an arthrotomy.[5,31] Scar tissue may help to stabilise the reconstructed joint but might also interfer with its range of motion.[4-6] In our study, cases with reduced flexion of the operated stifle were not found to be more stable than the joints showing a normal range of motion on passive manipulation. It remains difficult to recommend surgical therapy on the basis that surgery will restore the joint stability. It was disappointing to notice that nearly two-thirds of the stifles surgically treated with an intra-articular polyester prosthesis showed a positive tibial compression radiograph at longterm follow-up. Instability after cruciate surgery has been described by others after several techniques using autogenous and synthetic material.[5,17,32-35] Although craniocaudal instability tests are helpful in diagnosing CCL injury, there seems to be a poor relationship to functional disability. Subjective improvement of limp function was generally satisfactory and did not seem to be related to the return of postoperative joint laxity.[20,35-38] In the walking dog, many forces are acting on the stifle, and the tolerance of the canine stifle joint for cranial drawer motion is not yet fully understood.[39,40]

Experiments in dogs have shown that osteophytes rapidely form after CCL transection.[41] After initiation of OA by the joint instability, the radiographically apparent bony changes are observed to mature even in face of restored joint stability.[36,42] Despite clinical successes in surgically treating CCL rupture, no current therapy seems to stop the progression of DJD after surgery.[9,35-37,42-45] In the studied cases, radiographic apparent bony changes had developed by the time of follow-up examination in all operated stifle joints, even in those without known evidence of pre-operative OA. It might be questionned whether surgical intervention iatrogenically contributes to DJD within the affected stifle joint. Experimental section and consecutive closure of the joint capsule in dogs promotes the initiation of degenerative changes.[46] Recent analysis of cytokine levels suggest that biomechanical as well as biochemical factors may contribute to posttraumatic OA.[47]

It has been argued that meniscal tears have their influence on the recovery rate and on the progression of OA in the affected stifle joint[20,48-51] although other follow-up studies[37,52,53] did not support this point of view. Partial meniscectomy was performed in all dogs with medial meniscal tearing in our study, and there was no evidence that it had any negative effect upon the functional nor radiographic outcome of these cases. None of the dogs in which intact menisci were diagnosed at the time of CCL reconstruction were seen for subsequent treatment of meniscal problems. However, the actual incidence of patients with poor postoperative function that might benefit from a meniscectomy at a second operation is not known since none of them underwent postoperative arthroscopy to assess the status of the menisci at follow-up. It is recently recommended to incise the intact medial meniscus near its lateral attachment on the intercondyloid eminence at the time of cruciate surgery.[54] The purpose of this meniscal release is to free the medial meniscus from the crushing effects of the femoral condyle and so minimise postsurgical meniscal damage.

Intra-articular implantation of a polyester prosthesis was the surgical method of choise to treat CCL-deficient stifle joints in dogs at Ghent University Veterinary Hospital for many years. At the time of surgery, all clients were informed that, as with any implant, removal of the polyester may be required at a later date. During a 5 years period, the prosthesis had to be removed in only 7 cases. If the implantation was carried out more than 6 months before removal was indicated, the polyester tape could be taken out with no resulting change in craniocaudal drawer or lameness. Only in the cases 1 and 3 months after surgery, the affected stifle joints needed restabilisation by imbrication after removal of the intra-articular polyester prosthesis.

Bilateral affection was found in more than a third of the dogs with CCL disease. This rate correlates well with the 20 to 40 per cent prevalence reported in other studies.[9,15,55-59] The number of bilaterally affected dogs can be a little underestimated since some might only tear their contralateral cruciate ligament after conclusion of the studied period.

It is well-known in veterinary medicine that pure traumatic damage to the CCL is an incidental event in dogs.[16,57,60,61] Contralateral cruciate problems are not expected in such patients. Instability at one joint could theoretically result in alterations of biomechanical forces acting on other joints, altered weight bearing, and altered ambulation as a compensatory response. Increased movements of the contralateral stifle and ankle joint are seen in dogs with experimental CCL transection.[62] Evidence of increased weight bearing in the contralateral limb has been noted by force plate analysis in several reports,[44,63] while others[64] have failed to confirm this observation. Unilateral CCL damage in itself does not seem to directly overload the contralateral stifle.[64,65] Neuromuscular reflexes protect the opposite CCL from pathological consequences of altered kinematics.

A striking difference was encountered in the frequency of subsequent contralateral CCL rupture in dogs with radiographic OA in the contralateral stifle joint at the time of initial diagnosis of unilateral lameness compared with those with normal opposite joints. This finding might further support the idea of a degenerative pathogenesis for rupture of the CCL in a vast amount of dogs. It was suggested that in some cases, a stretched or partially torn CCL initially only might lead to some joint effusion and extremely subtle radiographic changes.[57] At the time of clinical lameness due to true CCL rupture, these OA changes seem to have progressed greatly.

Previous retrospective studies on contralateral CCL rupture consistently reported on the time span between initial diagnosis of CCL rupture at the first side and diagnosis of bilateral affection, the mean interval ranging from 8 to 16 months.[9,15,21,56,57] Although a smaller number of cases could be assessed in this way, the interval between cruciate surgery at the first stifle joint and operative repair of the second ruptured cruciate was assessed in this study. A mean of 8 months was calculated. The choice to compare the interval between both surgeries reveals accurate data whereas comparison of the interval between both diagnoses is biased. Several of the bilaterally affected dogs were not automatically represented by their owners at the time of contralateral lameness.

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CHAPTER 5

IMMUNOPATHOLOGICAL MECHANISMS IN CANINE CRANIAL CRUCIATE LIGAMENT DISEASE

5.1. Prevalence and relevance of antibodies to type-I and -II collagen in synovial fluid of dogs with cranial cruciate ligament damage

5.1. Prevalence and relevance of antibodies to type-I and -II collagen in synovial fluid of dogs with cranial cruciate ligament damage

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SUMMARY

Synovial fluid antibody titers to type-I and -II collagen were measured by an ELISA and compared in clinically normal and diseased joints in dogs. Synovial fluid samples were collected from 7 dogs with clinically normal stifles (control group) and 82 dogs with diseased joints (50 stifle joints with instability caused by complete rupture of the CCL, 20 stifle joints with partial damage of the CCL, and 12 joints with radiographic signs of osteoarthritis secondary to other arthropathies).

In dogs with complete and partial CCL rupture, synovial fluid antibody titers to both types of collagen were significantly increased, compared with control dogs. Dogs with osteoarthrosis secondary to other pathologic changes also had significantly increased synovial fluid antibodies to type-I and -II collagen.

Increases in autoantibodies to collagen in synovial fluid are not specific for the type of joint disorder. It is unlikely that the anticollagen antibodies play an active role in the initiation of weakening of the CCL in dogs.

INTRODUCTION

In humans, rupture of the cruciate ligament is mostly a purely traumatic event to the knee joint.[1] By contrast, in dogs, this structure may be damaged or ruptured without a history of vigorous trauma.[2] It is defined as a spontaneous cranial cruciate ligament (CCL) rupture if it occurs during movements and activities that normally should not injure this ligamentous structure. Various predisposing factors such as aging of the ligament,[3] lack of exercise,[4] conformational abnormalities,[5] or osteoarthritis (OA) within the stifle joint[3] are associated with damage to the CCL. In dogs, the exact cause and pathogenesis of this disease (excluding the acute traumatic form) still is unclear. Many veterinarians and scientists perform studies on canine CCL specimens to better understand the pathophysiologic mechanisms of this disease. The challenge to unravel the multifactorial etiopathogenesis of CCL disease remains. It is intriguing that 2 main clinical entities of canine CCL disease seem to exist. Ruptures occur in elderly, small- and medium-sized dogs, and also in young, large-breed dogs.[6]

The study presented here on the involvement of synovial fluid anticollagen antibodies in CCL disease in dogs was undertaken because of the inability to explain the high occurrence of clinical CCL rupture in dogs in the absence of severe trauma. Different types of collagen exist. Type-I collagen is the main constituent of skin, bone, tendon, and synovial tissue.[7] The canine meniscus also mainly contains collagen type I.[8] Type-II collagen is restricted to the articular cartilage, the intervertebral discs, and the vitreous humor.[7,9] The concept that chondrocytes in osteoarthritis cartilage switch their collagen synthesis from the characteristic type II to type I is no longer supported.[10] Potential relationships in dogs between anticollagen antibody titer in synovial fluid from stifle joints with CCL disease, the degree of degenerative joint disease, and duration of clinical signs were explored.

