Acta orthop. scand. *49*, 407–414, 1978

IMMEDIATE EFFECTS OF MENISCECTOMY ON THE KNEE JOINT

The Effects of Tensile Load on Knee Joint Ligaments in Dogs

NILS ORETORP,* ANDERS ALM,* HANS EKSTRÖM** & JAN GILLQUIST*

Department of Surgery and the Department of Mechanical Design Engineering,
University of Linköping, Sweden.

Tensile strength variables for the collateral ligaments were compared after excision of the meniscus in one knee, the corresponding meniscus in the contralateral knee of the same dog being intact. Removal of the meniscus was associated with a three-fold increase in initial laxity, two-fold for the lateral and three-fold for the medial ligament. The maximum tensile load uptake of the medial collateral ligament was reduced by more than 10 per cent after medial meniscectomy; the load uptake of the lateral ligament was not affected by lateral meniscectomy. It is proposed that tensile loads are distributed more favourably in the medial collateral ligament by the intact medial meniscus with firm capsular attachments than in the "normal" ligament after meniscectomy.

Key words: knee joint; ligament articular; semilunar cartilage; tensile strength

Accepted 22.i.78

Many different functions have been attributed to the menisci of the knee joint. Smillie (1970) maintains that the menisci increase the stability of the joint "by deepening the tibial surface and filling in the dead space". Slocum & Larson (1968) describe rotatory instability of the knee joint, and state that the medial meniscus to some extent blocks this instability by virtue of the posterior horn volume. Wang & Walker (1974) found experimental evidence of a rotatory stabilizing function of the menisci. Fairbank (1948) also suggested a weight-bearing function. Several others believe that the stability of the knee joint is impaired after medial meniscectomy (Smillie 1970, Johnson et al. 1974, Kennedy et al. 1974).

This study was designed to answer the following questions.

1. Do the menisci contribute to the stability of the knee joint?
2. If so, is the stabilizing effect due only to the volume and form of the menisci; or is it dependent on the close anatomical relationship between the meniscus and collateral ligament on the medial side and is consequently confined to this compartment?
3. Is the maximum load uptake of the medial collateral ligament affected by meniscectomy?

---

* Department of Surgery, University Hospital, S-581 85 Linköping, Sweden.

** Faculty of Technology, University of Linköping, S-581 85, Linköping, Sweden.

MATERIAL AND METHODS

The study was performed on beagle dogs of average weight 11.7 kg (range 7.7–17.5) and mean age 12 months (range 11–13). They were bred at the same kennels, and were all in good condition at the time of killing. Two different series were studied separately.

Series A. Twenty joints from 10 animals were used to compare the tensile strengths of the right and left medial collateral ligaments. Meniscectomy was not done on these joints, which had been frozen before the tests.

Series B (Figure 1). Another series of fresh samples was run to compare the tensile strength of one collateral ligament of one knee with that of the corresponding ligament of the other knee from the same animal, on the one side in the presence of the intact meniscus and on the other after removal of that structure. The groups were selected at random. This series comprised fresh knee joints from 40 dogs, the tests being carried out within 2–10 hours of killing. During this time all specimens were kept cool. The load-deformation curves were analysed, and the results treated statistically by the usual methods (Snedecor & Cochran 1967).

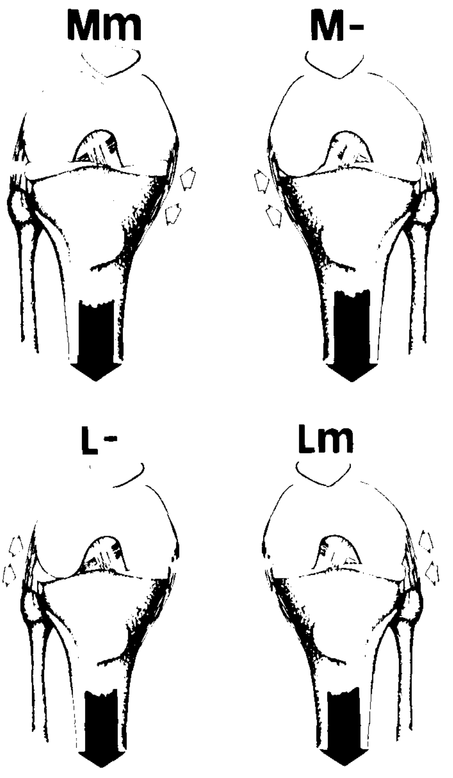

Figure 1. Tensile load applied to the medial or lateral collateral ligament in both *knees of the same animal. All other capsular and ligamentous structures divided. The corresponding (medial or lateral) meniscus on* one *knee removed before load application. Arrows indicate the tested ligament.*