MATERIALS AND METHODS

CCL-group dogs—Dogs admitted to the University of Ghent Veterinary School Department of Diagnostic Imaging between Feb 1996 and Jan 1998 for surgical stabilization of stifle joints with CCL disease were studied. Fifty dogs had a complete rupture of the CCL, whereas in another 20 dogs, a diagnosis of partial rupture was made during surgery. Breed, age at time of hospital admission, body weight, and sex were recorded. Data on the duration of the clinical signs of lameness were available for all but 4 dogs. Radiographic views taken before surgery were evaluated to determine the degree of arthrosis before surgery. The grading (grade 0 to 3) was done according to a modification of the criteria of Brünnberg.[11] The grade of OA could not be determined in 4 dogs, because no radiographs were available. During surgery, synovial fluid was aspirated from the affected stifle joint just prior to the stab incision. The joint was held sufficiently flexed to cause tension of the capsule, and the needle was passed lateral to the straight patellar ligament, directed obliquely and caudally.

OA-group dogs—Twelve dogs without CCL rupture that had an orthopaedic joint disorder in 1 joint were screened in a similar manner. Unfortunately, duration of clinical signs of lameness of the affected limb was inconsistently recorded. In all dogs, the degree of radiographic OA was determined. Synovial fluid samples were collected from the following diseased joints: 2 stifle joints, 3 shoulder joints, 6 elbow joints, and 1 tarsal joint. Synovial fluid samples were collected from joints other than the stifle prior to installing an arthroscopic portal.

Control-group dogs—Seven dogs that were euthanatized for nonorthopaedic reasons by IV administration of a drug[a] were used as a source of synovial fluid from clinically normal stifles. Prior to euthanasia, results of clinical and radiographic assessment indicated no swelling of the stifle joints. Synovial fluid was collected by aseptic percutaneous arthrocentesis. At necropsy, the absence of macroscopic signs of degenerative joint disease was confirmed. In addition, the presence of intact CCL was established.

Sample storage—Synovial fluid samples were centrifuged to separate contaminating blood, cells, and debris. Subsequently, the purified sample was stored at -18 C until testing.

ELISA for anticollagen antibody measurement—Synovial fluid from the dogs was tested for autoantibodies against type-I (human) and -II (bovine) collagen. An ELISA was used to determine antibody concentrations. Polysorb 96-microwell plates[b] were coated with highly purified human type-I collagen[c] or bovine type-II collagen[c]. Both antigens were diluted in 50 mM carbonate/bicarbonate coating buffer (pH 9.4) to a concentration of 30 µg/ml. One hundred microliters of coating solution was added to each well and incubated for 24 hours at 4 C.

The collagen-coated wells were then washed at least 4 times with PBS solution supplemented with 0.05% (vol/vol) Tween 20[d]. Subsequently, 2-fold dilutions of inactivated synovial fluid samples (30 minutes at 56 C) in washing solution supplemented with 3% (wt/vol) BSA (dilution buffer) were added to the wells. As a blank, collagen-coated wells were incubated with 100 µl of the diluent only. Also, negative and positive control samples were assayed in each assay. The samples were incubated at room temperature (approx 25 C) for 1.5 hours.

Bound antibodies were detected by adding 100 µl of an appropriate dilution of affinity isolated rabbit antidog IgG (whole molecule) conjugated to horseradish peroxidase[e]. The conjugate was incubated for 2 hours at 37 C. Between each step, the wells were washed 4 times with the washing solution. Binding of conjugate was observed by adding 50 µl of 2,2'-Azino-di-[3-ethylbenzthiazoline sulfonate (6)] diammonium salt crystals substrate. Absorbance at 405 nm was measured after 60 minutes of incubation at 37 C, using an ELISA-reader[f].

Antibody titers—The anticollagen-specific antibody titer of a sample is the highest dilution of that sample with an optical density (OD) just above the cutoff value. For each collagen type, the cutoff value was determined by calculating the sum of the mean OD of all synovial fluid samples with negative results for the collagen type and the corresponding 3 standard deviations ($P < 0.01$). For each sample, the significance limit represents the mean OD of synovial fluids from control-group dogs plus 2 standard deviations.

Statistical Analysis—Mann-Whitney rank sum tests were used to compare data such as age, body weight, degree of OA, and duration of the clinical signs between dogs with complete CCL ruptures and dogs with partial CCL ruptures. The titers were $\log_2$ transformed to meet normal distribution (Wilk-Sharpiro/Rankit Plot). One-tailed 2-sample t-tests (for equal or unequal variances as applicable) were used to compare data from a clinically affected group with the control-group, whereas a paired t-test was used to compare the titers to type-I collagen with those to type-II collagen for samples from all different groups.

Simple regression analyses were used to explore the potential relationships between the titer of antibodies against type-I or -II collagen and the degree of OA in the OA-group dogs. For the CCL-group dogs, multiple regression analyses were performed separately for dogs with complete or partial rupture to assess potential relationships between the titer and the type of anticollagen antibodies (as dependent variables) and the age of dogs, their body weight, the degree of OA on the radiographic views before surgery, and the duration of the clinical signs (as independent variables). Stepwise regression was performed to find the best-fitting model relating the prevalence of anticollagen antibodies to the independent variables. Furthermore, the relationships between these variables and autoantibodies to type-I and -II collagen were assessed by Mann-Whitney rank sum tests. The same statistical test was used to compare the titer and type of anticollagen antibodies between the dogs with meniscal damage and those without. Hypotheses tested were accepted if the P value was < 0.05.

RESULTS

Of the 70 dogs in the CCL group, 7 were considered to be mixed-breed dogs. Purebred dogs included Rottweilers (n = 17), Boxers (5), Yorkshire terriers (5), Bernese Mountain Dogs (3), and Golden Retrievers (3). There were 2 each of the following breeds: Beauceron, Braque, Doberman Pinchers, English Bulldog, Labrador Retriever, Neapolitan Mastiff, Nizinny, and Poodle. Furthermore, 1 of each of the following were included: American Cocker Spaniel, American Staffordshire Terrier, Bichon Frise, Bullmastiff, Cairn Terrier, English Springer Spaniel, French Mastiff, Giant Schnauzer, Maltese, Newfoundland, Saarloos Wolfhound, Saint Bernard, Siberian Husky, and Whippet. Twenty dogs had a partial CCL tear, of which 5 also had a medial meniscal tear (Table 1). The remainder (50/70) had complete ruptures; in 33 of them, the medial meniscus was also damaged.

The mean age of CCL-group dogs was 5 years (range, 0.5 to 12 years old) with a mean body weight of 32.8 kg (range, 3 to 72 kg). Dogs in the group with partial rupture of the CCL was significantly younger than the dogs with complete ruptures (P = 0.04), whereas there was no significant difference found in body weight between groups. The period between the first clinical signs and repair of the ruptured CCL varied greatly, ranging from < 1 week to > 2 years old. In dogs with partial CCL rupture, the lameness had been present for a significantly longer time, compared with the dogs with complete CCL rupture (P = 0.02).

The 12 dogs in the OA-group were of similar breeds and sizes as those in the CCL group. Only 1 mixed-breed dog was screened. Fifty percent of the OA dogs were Rottweilers (n = 6). Of the other breeds, there was 1 each of the following: Bernese Mountain Dog, Doberman Pincher, Newfoundland, Poodle, and Saint Bernard. Most dogs in the OA group were young (mean, 2.7 years old; range, 0.5 to 15.5 years old). The mean body weight was 33.2 kg (range, 9 to 50 kg).

Table 1. Mean (range) distribution of dogs by age, body weight, degree of osteoarthritis, and duration of clinical signs

Groups	Number of dogs	Age (y)	Body weight (kg)	Degree of OA	Duration of signs (m)
CCL Group	70	5.0 (0.5-12)	32.8 (3-72)	2 (0-3)	2.4 (0.2-24)
cCCL	50	5.4 (1-11.5)	31.0 (3-72)	2 (0-3)	1.3 (0.2-7)
pCCL	20	3.8 (0.5-12)	37.2 (18-60)	2 (1-3)	4.5 (0.2-24)
OA Group	12	2.7 (0.5-15.5)	33.2 (9-50)	1 (0-3)	NA
Control Group	7	5.3 (0.5-14)	22.6 (10-35)	0 (0-0)	0 (0-0)

CCL Cranial cruciate ligament rupture, cCCL Complete cranial cruciate ligament rupture, pCCL Partial cranial cruciate ligament rupture, OA Osteoarthritis secondary to pathologic changes other than CCL rupture, Control Normal, NA Not available

Table 2. Synovial fluid anticollagen antibodies in canine arthropathies

Groups	**Number of samples**	**Anti-collagen antibody titers in $\log_2$**	
		Type I	**Type II**
CCL Group	70	1.3857±1.5064†	1.9857±0.7559†
cCCL	50	1.5200±1.5810†	2.1400±1.5651†
pCCL	20	1.0500±1.2763*	1.6000±1.5009*
OA Group	12	1.6667±1.3707†	3.5833±1.4434‡
Control Group	7	0.2857±0.4880	0.7143±0.7559

Mean titers significantly (*P<0.05, †P<0.01, ‡P<0.001) different from the control group values
See Table 1 for key

In the control group, 7 dogs belonged to the following breeds: Beagle (n = 2), Belgian Malinois (1), German Shepherd Dog (2),and Labrador Retriever (1). One mixed-breed dog was included. These dogs ranged in age from 0.5 to 14 years old (mean, 5.3 years old), and their body weight varied from 10 to 35 kg (mean, 22.6 kg).

There was a significant difference in mean titer of antitype-I collagen antibodies between the CCL-group dogs with complete or partial ruptures and the control group (t = -4.26, P < 0.001 and t = -2.25, P = 0.02, respectively; Table 2). Also, the antitype-II collagen antibodies in synovial fluid of CCL-group dogs with complete or partial ruptures were significantly higher than those in synovial fluid samples from clinically normal dogs (t = -3.94, P < 0.001 and t = -2.01, P = 0.03, respectively). The mean titers of antitype-I and -II collagen antibodies were significantly different between OA group and the control-group dogs (t = -3.16, P = 0.003, and t = -4.85, P < 0.001, respectively).

Twenty-one of the 50 dogs with complete CCL rupture (42%) and 7 of the 20 dogs with partial CCL ruptures (35%) had an antitype-I antibody titer of < 10 (OD < 0.163; Fig 1). Most of CCL-group dogs had synovial fluid values that were within the range of control-group dogs. Antibody titers to type-I collagen were greater than the significance limit in 48% (24 of 50) of the dogs with complete CCL rupture and 35% (7 of 20) of the dogs with partial CCL rupture. Ten of 50 dogs with complete CCL rupture (20%) and 7 of 20 dogs with partial CCL rupture (35%) had an antitype-II antibody titer of < 10 (OD < 0.221; Fig 2). Antibody titers to type-II collagen were greater than the significance limit in 40% (20 of 50) of the dogs with complete CCL rupture and in 40% (8 of 20) of the dogs with partial CCL rupture.

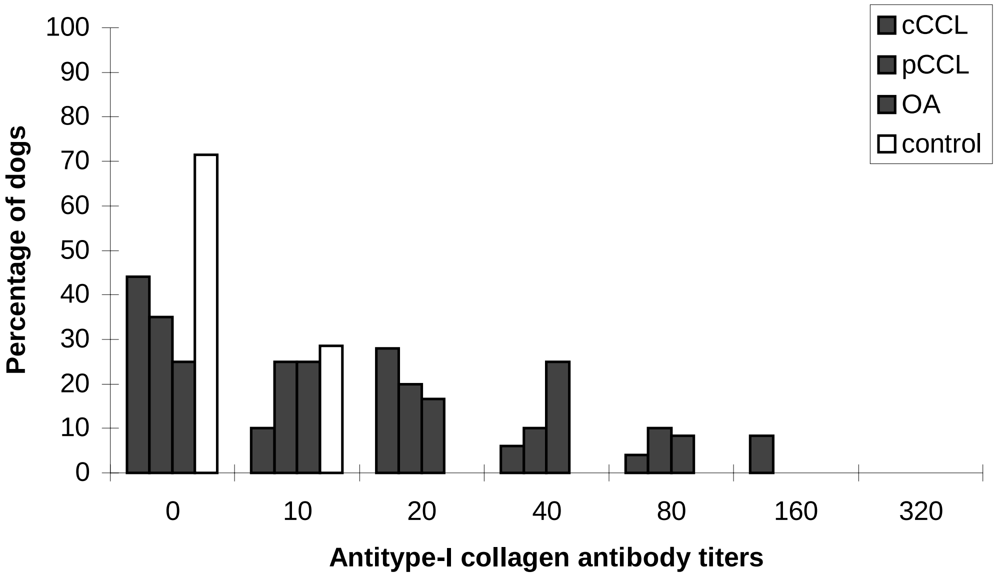

Fig 1. Antibody titers to type-I collagen in canine synovial fluids

cCCL Complete cranial cruciate ligament rupture, pCCL Partial cranial cruciate ligament rupture, OA Osteoarthritis secondary to pathologic changes other than CCL rupture, Control Normal

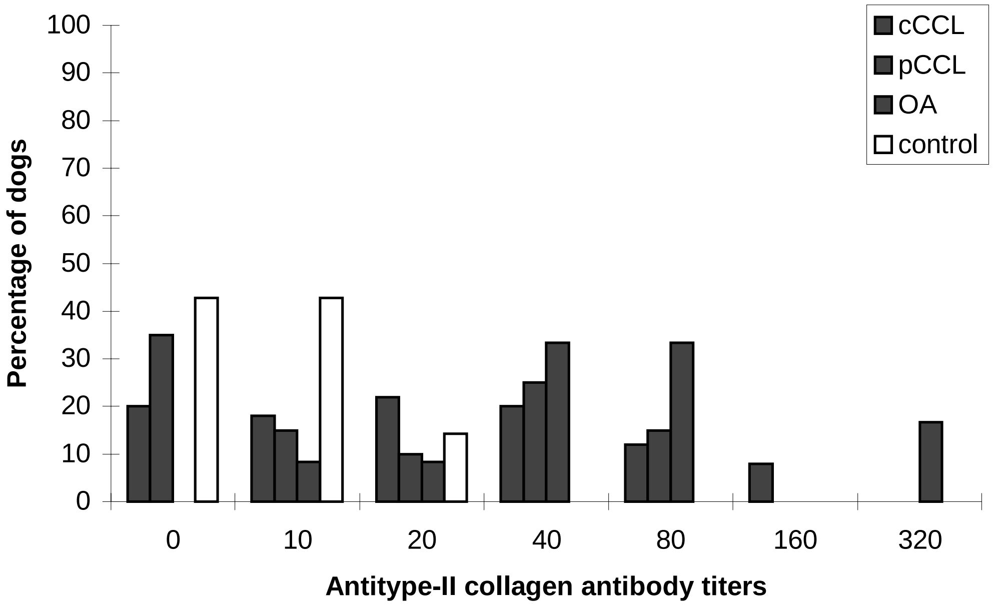

Fig 2. Antibody titers to type-II collagen in canine synovial fluids See Fig 1 for key

Synovial fluid prevalence of antitype-I and -II collagen antibodies did not correlate in any of the dog groups. Paired analyses revealed a significant difference between the titers of antibody to both collagen types in the CCL-group dogs ($t = -4.64$, $P < 0.001$) and the OA-group dogs ($t = -3.15$, $P = 0.009$). Titers against type-II collagen were higher than titers against type-I collagen. In the control group, no difference was found between antibody titers. For dogs with complete CCL rupture and dogs with partial CCL rupture, the mean titer of autoantibodies to type-I or -II collagen did not differ statistically between the group with meniscal damage and the dogs with intact menisci ($\alpha = 0.05$).