Preparation of specimens

After killing, the hind legs were disarticulated at the hip joints. The femur and tibia were freed from muscles without opening the knee capsule or interfering with ligament structures. The free ends of the femur and tibia were placed in aluminium cylinders. After centring, the bone was fixed in position with Wood's metal type B at 58°C. The bone, Wood's metal, and the cylinders were then transfixed with pins. This technique permits rigid fixation of both femur and tibia, leaving the knee joint and its capsular structures intact.

Before dissection, the angle between the tubes in full extension was measured for each specimen to guarantee accurate positioning in the machine. The fibres of the collateral ligament were then identified and dissected free. Identification of the most anterior and most posterior fibres was facilitated by lateral angulation of the joint at different degrees of extension and flexion. Two short incisions were made in the capsule, at the anterior and posterior borders of the ligament parallel to the fibres (Figure 2). The purpose of this incision was to facilitate the following dissection after mounting (see below), eliminating accidental injury to the collateral ligament fibres. At this point (in series B) it was announced whether the joint was to be tested with the meniscus intact or excised. Joints with intact menisci were then mounted in the machine, subsequent dissection being done with the aluminium cylinders rigidly fixed. All structures except the ligament to be tested were then divided.

Removal of meniscus

An incision was made along the periphery of the meniscus starting at the anterior end of the cartilage, with the knee flexed 90°. When the anterior and middle third had been separated from the capsule the meniscus was divided transversely (Figure 3) and the detached segment taken out. The posterior horn was thus left in place together with the intact posterior capsule, the collateral ligaments, and the cruciates while the specimen was being mounted in the machine. These intact ligaments guaranteed correct anatomical positioning of the joint. When the preparation had been rigidly mounted the cruciates, the posterior capsule, and the collateral ligament not being

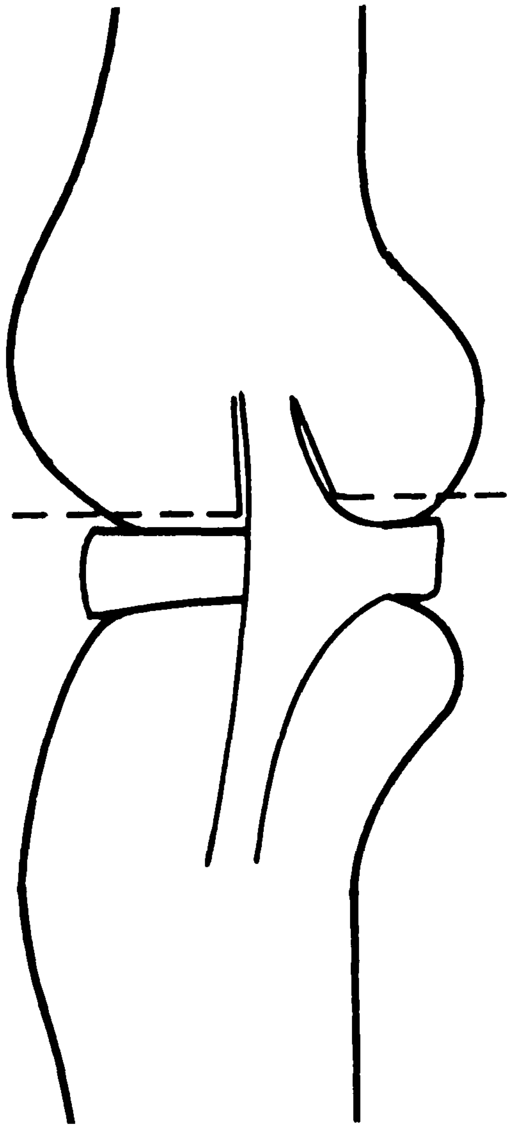

Figure 2. Incisions parallel to fibres of the collateral ligaments before mounting (—) and before excision of meniscus. Incisions made after mounting (- - - -).

tested were divided. With the posterior capsule wide open the posterior horn could then easily be cut out with the scalpel under full view. The entire meniscus could thus be excised without risk of damage to the ligament to be tested.