In CCL-group dogs, multiple regression analysis was used to indicate associations between anticollagen antibody titers and the variables age, body weight, degree of radiographic OA, and duration of clinical signs. In dogs with complete CCL rupture, there was a weak negative relationship between $\log_2$ antibody titers against collagen type I and body weight ($R^2 = 18\%$, $P = 0.003$). The age, duration of clinical signs, nor the degree of OA were significant variables for the model. For the dogs with partial tearing of the CCL, the only association found was a weak positive relationship between antitype-I collagen antibody titers and the dog age ($R^2 = 22\%$, $P = 0.03$). Significant relationships between antibody titers to type-II collagen and any of the variables were not found in the dogs with complete ruptures. In contrast, regression analysis for dogs with partial CCL ruptures indicated an association of antitype-II collagen antibodies with the variable degree of OA ($R^2 = 22\%$, $P = 0.03$). When the degree of OA and the age were expressed in a single regression model, 42% of the variance was covered ($P = 0.04$).

When data from CCL-group dogs was subdivided into those with samples with negative autoantibody results and those with samples with positive autoantibody results (irrespective of the titer of antibodies to collagen), the same variables were reassessed. In dogs with complete CCL rupture, the only variables that differed significantly were the body weight ($P = 0.03$) and the age ($P = 0.04$) of dogs between samples with positive and negative results for antitype-I collagen antibodies. The mean body weight for dogs with positive antitype-I results was lower, whereas their mean age was higher, compared with dogs with negative results. In dogs with partial CCL rupture, samples with positive results for autoantibodies to type-I collagen also had an higher mean age ($P = 0.02$), compared with dogs with negative results. None of the other variables differed between dogs with positive and negative results. The use of simple regression analysis failed to reveal any association between antitype-I or -II collagen antibodies and the degree of OA in the OA group ($\alpha = 0.05$).

DISCUSSION

Results of our study indicate that there is a significant increase in synovial fluid antibody titers to antitype-I collagen and -II collagen in canine joint disorders. The presence of these anticollagen antibodies in synovial fluid of dogs with OA was not a new finding and was in agreement with previous studies.[12-14] In our study, tests on synovial fluid samples from stifle joints with CCL disease and from joints in which the OA was unrelated to CCL disease were simultaneously conducted for antitype-I and -II antibodies. To our knowledge, this is the first report on autoantibodies to collagen in synovial fluid of dogs with CCL rupture that differentiates between partial and complete damage.

The group of dogs with a partially ruptured CCL was generally younger but did not differ in body weight from the dogs with complete CCL ruptures. Most dogs with partial rupture were lame for a more extended period of time before they were admitted for surgery.

It is widely accepted that immunologic processes are involved in the pathogenesis of many joint disorders in dogs. Degenerative joint disease is no longer considered a purely noninflammatory process. In dogs with naturally occurring rupture of the CCL, high immunoglobulin depositions are found in the synovial membrane,[15] and lymphocytic-plasmacytic synovitis has been associated with damage to the CCL.[16-18] The latter finding has been confirmed after experimental section of the CCL, where discrete cell aggregates of small lymphocytes and plasma cells, suggestive of immune-mediated disorders, were found in the synovium of dogs 2 months after surgical section of the CCL.[19] These studies only provided histologic and immunohistopathologic data. Experimental transection of the CCL in dogs is well known as the Pond-Nuki model.[20] The resulting joint instability initiates a sequence of events to the affected stifle joint and is a key factor in the production of degenerative joint disease. Experimental models can provide extremely useful information about natural processes. However, results of a study on synovial fluid mediators[21] did not establish an identical pathogenesis for degenerative changes, secondary to spontaneous CCL damage or after experimental transection of the CCL.

Abnormal loading of the unstable stifle joint during weight bearing causes mechanical damage to the joint cartilage, which in turn may release antigenic material and expose it to the immune system. Autoantibodies can be formed in response to prolonged and abundant presentation of this antigen, immunologically recognized as foreign substance.[13,22] Because collagen type II is the major constituent of cartilage,[7,9] a high antibody-titer against collagen type II may be expected in synovial fluid from OA joints. Results of our study indicate that there is a weak association between the degree of radiographic OA and the antitype-II antibody titer in the subgroup of dogs with partial CCL rupture. In the other dog groups (dogs with complete CCL rupture and OA-group dogs), the degree of radiographic OA was not correlated with the amount of detected autoantibodies. This is in accordance with the findings of Arican et al.[14] who failed to relate the release of cartilage breakdown products such as glycoaminoglycans and keratan sulphate to anticollagen autoantibodies. Consideration should also be given to the fact that the radiographic degree of OA does not always reflect the exact amount of osteophytosis found during arthrotomy.

Stifle joint instability does not only cause damage to the cartilage but also increases the risk of medial meniscal damage. The menisci, as well as the intra-articular CCL, are mainly composed of type-I collagen fibers tissue.[7,8] Damage to the CCL or to the meniscus can, therefore, expose this collagen type as an antigenic target. In our study, damage to the medial meniscus did not influence the titer of antibodies to type-I collagen the CCL-group dogs. Forty-four percent of the dogs with CCL rupture (48% of dogs with complete rupture and 35% of dogs with partial ruptures) in our study did have high antitype-I antibody titer in the synovial fluid. The dogs with complete or partial rupture of the CCL in which antitype-I antibody positivity was observed were older than the dogs with samples with negative results. The detected titers of autoantibodies in synovial fluid of dogs with partial CCL rupture were slightly low, compared with samples from dogs with complete tearing. Conversely, in other joints with pathologic changes, positive antitype-I antibody titer results could also be detected in half of the dogs.

Observations on the titers of autoantibodies to collagen in the synovial fluid of dogs with CCL disease (complete and partial ruptures) were not in line with some reported data. Niebauer et al.[12] found similar titers of anticollagen antibodies for collagen type I and II. In our study, no correlations were found between antitype-I and -II collagen antibody titers in the synovial fluid of individual dog and joint disease, irrespective of the joint problem. Nevertheless, the mean titer of antitype-I collagen antibodies in both subgroups of CCL disease dogs was increased, compared with the control group, and the same was true for the antitype-II titer. A possible explanation could be the origin of the collagen used in the ELISA. Results of inhibition experiments indicate weak cross-reactivity between collagen type I and type II.[12,13,22] Commercially available highly purified antigenic solutions of human type-I and bovine type-II collagen were used as antigenic targets. Apart from the availability, the choice of coating collagen was inspired by a publication of Bari et al.[13] Results of their research revealed an equal test reaction of canine serum with bovine type-II collagen as with canine type-II collagen. However, testing of canine synovial fluids, preliminary to our study in which bovine type-I and human type-I collagen were compared as antigenic targets consistently resulted in high nonspecific reactions when bovine collagen was used (data not shown).

Niebauer et al.[12] suggested that high autoantibody titers are observed more often in dogs with signs of acute arthritis (rupture up to a few weeks before), although no statistical evidence for this statement was presented. In our study, we investigated whether the prevalence of autoantibodies in dogs with CCL disease was correlated directly with the duration of the signs. Results of our study revealed no correlation between the dogs with complete and partial CCL rupture. The history is, of course, only an approximation of the real duration of signs. The lameness may only be subtle and the real onset initially unnoticed by the owner. Measurement of anticollagen antibodies in the dogs' sera was reported to be less diagnostic for particular joint diseases,[23,24] so this line of investigation was not pursued in our study.

Our data do not support the idea that autoantibodies to collagen play an active role in the initiation of CCL rupture. Several findings suggest that antitype-I and -II collagen antibodies only play a role in the perpetuation of joint inflammation in general. Differences in the anticollagen antibody titers between dogs with acute and chronic disease could not be established. Autoantibodies to type-I collagen did not seem to be specific for dogs with damage to the CCL. Moreover, antitype-II collagen antibody titers were generally higher than those of antitype-I. Furthermore, in humans, rupture of the anterior cruciate ligament is primarily a traumatic event. One may expect, however, that formation of autoantibodies to collagens is also occurring in human knee joints of OA patients, but spontaneous rupture of the anterior cruciate ligament in humans is not reported. The presence of anticollagen autoantibodies does not necessarily mean that CCL rupture is an immune-mediated event in dogs.