Equipment

A material testing system (MTS 5 Mp, MTS Corporation, Minneapolis, Minnesota, USA) with

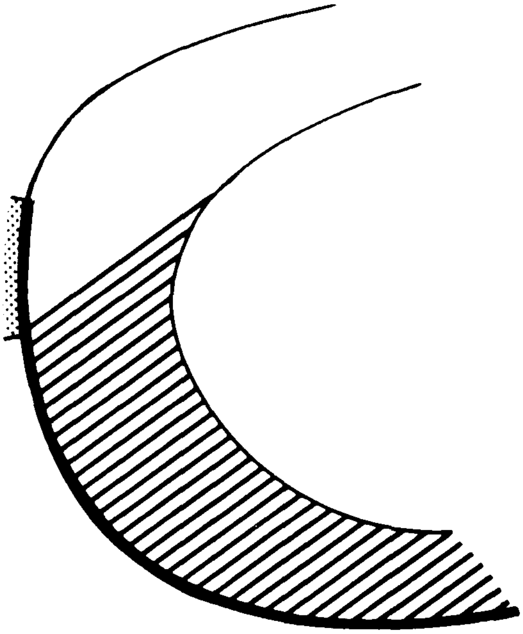

Figure 3. ▨ Meniscus segment excised before mounting (M-, L-) (▬) Meniscus and its attachment to the capsule divided. ☐ Segment removed after mounting, before test.

an error of ± 1 per cent of the recorded load was used. All tests were carried out at a deformation rate of 15 mm/s. The deformation of the test structures was recorded with an inductive transducer built into the movable piston of the machine. The load was registered as a function of the deformation on a Bryans 26000 xy-recorder (Bryans Southern Instruments Ltd, Mitcham, Surrey, England).

Symbols and definitions

Maximum load — maximum tensile load corrected for body weight (Pmax, N/kg b.w., Figure 4).
Elasticity angle — the angle between the linear part of the curve and the horizontal axis (α, °).
Laxity — the distance on the load deformation diagram from zero to the point extrapolated from the linear part of the curve on the x-axis (δ_0, mm).
Elongation — the elastic and plastic phase of deformation projected on the x-axis (δ_1 mm).
Total elongation — the sum of laxity and elongation phase (mm).
Ligament - condyle distance — the distance from the tested ligament to the midpoint of the femorotibial contact area on the contralateral tibial condyle (MFTC) (c, mm).

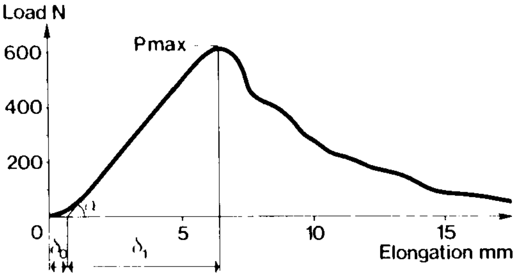

Figure 4. Characteristic load-deformation diagram for a ligament, showing three phases: the initial laxity (the "toe"), the second phase of elastic deformation, and the third phase of plastic deformation.

Laxity angle — the approximate angle (β) corresponding to the laxity phase when the vertical deformation movement is theoretically converted into an angulation in the transversal plane with an axis through MFTC. $\mathrm{Tg}\,\beta = \frac{\delta_0}{c}$.

Rupture angle — the approximate angle (γ) corresponding to the total elongation of the ligament when the vertical deformation is theoretically converted into a transverse angulation with an axis through MFTC. $\mathrm{Tg}\,\gamma = \frac{\delta_0 + \delta_1}{c}$

RESULTS

Series A (n = *20):* The twenty controls showed a coefficient of variation between right and left legs of ±5.4 per cent with regard to ***maximum load at rupture*** of the medial collateral ligaments. The difference between right and left was not significant. Concerning *laxity*, the difference between right and left was not statistically significant, but *elongation* was significantly less on the right side than on the left ($P < 0.02$). Small unexpected aberrations in the linear part of the curve were seen more often for the left ligament than for the right (Figure 5).