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[a] T_{61}, Hoechst Roussel Vet GmbH, Unterschleissheim, Germany

[b] Polysorb 96-microwell plates, NEN Science Products, Zaventem, Belgium

[c] Collagen, Southern Biotechnology Associates, Inc., Birmingham, Alabama

[d] Tween 20, Merck-Schuchardt, Hohenbrunn, Germany

[e] Horseradish peroxidase, Sigma Biosciences, Saint Louis, Missouri

[f] Tecan Spectra Flour, Sercolab Systems, Mechelen, Belgium

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GENERAL DISCUSSION

The cruciate ligaments are extremely important dynamical structures in the centre of the stifle joint, strongly connecting the femur with the tibia.[1,2] In the dog, the cranial cruciate ligament (CCL) is formed by a craniomedial and a caudolateral bundle which are loaded independently from each other during movement and weight bearing.[3]

Injury to the CCL is more common than any other type of stifle injury in both dogs[4,5] and men[6,7]. CCL rupture can be complete or partial. Purely traumatic CCL damage is, unlike in men[6,8-10], only an incidental event in dogs[11-14]. Traditionally, CCL rupture was mostly presented as a degenerative syndrome in middle-aged to older, small to medium-sized dogs. More recently, young large breed dogs became overrepresented.[15,16] Contralateral CCL problems occur in 20 to 40 per cent of the dogs, with a mean interval of 8 to 16 months between initial diagnosis of CCL rupture at the first side and diagnosis at the second stifle.[13,15-21]

Cruciate injury is generally evaluated by physical examination. The most consistent findings are joint swelling and instability of the stifle. However, it is not always possible to establish a diagnosis based on clinical instability by the classical cranial drawer test or the tibial compression test.[22-24] Direct intra-articular inspection during arthrotomy or arthroscopy to provide a definite diagnosis is sometimes required.[25,26]

Damage to the CCL causes craniocaudal instability and osteoarthrotic changes in the stifle joint.[27] Conservative treatment can give a satisfactory clinical improvement in dogs weighing less than 15 kg.[28] The goal of surgical intervention is correction of the craniocaudal instability and restoration of normal stifle biomechanics. The choice of treatment will greatly depend on the surgeon’s preference, since the ideal technique has yet to be discovered.[29]

The aims of this study were to examine diagnostic, therapeutic and etiopathogenetic aspects of CCL disease in the dog.

Several surveys attempted to gain information on the type of dog affected by CCL disease.[14,16,30-34] In the dogs with cruciate deficiency presented to the Department of Medical Imaging, most findings were in keeping with those reports (Chapter 4.1.). An increased prevalence of CCL rupture compared to the hospital population was found in the Rottweiler, the Maltese and the Boxer. The mean age for spontaneous CCL rupture was situated around 5 years of age, although small dogs were generally presented at an older age whereas large breed dogs were mostly affected at a younger age. The finding that two third of the dogs which sustained cruciate rupture were weighing 22 kg or more might be a reflection of relatively higher demands and vulnerability of the CCL with increasing body weight.

Quite often, CCL problems in dogs start rather insidious.[15,35] At first, owners might not be alarmed by slight intermittend limping of their pets. In this stage, CCL damage is still often overlooked by the veterinarian at the time of the initial presentation. The practitioner may not consider the classical instability tests or he may encounter difficulties in eliciting appreciable instability in response to the small manual forces used on manipulation of the affected stifle joint.[24] Especially in chronic situations of cruciate deficiency, thickening of the joint capsule and fibrosis increase the stability of the stifle joint and might obscure the clinical diagnosis of cruciate damage.[23,36] Palpable cranial displacement of the proximal tibia can also be blocked by the presence of a torn meniscus.[36,37] Furthermore, the remaining intact portion of a partially ruptured CCL might obscure existing laxity at certain joint angles and might resist drawer motion to varying degrees.[38,39]

Even in men, anterior cruciate ruptures are initially overlooked in a rather high proportion.[40,41] Therefore, a combination of several manual and radiological biomechanical tests has been recommended for the clinical diagnosis of cruciate ligament instability.[42]

The present study, as a matter of fact, is actuated by the idea of H. van Bree to convert the existing tibial compression test into a stress radiographic technique (Chapter 2). In contrast with the physical test, the stifle is held at an angle of 90° while making the tibial compression radiograph. At full extension, a false negative result is likely if only the craniomedial bundle of the CCL has ruptured, because the caudolateral bundle can mask the instability. In flexion, however, the caudal bundle of the CCL is always loose, regardless of the state of the cranial bundle.[3] As a result, fewer cases of incomplete damage will be missed when tibial compression stress is exerted on a flexed stifle joint. Great care is given to radioprotection, because the dog has to be restrained by a handler while the tibial compression radiograph is taken. A tibial compression radiograph shows abnormal spatial relationship between the femoral condyles and the tibial plateau in cases of CCL damage (Chapter 2.1.;Chapter 2.2.). It is a useful technique to prove a tentative diagnosis of CCL damage, especially when there is a lack of cranial drawer sign on clinical examination. The radiographic test is objective and there is no interposition of soft tissue. Tibial compression radiographs are now routinely taken in all cases suspected of rupture of the CCL (Chapter 4.1.). No false positive results were obtained. The technique was also used to assess postoperative stability at varying intervals after stabilising surgery (Chapter 4.3.). Although craniocaudal instability tests are helpful in diagnosing CCL injury, there seems to be a poor relationship to functional disability after surgery.[38,43-46] Kinematic evaluations are probably to be preferred above radiographic assessments of postoperative outcome of cruciate surgery.

We assessed the accuracy and usefulness of 2 measuring techniques for dogs with suspected damage to the CCL, without obvious radiographic displacement on lateral radiographic view with the joint positioned in tibial compression (Chapter 2.3.). Although statistically significant differences were found in the laxity between the stifle joints with partial or complete CCL rupture and healthy joints, cruciate pathology did not necessarily induce detectable changes in laxity of an individual affected stifle joint as compared to the range in measurements for stifle joints with normal CCLs. Inspired by our publications, another measurement technique was described recently and the results perfectly correspond to our findings.[47]

Displacement of the popliteal sesamoid is a useful and easy parameter in the interpretation of tibial compression radiographs (Chapter 2.4.). Distomedial displacement of the sesamoid bone has only been reported twice on standard lateral radiographs, both in cases of avulsion of the popliteus muscle.[48,49] The popliteal sesamoid bone also appears more distally on tibial compression radiographs when there is damage to the CCL. In a small number of dogs the popliteal sesamoid does not ossify, and therefore remains invisible as a radiographic parameter.[50] A lack of ossification mainly occurs in small breed dogs. In most of those dogs, however, the craniocaudal displacement of the tibia will already be so obvious on the tibial compression radiograph that no additional parameters need to be assessed to come to a definite diagnosis of CCL damage.

Numerous autografts and synthetic materials have been used for reconstructive surgery of the CCL in dogs.[29] We evaluated braided polyester as an intra-articular substitute for a ruptured CCL in the dog (Chapter 3; Chapter 4). Any replacement material should behave in a manner similar to the natural ligament in the expected range of loading and recovery, and it should have load-elongation characteristics that closely resemble those of the original ligament during ultimate loading. Braided polyester tape loops are strong, although not as strong as the original CCL (Chapter 3.1.). Nevertheless, based on their *in vitro* biomechanical characteristics, the polyester prostheses should easily be able to resist normal weight bearing forces in all sizes of dogs. The tapes also proved to be able to absorb the shock of traumatic overload, even after cycling, when the amount of energy absorbed prior to failure is reduced (Chapter 3.2.). They are not able to elongate and recover to the same extent throughout their entire lifetime as the original structure does.

Reported clinical improvement following cruciate surgery in dogs varies between 85 and 95 per cent, regardless of the surgical technique.[19,21,43,51-55] It is believed that an intra-articular prosthesis can better mimic the original position and function of the CCL, compared with extracapsular placement of stabilisation sutures.[56] The owners of the dogs were pleased with the surgical results after implantation of a polyester prosthesis (Chapter 4.3.). In spite of this satisfactory clinical outcome, most of the stifles stabilised by an intra-articular polyester prosthesis were found to become unstable again over time. The behaviour of polyester loop as a CCL prosthesis *in vivo* is obviously less favourable than would be expected based on the *in vitro* biomechanical tests only. It is furthermore postulated that the use of synthetic ligaments offers relative advantages such as decreased surgical morbidity and faster rehabilitation.[57-59] The recovery after surgery of the studied dogs was not found to be markedly faster compared to dogs operated on by other techniques. On the other hand, implantation of any synthetic material may require removal at a later date.[60] The presence of foreign material makes tissues susceptible to both immediate and delayed infection.[61,62] In our cases, removal of the polyester was only indicated in very few clinical cases.

CCL rupture in dogs has been treated with different surgical techniques but none of them has proven to be able to stop the progression of OA in the affected stifle joint.[1,15,44,45,63-66] Although immediate postoperative stability was gained after intra-articular implantation of the polyester tape, nearly two thirds of the stifle joints showed a positive tibial compression radiograph at longterm follow-up (Chapter 4.3.). Instability after cruciate surgery has been described by others after several techniques using autogenous and synthetic material.[43,44,53,67-70] It is not entirely clear if the medial meniscus is at risk in face of the returned craniocaudal instability. Very few studies report on the necessity of secondary meniscectomies.[33] A recent trend is to incise the intact medial meniscus near its lateral attachment on the intercondyloid eminence at the time of cruciate surgery.[71] The purpose of this meniscal release is to free the medial meniscus from the crushing effects of the femoral condyle. The efficacy of this additional procedure in preventing postsurgical meniscal damage has not yet been demonstrated in the literature. At the other hand, it is also not clear whether the original joint protective functions of a normally attached intact meniscus will all be maintained after it has been surgically released.

It has been suggested that in some cases of CCL disease, a stretched or partially torn cruciate ligament initially only leads to some joint effusion and extremely subtle radiographic changes without detectable lameness.[13] The prevalence of bilateral CCL rupture in dogs with radiographic OA in the contralateral stifle joint at the time of initial diagnosis of unilateral lameness was much higher than in dogs with normal contralateral joints (Chapter 4.3.). This finding strongly supports the benefit of bilateral radiographic screening of all patients at initial presentation. The presence of contralateral OA can contribute to the prediction of contralateral CCL disease. It might further support the idea of a degenerative pathogenesis for spontaneous CCL rupture in a vast amount of dogs. Contributing factors responsible for ligament degeneration and weakening may be numerous and many of the provoking factors remain unidentified to date.

At arthrotomy, synovial fluid samples were taken for immunological examination. In cases of partial as well as complete damage to the CCL, synovial fluid antibody titers to type-I and -II collagen were significantly increased in affected stifles, compared with control joints (Chapter 5.1.). Type-I collagen is the main constituent of bone, tendon, meniscus, and synovial tissue.[72,73] Articular cartilage mainly contains type-II collagen.[72] The presence of these anti-collagen auto-antibodies in synovial fluid does not necessarily imply that the initiation of CCL rupture is immune-mediated, as earlier suggested by Niebauer and colleagues.[74] Exposure of ligamentous collagen from a torn cranial cruciate might incite an antigenically stimulated joint inflammation. Additionally, the presence of autoantibodies to collagen was not found to be specific for the type of joint disorder. We also screened the synovial fluid of dogs with OA secondary to other pathologies. They also showed significantly increased antibody levels to type-I and -II collagen as compared with normal samples.

The etiopathogenesis of spontaneous CCL rupture in dogs remains largely enigmatic up to now. Further research in this particular field is highly required. In a next project, we will try to achieve a better knowledge on the types of immunopathological processes associated with cruciate disease in the dog. It is recently understood that not only biomechanical but also biochemical factors may contribute to the development of OA.[75] Within the joint, pro-inflammatory cytokines aggravate disease processes by their effects on immunologic and other cellpopulations. Other destructive mediators such as metalloproteinases are liberated. The level and the temporal patterns of several mediators in the cruciate-deficient as well as in the contralateral stifle joint of dogs affected by CCL rupture will be studied. Only a better understanding of the pathogenesis and the development of CCL rupture might allow to alter its course and possibly prevent contralateral cruciate damage.

In conclusion, the present study contributed to the knowledge of various aspects in CCL disease in the dog.

Bilateral radiographic screening is stongly recommended in dogs with unilateral lameness to prognosticate the risk of CCL problems in the contralateral stifle joint. The tibial compression radiograph is an easy and non-invasive diagnostic technique. It is an accurate aid in the diagnosis of CCL instability.

Polyester prostheses have *in vitro* characteristics which makes them biomechanically suitable to serve as replacements for ruptured CCLs in dogs. Intra-articular implantation of polyester gives satisfactory clinical results with minimal complications, although the results are not strinkingly better than after other techniques.

Finally, our preliminary immunological findings will serve as a run-up to a new project on the immunopathological mechanisms involved in CCL disease in the dog.

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SUMMARY

This thesis is introduced by a thorough review of the literature (Chapter 1).

Damage to the cranial cruciate ligament (CCL) is a common orthopaedic problem in dogs. All breeds and all sizes of dogs appear to be at risk. The rupture can be complete or partial, or the ligament can even appear grossly intact when stretched without visible disruption. Conventional diagnosis of CCL rupture is based on clinical instability tests. The results, however, are very subjective and often far from conclusive. In a rather high proportion, cruciate problems are initially overlooked by practitioners. Any delay in the diagnosis implies increased muscle atrophy and secondary changes in and around the affected stifle. Osteoarthrotic (OA) changes will rapidly develop in the unstable joint. It is advocated to deal with CCL deficiency at the earliest possible time following diagnosis to re-establish joint stability. A variety of surgical stabilisation techniques have been described. The choice of technique depends on the dog's size but is particularly based on the surgeon's training and experience. Until now, none of the surgeries is able to stop the progression of OA.

The aim of the present studies was first of all to evaluate a new diagnostic technique for practitioners. Secondly we wanted to compare intra-articular implantation of a polyester prosthesis as a stabilisation method for cruciate-deficient stifles with previously described techniques in dogs. Finally, we wanted to shed more light on the enigmatic cause of atraumatic CCL damage in dogs.

In the first part of the study, a new technique for diagnosing rupture of the CCL was evaluated (Chapter 2).

Stress radiographics have been introduced in an attempt to improve the diagnostic accuracy of clinical evaluation of craniocaudal instability. A protocol for obtaining a specific tibial compression radiograph has been designed for dogs: the stifle is fixed at an angle of 90°, while manual stress is exerted on the metatarsals in order to flex the hock joint maximally. An injuried CCL will allow the proximal tibia to move cranially in relation to the distal femur. After establishing the technique, a control group of normal dogs was screened. Tibial compression radiographs were routinely taken in all dogs suspected of having damage to the CCL. The tibial compression radiograph is a simple, objective aid in the diagnosis of cranial cruciate damage in dogs. It is reliable for both complete and partial CCL ruptures, showing a high sensitivity and a hundred per cent specificity (Chapter 2.1.; Chapter 2.2.).

An additional technique was developed to measure relative displacement of bony landmarks on paired lateral radiographs (neutral and tibial compression). A wide range of measurements of laxity was found for stifle joints with intact CCLs. Pathological changes to the CCL will not necessarily induce detectable changes in laxity of stifle joints in dogs (Chapter 2.3.).

The location of the sesamoid bone of the popliteal muscle on stress radiographs was studied in joints with confirmed CCL rupture. Distal displacement of the popliteal sesamoid is a useful parameter in the interpretation of tibial compression radiographs in cases of CCL rupture in the dog. This means that, in most cases, more complex and time-consuming measurements on tibial compression radiographs are unnecessary to assist in the diagnosis of CCL injury (Chapter 2.4.).

In the second part of the study, the biomechanical characteristics of polyester were studied *in vitro* to determine its usefulness as intra-articular prosthesis material in CCL-deficient stifle joints (Chapter 3).