Series B (n = *80):* The following results were obtained: Table 1 shows the *laxity* of the medial collateral ligament. With the mensicus intact the values were higher at 30° flexion than with the knee extended ($P < 0.02$). After excision of the mensicus (Group M-) the values were still higher, both in extension ($P < 0.001$) and 30° flexion ($P < 0.02$). The corresponding values for the lateral collateral ligament (Table 2) were also significantly higher ($P < 0.001$) after excision of the lateral

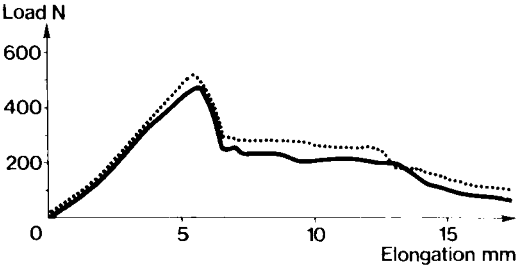

Figure 5. Load-deformation diagram of right (.....) and left (–) medial collateral ligaments from the same animal. An aberration is seen in the curve for the left ligament before breaking point. Apart from this there is close agreement between the two sides before the rupture. The diagram also shows that continuity of the ligament is lost at a late stage and at great deformation.

Table 1. The laxity (δ_0, mm) of the medial collateral ligament with intact (Mm) and extirpated (M-) medial meniscus in different positions of the knee joint (mean ± s.e.m.). All structures but the test ligament were divided in four dogs before fixation in the test machine, and these figures were therefore excluded from this part of the study.

	Medial meniscus		
Test position	intact (Mm)	extirpated (M-)	
extension ($n = 11$)	0.26 ± 0.17	0.75 ± 0.29	$P < 0.001$
flexion 30° ($n = 14$)	0.50 ± 0.28	0.75 ± 0.25	$P < 0.02$
	$P < 0.02$	n.s.	

Table 2. The laxity (δ_0, mm) of the lateral collateral ligament with intact (Lm) and extirpated lateral meniscus (L-). All tests were carried out on the extended joint.

	Lateral meniscus		
Test position	intact (Lm)	extirpated (L-)	
extension ($n = 11$)	0.31 ± 0.19	0.54 ± 0.21	$P < 0.001$

Table 3. The maximum load (P_{max} N/kg body weight) for the medial (Mm, M- resp.) and lateral (Lm, L- resp.) collateral ligaments with intact and with extirpated meniscus.

	Meniscus		
Tested ligament	intact	extirpated	
Medial coll. lig. ($n=29$)	44.1 ± 10.7	38.8 ± 9.8	$P < 0.001$
Lateral coll. lig. ($n=11$)	43.7 ± 6.8	43.9 ± 9.1	n.s.

meniscus (Group L-). The *laxity* in Group M- was, however, significantly higher than in Group L- when tested in the same position ($P < 0.05$). There was no significant difference in elongation of the collateral ligament between groups Mm and M- and Lm and L-, respectively (means for the medial collateral ligament 5.01 ± 0.80 in extension and 5.59 ± 0.68 in 30° flexion).

The Young modulus of elasticity for collagenous structures was not calculated owing to lack of precise methods for studying the cross-sectional area of the ligament (Ellis 1969).

The values for *maximum load* were lower after medial meniscectomy (see Table 3). The tests on the medial collateral ligament with intact meniscus showed a mean load at rupture of 44.1 ± 10.7 N/kg body weight, whereas the other knees from the same dogs showed a mean load at rupture of only 38.8 ± 9.8 N/kg body weight after excision of the medial meniscus. This difference is highly significant ($P < 0.001$). Excision of the lateral meniscus caused no significant change in tensile strength of the lateral collateral ligament.

With the approximation that transverse angulation of the tibia occurs about an axis through the midpoint of the tibial condylar surface when this is under compression and not subject to sliding and rotation, the *laxity* and *rupture angles* were calculated from the following formulae

$$\mathrm{Tg}\,\beta = \frac{\delta_0}{c} \text{ and } \mathrm{Tg}\,\gamma = \frac{\delta_0 + \delta_1}{c}$$

The *mean laxity angle* increased in both groups after medial meniscectomy from 0.7° to 2.1°, and after lateral meniscectomy from 0.7° to 1.2°, when tested under extension. The *rupture angle* showed no significant change after meniscectomy (medial mean 15.9°, and lateral mean 13.3°).

Localization of tear in ligament

Nearly 80 per cent of the tears on the medial side took place 1/2–1 cm below the condylar surface of the tibia, that is, where deep fibres of the ligament are inserted and the superficial fibres ride over the convex part of the tibial surface. The other 20 per cent were situated at the proximal and distal insertions of the ligament. Groups Mm and M- showed no observable difference concerning type or localization of the tear. The lateral tears revealed a weak point just at the fibular insertion of the ligament, where most tears occurred.

DISCUSSION

For practical and ethical reasons it is often impossible to obtain suitable human material. Many biomechanical investigations have therefore been done on tendon and ligament preparations from rats, rabbits, cats, dogs, monkeys and other species (Smith 1954, Viidik & Lewin 1966, Matthews & Ellis 1968, Haut & Little 1969, Gupta et al. 1971, Welsh et al. 1971 and Noyes et al. 1974). The gross morphology of the knee joint with regard to menisci and cruciate and collateral ligaments is essentially similar in man and many breeds of dogs, and like some other researchers (Marshall & Olsson 1971, O'Donoghue et al. 1971, Alm et al. 1974) we therefore used dogs for this study. Caution should be exercised, however, when applying these results to human conditions.

The increased laxity of the ligament after removal of a meniscus might suggest that the structure has in some way undergone change. Laxity was increased not only for the medial collateral ligament after medial meniscectomy, however; the lateral collateral ligament also showed increased laxity after lateral meniscectomy in spite of the known absence of anatomical relations between the meniscus and ligament in this compartment. This means, then, that resection of the anterior and middle two-thirds of the meniscus with all ligaments and practically all capsular structures intact leads to a slight but significant alteration in femoro-tibial orientation, which in turn implies that the menisci are normally under pre-stress when no external tension or compression is applied. Owing to their form and position the menisci will then come under further stress when the joint is compressed by weight-bearing. These changes in the initial part of the tension-load-deformation curve therefore corroborate the theory that the menisci have a weight-bearing function. Preliminary studies on load-deformation due to compression forces in human knee joints before and after meniscectomy have been published by Seedom et al. (1974), who found the part played by the meniscus in weight-bearing to be about 50 per cent. Using pressure transducers on cadaver knees Walker & Erkman (1975) also found the menisci to take up at least 50 per cent of the total load through the joint, more being taken up on the lateral side than the medial. Apart from the finding of normal meniscus pre-stress we are unable on the basis of our present findings to assess further the contribution of the menisci in weight-bearing. The pre-stress of the menisci reflected by our figures for *laxity* seems to vary with flexion and extension. Walker & Hajek (1972) studied the part played by the menisci in the contact stress on the central areas of the articular cartilage, and found reduction in contact stress especially at the extremes of motion. Our results correspond with this. However, laxity and pre-stress are affected by the mutual relations of the joint mechanics and ligament insertions in different positions of the joint.

As we have shown, meniscectomy may also lead to a three-fold increase in transverse angulation. An initial laxity of 2° might seem too small to be of any importance. Nevertheless, in a study on weight transmission through the human knee joint Kostuik et al. (1975) found that a lateral angulation of 3° in either direction completely disburdened the opposite condyle. Consequently, this apparently minor change after meniscectomy may have far-reaching mechanical consequences for the joint. Furthermore, experimentally induced instability of the knee joint in dogs is known to promote degenerative changes (Marshall & Olsson 1971, O'Donoghue et al. 1971), and such changes are seen also in man (Salter 1970). The increased laxity and alteration in femoro-tibial orientation we have found may help to explain the high incidence of degenerative changes in the human knee joint cartilage (Fairbank 1948, Tapper & Hoover 1969, Dandy & Jackson 1975) after meniscectomy.

The increase in laxity was greater after excision of the medial than the lateral meniscus, suggesting that factors other than mere loss of meniscus volume may be in operation on the medial side. Meniscectomy may possibly lead to unavoidable disturbance of the intimate relationship between the meniscus and the medial ligament complex. Surprisingly, the leaving behind of a small rim of meniscus in a few cases did not seem to influence the result. The effects of this anatomical relationship on the tensile properties of the ligament have not been investigated in man.

The maximum tensile strength also differed on the medial and lateral sides. As expected, meniscectomy did not affect the tensile properties of the lateral collateral ligament, but the maximum tensile strength of the medial ligament diminished by 12 per cent. A corresponding reduction in elongation might have been expected, but this was not significant. The tear occurred not at the level of the excised meniscus but more distally, however. Furthermore, also when a small rim remained the medial ligament proved less resistant than in intact knees. Trauma to the fibres would thus not seem to be the cause of the reduced tensile strength of the medial ligament after meniscectomy. Hypothetically, the stress over the tibial area, where most of the ruptures occurred, would appear to be better distributed under physiological conditions by the intact bonds between the medial meniscus and the ligament than after meniscectomy.