In load-controlled tensile tests, the breaking strength of normal CCLs and braided polyester tapes of 4 and 8 mm, mounted as knooted loops, were determined under a loading rate of 0.1 kN/s. The results filled the existing gap for the choice of the polyester size in clinical situations. Based on the comparative data, the smallest tape would be a valuable choice for replacing a torn CCL in dogs up to 15 kg of bodyweight (Chapter 3.1.).

Displacement-controlled tensile tests were designed to better mimic clinical situations of loading of the stifle joint. Polyester tapes of 4 and 7 mm and polyamide tapes of 4 mm were tested to failure at 1000 mm/min. Cyclic loading experiments were also performed on the polyester tapes. The polyester tapes were repetitively loaded for 25 sets of 2000 cycles between physiologic limits of force. Ultimate loads and corresponding stiffnesses of the polyester and polyamide tapes were measured. Failure properties of polyester tapes were affected by previous precycling. Polyester tapes should be able to resist forces resulting from weigth bearing in dogs (Chapter 3.2.).

In the third part, the patient group with confirmed CCL damage as presented to the Department of Medical Imaging, Gent University was studied extensively (Chapter 4).

The patient data and clinical findings in 240 cruciate-deficient stifle joints were listed and discussed. Increased prevalence of CCL rupture was found in the female dog, and in the Rottweiler, the Maltese, and the Boxer. Diagnosis of CCL disease was based on the orthopaedic examination and on tibial compression radiography, and confirmed during arthrotomy (Chapter 4.1.).

The surgical technique of intra-articular implantation of a polyester tape has been described in detail (Chapter 4.2.).

Dogs with an intra-articular polyester prosthesis were followed-up at varying intervals (Chapter 4.3.). Clinical and radiographic variables were assessed in 75 cases at a longterm follow-up 3 to 49 months after surgical intervention. Radiographic features that were evaluated included OA changes and tibial compression. Nearly two thirds of the surgically stabilised stifle joints showed a positive follow-up stress radiograph. Surgical treatment did not stop the development of OA in the majority of the cases. No statistical association could be established between craniocaudal instability, OA changes, or function of the operated stifle joint. The longterm functional outcome of treatment was also assessed by the owners. In 89 per cent, improved limb function was reported. The owner-based assessments were compared to the results of the clinical and radiographic examination. The range of parameters assessable by owners was very small (Chapter 4.3.).

In the final part, the prevalence and relevance of antibodies to collagen in synovial fluid of dogs with CCL damage was assessed (Chapter 5).

Type-I collagen is the main constituent of the cruciate ligaments and the menisci. Articular cartilage mainly contains type-II collagen. Synovial fluid antibody titers to type-I and type-II collagen were measured in clinically normal and diseased joints in dogs. In dogs with complete and partial CCL rupture, synovial fluid antibody titers to both types of collagen were significantly increased, compared with control dogs. Dogs with OA secondary to other pathologic changes also had significantly increased synovial fluid antibodies to type-I and -II collagen. Several findings suggest that antitype-I and -II collagen antibodies only play a role in the perpetuation of joint inflammation in general. Our data do not support the idea that autoantibodies to collagen play an active role in the initiation of CCL rupture. Autoantibodies to type-I collagen did not seem to be specific for dogs with damage to the CCL.

The final conclusion of this study is that, although advances are made in the knowledge on CCL disease in the dog, some of the enigmas still remain. The diagnosis of CCL instability is remarkably simplified for the practitioner by the advent of the radiographic tibial compression technique. An early diagnosis will allow the patients to be treated in earlier stage of the disease. None of the existing surgical techniques so far reaches the ultimate goal of restoration of normal stifle biomechanics.

Lively disputes will continue as long as the ambiguities concerning the etiopathogenesis of CCL disease in the dog are not further clarified. Only a better understanding of the pathogenesis and the development of the disease, might allow to alter the course of the cruciate damage and possibly also help in the prevention of contralateral cruciate rupture.

SAMENVATTING

Een uitgebreid literatuuroverzicht leidt deze doctoraatsstudie in (Hoofdstuk 1).

Ruptuur van de voorste kruisband (VKB) is bij de hond veruit de voornaamste oorzaak van manken achteraan. Kruisbandproblemen komen voor bij honden van alle rassen en alle gewichtsklassen. De ruptuur kan volledig zijn of slechts gedeeltelijk; daarnaast kan de VKB er macroscopisch normaal uitzien terwijl hij uitgerekt en functieloos is. De gangbare diagnosetechnieken voor kruisbandruptuur bij de hond berusten op klinische instabiliteitstesten. De interpretatie van hun resultaten is echter eerder subjectief en vaak onduidelijk. Bij beginnende kruisbandproblemen wordt de diagnose door praktijkdierenartsen nog in een vrij hoog percentage gemist. De spieratrofie neemt ondertussen verder toe en de degeneratieve veranderingen in en rond het aangetaste kniegewricht verergeren. Bij de hond treedt door de gewrichtsinstabiliteit ook heel snel artrose op in de aangetaste knie. Een vroegtijdige diagnose waarbij de knie zo snel mogelijk weer gestabiliseerd kan worden is daarom belangrijk. Een grote waaier aan chirurgische technieken werd beschreven. De keuze van de techniek hangt af van de grootte van de hond maar wordt vooral ook beïnvloed door de opleiding en de ervaring van de behandelende dierenarts-chirurg. Tot dusver kan met geen enkele operatietechniek de vorming van verdere artrose volledig afgeremd worden.

Het doel van ons onderzoek was in de eerste plaats een nieuwe, eenvoudige en betrouwbare diagnosetechniek voor praktijkdierenartsen te ontwikkelen. Daarnaast wilden we de intra-articulaire inplanting van een polyesterprothese vergelijken met andere reeds beschreven stabilisatietechnieken bij honden met een gescheurde VKB. Tenslotte probeerden we ook een tipje van de sluier op te lichten over mogelijke oorzaken van atraumatische kruisbandruptuur bij de hond.

In het eerste deel van deze doctoraatsstudie werd een nieuwe diagnosetechniek voor ruptuur van de VKB bij honden geëvalueerd (Hoofdstuk 2).

Door het nemen van radiografieën onder stress werd gepoogd om de klinische beoordeling van gewrichtsinstabiliteit op een meer betrouwbare wijze vast te leggen. Er werd een protocol uitgewerkt om bij honden een tibiale compressie radiografie te nemen. Hierbij wordt de knie onder een hoek van 90° gefixeerd, terwijl de sprong maximaal wordt gebogen door manuele druk op de voetwortelbeentjes. Bij beschadiging van de VKB zal het bovenste gedeelte van het scheenbeen voorwaarts kunnen bewegen in verhouding tot het onderste deel van het dijbeen. Na het op punt stellen van deze techniek werd een groep controlehonden radiografisch getest. Tevens werden routinematig stressopnamen gemaakt van alle honden verdacht van ruptuur van de VKB. De tibiale compressie radiografie blijkt een eenvoudig en objectief hulpmiddel te zijn bij de diagnose van VKB-problemen bij de hond. Het resultaat is betrouwbaar bij volledige zowel als bij gedeeltelijke kruisbandscheuren, zoals aangeduid door de hoge gevoeligheid en de perfecte specificiteit van de tibiale compressie radiografische test (Hoofdstuk 2.1.;Hoofdstuk 2.2.)

In een aanvullende studie werden meettechnieken ontwikkeld om de relatieve verplaatsing van benige herkenningspunten te meten op gepaarde radiografieën (neutrale en tibiale compressie opnamen). Dergelijke metingen leverden een brede waaier aan resultaten op voor kniegewrichten met normale VKB. Kruisbandproblemen geven niet noodzakelijk aanleiding tot meetbaar grotere verplaatsingen in aangetaste knieën (Hoofdstuk 2.3.).

De positie van het sesambeentje in de popliteusspier op de tibiale compressie opname werd eveneens bestudeerd bij honden met chirurgisch-bevestigde ruptuur van de VKB. Een neerwaartse verplaatsing van het sesambeentje is een nuttige parameter bij de interpretatie van tibiale compressie radiografieën. Hierdoor valt de noodzaak aan ingewikkelde en tijdrovende metingen op stressradiografieën om VKB-ruptuur te diagnosticeren in de meeste gevallen weg (Hoofdstuk 2.4.).