The strength of the medial collateral ligament in dogs has also been studied by Tipton et al. (1970). If their figures for separation force are corrected for mean body weight, the ligament in the trained group of dogs showed a mean strength of only 27.0 N/kg body weight, that is, much lower than in this study. The material differed, however, and furthermore the deformation rate was only 0.25 mm/s. Collagenous tissue shows a strain-rate sensitivity. At high rates of deformation, tissue elasticity is changed, collagenous tissue tolerates a greater load before rupture, and the incidence of ligamentous tears will exceed the incidence of bone avulsion (Noyes et al. 1974). Our findings consequently seem more physiological.

Elongation was the only factor that showed a significant difference between right and left. This is not accompanied by a significant change in stiffness (tan α) between the compared ligaments, however. The difference seemed instead to be due to small aberrations in the curve, commoner in the left-side preparations than in the right. It cannot be determined whether these changes in deformation of the bone-ligament-bone preparation occur within the ligament substance or at the insertions. It seems quite possible that the aberrations could represent tears of isolated fibre bundles before ligament failure occurs, and in fact such microscopical breaches preceding ultimate disruption have been described (Noyes et al. 1974). Differences in tensile properties and elasticity of bone-ligament-bone preparations between trained and untrained limbs have also been reported (Viidik 1968, Laros et al. 1971). Viidik (1968) felt that qualitative changes must take place within the ligamentous tissues owing to differences in the load-relaxation phenomenon. Our findings may indicate that there is some qualitative difference in the medial collateral ligaments on the dominant and non-dominant sides.

Summary and conclusions

The knee joint of beagle dogs, which bears essential similarities to the human knee joint, showed the following changes after excision of the medial or lateral meniscus.

1. Removal of a medial or lateral meniscus leads to a small but significant change in the laxity of the joint. The results indicate that the menisci are normally under prestress.
2. The increase in laxity angle is nearly two-fold after removal of the lateral meniscus and three-fold after removal of the medial, the greater increase after medial meniscectomy possibly being due to disturbance of the intimate anatomical relationship between the medial meniscus and the deep capsular fibres of the medial collateral ligament.
3. The medial collateral ligament shows a reduction of load at failure of more than 10 per cent *immediately* after meniscectomy.
4. The results accord with previous compression load investigations, indicating that the meniscus may have a load-bearing function. With this experimental model, however, the magnitude of this function cannot be studied.

ACKNOWLEDGEMENT

The authors wish to extend their thanks to the staff of the Toxicological Laboratory ASTRA AB, Södertälje, Sweden, who kindly supplied us with specimens. Financial support was provided by the Swedish Medical Research Council (Projekt nr 17X-3916, 17X-645).

REFERENCES

Alm, A., Ekström, H. & Strömberg, B. (1974) Tensile strength of the anterior cruciate ligament in the dog. *Acta chir. scand.*, Suppl. 445, 15–23.

Appel, H. (1970) Late results after meniscectomy in the knee joint. A clinical and roentgenologic follow-up investigation. *Acta orthop. scand.* Suppl. 133.

Dandy, D. J. & Jackson, R. W. (1975) The diagnosis of problems after meniscectomy. *J. Bone Jt Surg.* **57**-B, 349–352.

Ellis, D. G. (1969) Cross-sectional area measurements for tendon specimens: a comparison of several methods. *J. Biomech.* **2**, 175.

Fairbank, T. J. (1948) Knee joint changes after meniscectomy. *J. Bone Jt Surg.* **30**-B, 664–670.

Gupta, B. N., Subramanian, K. N., Brinker, W. O. & Gupta, A. N. (1971) Tensile strength of canine cranial cruciate ligaments. *Amer. J. vet. Res.* **32**, 183–190.

Haut, R. C. & Little, R. W. (1969) Rheological properties of canine anterior cruciate ligaments. *J. Biomech.* **2**, 289–298.

Johnson, R. J., Kettelkamp, D. B., Clark, W. & Leaverton, P. (1974) Factors affecting late results after meniscectomy. *J. Bone Jt Surg.* **56**-A, 719–729.

Kennedy, J. C., Weinberg, H. W. & Wilson, A. S. (1974) The anatomy and function of the anterior cruciate ligament. *J. Bone Jt Surg.* **56**-A, 223–235.

Kostuik, J. P., Schmidt, O., Harris, R. W. & Wooldridge, C. (1975) A study of weight transmission through the knee joint with applied varus and valgus loads. *Clin. Orthop.* **108**, 95–98.

Laros, G. S., Tipton, C. M. & Cooper, R. R. (1971) Influence of physical activity on ligament insertions in the knees of dogs. *J. Bone Jt Surg.* **53**-A, 275–286.

Marshall, J. L. & Olsson, S. E. (1971) Instability of the knee: a long-term experimental study in dogs. *J. Bone Jt Surg.* **53**-A, 1561–1570.

Matthews, L. S. & Ellis, D. G. (1968) Viscoelastic properties of cat tendon: Effects of time after death and preservation by freezing. *J. Biomech.* **1**, 65–71.

Noyes, F. R., Delucas, J. L. & Torvik, P. J. (1974) Biomechanics of anterior cruciate ligament failure. An analysis of strain-rate sensitivity and mechanisms of failure in primates. *J. Bone Jt Surg.* **56**-A, 236–253.

O'Donoghue, D. H., Frank, G. R., Jeter, G. L., Johnson, W., Zeiders, J. W. & Kenyon, R. (1971) Repair and reconstruction of the anterior cruciate ligament in dogs. Factors influencing long-term results. *J. Bone Jt Surg.* **53**-A, 710–718.

Salter, R. B. (1970) *Textbook of disorders and injuries of the musculo-skeletal system*, p. 195. Williams & Wilkins Co, Baltimore.

Seedom, B. B., Dowson, D. & Wright, V. (1974) The load-bearing function of the menisci: a preliminary study. *Proceedings of the International Congress, Rotterdam*, September 1973. *The knee joint*, p. 37–42, Excerpta Medica, Amsterdam.

Slocum, D. B. & Larson, R. L. (1968) Rotatory instability of the knee. *J. Bone Jt Surg.* **50**-A, 211–225.

Smillie, J. S. (1970) *Injuries of the knee joint.* p. 31. Livingstone, London.

Smith, J. W. (1954) The elastic properties of the anterior cruciate ligament of the rabbit. *J. Anat.* **88**, 369–380.

Snedecor, G. W. & Cochran, W. G. (1967) *Statistical methods.* Iowa State University Press, Iowa.

Swanson, S. A. V., Freeman, M. A. R. & Day, W. H. (1971) The fatigue properties of human cortical bone. *Med. biol. Engng* **9**, 23.

Tapper, E. M. & Hoover, N. W. (1969) Late results after meniscectomy. *J. Bone Jt Surg.* **51**-A, 517–526.

Tipton, C. M., James, S. L., Mergner, W. & Tcheng, T. K. (1970) Influence on the strength of the medial collateral knee ligaments of dogs. *Amer. J. Physiol.* **218**, 894–901.

Viidik, A. & Lewin, T. (1966) Changes in tensile strength characteristics and histology of rabbit ligaments induced by different modes of postmortal storage. *Acta orthop. scand.* **37**, 141–155.

Viidik, A. (1968) Function and structure of collagenous tissue. Investigation on the tensile strength, general rheology and morphology of tendons and joint ligaments in the rabbit. Doctoral Dissertation Göteborg.

Walker, P. S. & Erkman, M. J. (1975) The function of the menisci of the knee. Proceedings of the American Academy of Orthopedic Surgeons. *J. Bone Jt Surg.* **57**-A, 1028.

Walker, P. S. & Hajek, J. V. (1972) The load bearing area in the knee joint. *J. Biomech.* **5**, 581–589.

Wang, C. J. & Walker, P. S. (1974) Rotatory laxity of the human knee joint. *J. Bone Jt Surg.* **56**-A, 161–170.

Weightman, B. O., Freeman, M. A. R. & Swanson, S. A. V. (1973) Fatigue of articular cartilage. *Nature (Lond.)* **244**, 303–304.

Welsh, R. B., McNab, I. & Riley, V. (1971) Biomechanical studies of rabbit tendon. *Clin. Orthop.* **81**, 171–177.

Correspondence to: Nils Oretorp, Dept. of Surgery, Linköping University, S-581 85 Linköping, Sweden.