In een tweede deel van de studie werden de biomechanische eigenschappen van polyester bestudeerd. Aan de hand van laboratoriumproeven werd de bruikbaarheid van polyester als vervangingsmateriaal voor een gescheurde kruisband bij de hond onderzocht (Hoofdstuk 3).

In de eerste plaats werd de breeksterkte van normale kruisbanden en van gevlochten polyesterbanden met een breedte van 4 en 8 mm bepaald in belasting-gecontroleerde trekproeven (0.1 kN/sec.). Hierdoor werd snel tegemoetgekomen aan de bestaande leemte bij de keuze van de meest geschikte breedte van polyesterband bij patiënten aangeboden voor operatie. Uit de vergelijkende gegevens bleek dat de smalste band een gepaste keuze was voor honden van 15 kg of minder (Hoofdstuk 3.1.).

Daarna werden verplaatsing-gecontroleerde testen op punt gesteld om de klinische belasting beter na te bootsen. Polyesterbanden van 4 en 7 mm en polyamidebanden van 4 mm werden belast tot breuk aan 1000 mm/min.. Daarnaast werden ook cyclische belastingsproeven uitgewerkt voor de polyesterbanden. Hierbij werden de prothesen afwisselend belast en ontlast tussen de fysiologische onder- en bovengrenzen van krachten inwerkend op de normale hondenknie. De breeksterkte en stijfheid van de polyester- en polyamidebanden werd gemeten. Voorafgaandelijke cyclische belasting beïnvloedde de resultaten van de daaropvolgende belastingsproeven. De biomechanische parameters van de polyesterbanden voldoen om de normale krachten die inwerken tijdens het steunen op te vangen (Hoofdstuk 3.2.).

In een derde deel werd de patiëntengroep met chirurgisch-bevestigde ruptuur van de VKB die aangeboden werd op de Vakgroep Medische Beeldvorming van de RUG, uitgebreid onderzocht (Hoofdstuk 4).

Gegevens werden verzameld aangaande patiënten en hun klinische bevindingen in 240 kniegewrichten met kruisbandletsels. Een verhoogd voorkomen van VBKruptuur werd vastgesteld bij vrouwelijke honden en bij Rottweilers, Maltezers en Boxers. De diagnose van ruptuur van de VKB werd gesteld aan de hand van een klinisch onderzoek en de radiografische tibiale compressietest en werd uiteindelijk bevestigd tijdens chirurgie (Hoofdstuk 4.1.). De operatietechniek van intra-articulaire inplanting van een polyesterband werd in detail besproken (Hoofdstuk 4.2.).

Honden met een polyesterband ter vervanging van de gescheurde VKB werden opgevolgd. Van 75 gevallen konden klinische en radiografische gegevens worden verzameld 3 tot 49 maanden na de ingreep. Radiografisch werd gelet op de artrose en de tibiale compressie. Ongeveer twee derde van de gestabiliseerde kniegewrichten waren opnieuw instabiel ten tijde van de follow-up radiografieën. Ondanks de chirurgische behandeling werd de verdere toename van artrose niet gestopt. Statistisch kon geen enkel verband aangetoond worden tussen de voorwaartse instabiliteit, de artrosetoename en het gebruik van de geopereerde poot. Klinisch deden 89 percent van de honden het na de ingreep duidelijk beter dan voor de ingreep. De beoordeling gemaakt door de hondeneigenaars werd vergeleken met het klinisch en radiografisch onderzoek. Slechts weinig parameters blijken door de eigenaars correct beoordeeld te kunnen worden (Hoofdstuk 4.3.)

In het laatste deel van deze doctoraatsstudie werd het voorkomen en het belang van antistoffen tegen collageen in het gewrichtsvocht van knieën met VKB-letsels bestudeerd (Hoofdstuk 5).

Net zoals de menisci zijn de kruisbanden hoofdzakelijk opgebouwd uit collageen type I vezels. Kraakbeen daarentegen bevat voornamelijk collageen type II. Antistoffentiters tegen type I en type II collageen werden gemeten in het gewrichtsvocht van klinisch normale en aangetaste gewrichten. Honden met volledige of gedeeltelijke ruptuur van de VKB vertoonden verhoogde antistoffentiters tegen beide collageentypes in hun gewrichtsvocht in vergelijking met controlehonden. Honden met artrose als gevolg van andere aandoeningen hadden echter eveneens verhoogde antistoffen tegen type I en II collageen. Verschillende bevindingen doen dan ook veronderstellen dat deze anti-collageenantistoffen enkel een rol spelen bij het verder in gang houden van reeds bestaande gewrichtsontstekingen. Onze waarnemingen ondersteunen geenszins het idee dat auto-antistoffen tegen collageen een actieve rol zouden spelen bij het opwekken van VKB-ruptuur bij de hond. Auto-antistoffen tegen collageen type I blijken immers niet specifiek voor honden met kruisbandproblemen.

Alhoewel nieuwe aspecten aan het licht zijn gekomen, blijven sommige vraagtekens rond ruptuur van de VKB bij honden voortbestaan. De diagnose van gewrichtsinstabiliteit is opmerkelijk vereenvoudigd voor de praktijkdierenarts door de komst van de radiografische tibiale compressietechniek. Een vroege diagnose laat een behandeling toe in een vroeg ziektestadium. Geen enkele chirugische techniek is tot nu toe in staat om de normale biomechaniek ter hoogte van het aangetaste kniegewricht te herstellen.

Levendige discussies zullen gevoerd worden zolang niet meer eenduidige aanwijzingen gevonden worden over de oorzaak van kruisbandproblemen bij de hond. Enkel een beter inzicht in het ziekteverloop van VKB-ruptuur zal de kansen op meer doeltreffende behandelingen verhogen. Daarenboven zou misschien eveneens kunnen vermeden worden dat ook de VKB in de andere knie op termijn aangetast wordt.

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Hilde

CURRICULUM VITAE

Hilde de Rooster werd geboren op 27 september 1969 te Sint-Niklaas. In 1987 beëindigde ze haar humaniora-opleiding aan het Sint-Theresia College te Kapelle o/d Bos, richting Latijn-Wiskunde. In datzelfde jaar werd de studie Diergeneeskunde aan de Universiteit Gent aangevat. Ze promoveerde in 1993 met grote onderscheiding tot Doctor in de Diergeneeskunde. Met haar eindestudiewerk getiteld “Ruptuur van de craniale gekruiste band bij de hond - Radiografische diagnose met de tibiale compressie techniek en behandeling met behulp van een polyesterligament.” (Promotoren : Dr. B. Van Ryssen, Prof. Dr. H. van Bree) werd ze bekroond als laureaat van de Waltham Award 1993. Het onderzoek als laatstejaarsstudente had haar interesse in onderzoek, en in knieproblematieken bij de hond in het bijzonder, gewekt. Na het beëindigen van de studies Diergeneeskunde aan de Universiteit van Gent, vertrok ze naar Schotland waar ze in 1994 met het proefschrift getiteld “Surgical treatment of patellar luxation in dogs - Retrospective findings after wedge recession sulcoplasty and/or tibial tuberosity transposition.” (Supervisor: Mr. A. Miller) haar Masters Degree in Small Animal Orthopaedics (MVM) behaalde aan Glasgow University Veterinary School. Sedert haar terugkeer is ze werkzaam als praktijkdierenarts in een groepspraktijk in Berchem. In 1995 keerde ze ook terug naar de Universiteit van Gent, waar ze deeltijds als onbezoldigd medewerker aan de vakgroep Medische Beeldvorming van de Huisdieren verbonden was. In juli 1999 werd het getuigschrift van de Doctoraatsopleiding in de Diergeneeskundige Wetenschappen uitgereikt. In februari 2000 werd haar een personeelsmandaat toegekend via een project ten laste van het Bijzonder Onderzoeksfonds van de Universiteit Gent. Deze beurs liet haar toe om aan de vakgroep Medische Beeldvorming van de Huisdieren dit proefschrift over ruptuur van de voorste kruisband af te werken. De huidige inzichten over kruisbandproblematiek bij de hond zullen leiden tot verdere onderzoeken naar immunopathologische mechanismen die betrokken zijn bij deze vaak voorkomende aandoening.