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The Anterior Cruciate Ligament of the Knee: An Experimental Study of its Importance in Rotatory Knee Instability

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Summary. The importance of the anterior cruciate ligament (ACL) in relation to valgus-varus and axial rotation stability in the knee joint was investigated. Mobility patterns were drawn from ten osteoligamentous preparations after successive transection of the two parts of the ACL and the medial (MCL) and lateral collateral ligaments (LCL). The knee joint remained grossly stable after partial injury of the ACL, while sectioning of the entire ACL caused an increase in internal rotation in the extended-semiflexed position. Combined lesions to the ACL and the MCL caused considerable valgus instability increasing with flexion, the joints remaining stable in extension. Moreover, marked anteromedial instability occurred, while only slight posteromedial instability was found. Combined lesions to the ACL and the LCL caused varus instability, worst in the semiflexed position, and a consistent pivot shift in applying a valgus torque in flexion was noted. Moreover, moderate posterolateral instability was found, at its maximum in the semiflexed position. External rotatory stability is secured primarily by the MCL, secondarily by the posterior medial capsule, and finally by the ACL. The existence of lateral pivot shift is proof of damage to the ACL.

Zusammenfassung. Die Bedeutung des vorderen Kreuzbandes (ACL) des menschlichen Kniegelenkes bezüglich der Varus-Valgus- und der axialen Rotationsinstabilität wurde untersucht. An osteoligamentären Kniegelenkpräparaten wurden die Bewegungsabläufe nach schrittweiser Duchtrennung der beiden Anteile des ACL und des medialen (MCL) und lateralen (LCL) Seitenbandes aufgezeichnet. Das Kniegelenk blieb nach nur teilweiser Durchtrennung des ACL im wesentlichen stabil, während eine vollständige Durchtrennung eine zunehmende Innenrotation, sowohl bei voller Streckung als auch in halbgebeugter Stellung des Kniegelenkes zur Folge hatte. Kombinierte Verletzungen des ACL und des MCL riefen bei zunehmender Beugung eine beträchtliche Valgus-Instabilität hervor, wobei das Gelenk bei voller Streckung jedoch immer noch stabil war. Darüber hinaus konnte eine deutliche anteromediale — bei nur geringer posteromedialer — Rotationsinstabilität verzeichnet werden. Eine kombinierte Durchtrennung des ACL und des LCL erzeugte eine Varus-Instabilität, am deutlichsten in halbgebeugter Stellung des Gelenkes. Regelmäßig konnte ein Pivot-shift-Phänomen ausgelöst werden. Hinzu kam eine mäßige posterolaterale Instabilität mit maximaler Ausprägung in halbgebeugter Stellung. Die außenrotatorische Stabilität des Kniegelenkes wird in erster Linie durch das MCL, danach durch die hintere Gelenkkapsel und erst zuletzt durch das ACL gewährleistet.

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The cruciate ligaments, especially the anterior one (ACL), are generally considered to be of great importance in the control of internal and external rotation in the knee joint [7, 8, 14].

In 1944, Abbott et al. [1] found that the ACL consists of a smaller anteromedial part and a larger posterolateral part. Moreover, they found that in flexion only the anterior part was tight. Furman et al. [3] studied the importance of these two structures in knee stability, but the torque which they used was not clearly defined, and the instability found after ligament transections was only recorded at a few positions during flexion-extension.

Our intention in the present investigation was to clarify the role of the ACL by cutting its fascicles, either alone or together with the collateral ligaments, and recording rotatory instability continuously during flexion-extension under well-defined torque.

Material and Method

The experiments were carried out on ten macroscopically normal osteoligamentous knee preparations obtained at autopsy and deep-frozen immediately after removal. All dynamically stabilizing structures were removed at dissection, but the menisci, the cruciate ligaments, the collateral ligaments, and the posterior joint capsule with its posterior oblique, popliteal oblique, and popliteal arcuate ligaments were preserved.

The experimental set-up and the methods of measuring and registration have been described in other reports [11, 11a], but are briefly recapitulated here.

In each preparation the femur was fixed horizontally in a stand and a lever was mounted in continuation with the tibial shaft. The lever was fitted with strain gauges for the measurement of torque in three planes corresponding to flexion-extension, varus-valgus movement, and internal-external rotation. Thus one set of strain gauges was of the torque-sensitive type, the others of the conventional sort, sensitive to bending forces. The movements corresponding to the torques exerted were measured by potentiometers connected to the lever.

The lever, and thereby the tibia, was operated manually, and the knee joint was moved from the extended position into 135° of flexion and back again during simultaneous exertion of partly varus and partly valgus torque. The extension-flexion movement was then repeated with simultaneous application of internal and external torque respectively. Signals from strain gauges and potentiometers passed through an amplifier and a data acquisition system to a microcomputer, which stored the measurements. The results were calculated for a torque of exactly 3 Nm and the final mobility patterns were plotted at a regional computer service center (RECAU). All rotation curves were recorded with the tibia in a neutral position concerning the varus-valgus angulation, and vice versa.

The study was divided into two series, each comprising five preparations. Registration of stability was performed at various ligament statuses. (For convenience the following abbreviations are used: AMP, anteromedial part; PLP, posterolateral part; LCL, lateral collateral ligament; MCL, medial collateral ligament.)

First Series: (a) Ligaments intact; (b) AMP of ACL cut; (c) entire ACL cut; (d) ACL and MCL cut; (e) ACL and MCL cut plus medial meniscectomy.

Second Series: (a) Ligaments intact; (b) PLP of ACL cut; (c) entire ACL cut; (d) ACL and LCL cut; (e) ACL and LCL cut plus lateral meniscectomy.

Results

First Series

After transection of the AMP of the ACL, the joint remained stable apart from a slight increase in internal rotation in the semiflexed position. Cutting of the entire ACL caused slight valgus instability, maximal at 30° of flexion (Fig. 1). Moreover, an increase in internal rotation of 0°–30° was found, at its most in extension (Fig. 2).

Combined transection of ACL and MCL caused considerable valgus instability, growing with increasing flexion but not present in extension (Fig. 1). Furthermore, there was a pronounced increase in external rotation instability of the anteromedial type which also increased with the amount of flexion (Fig. 2). This instability was twice as great as that which we earlier found after isolated injury of the MCL [11a]. Abnormal internal rotation in the form of posteromedial instability was found to be only 4° (Table 1), regardless of the degree of flexion or extension. After removal of the medial meniscus there was a slight increase in valgus instability, and in

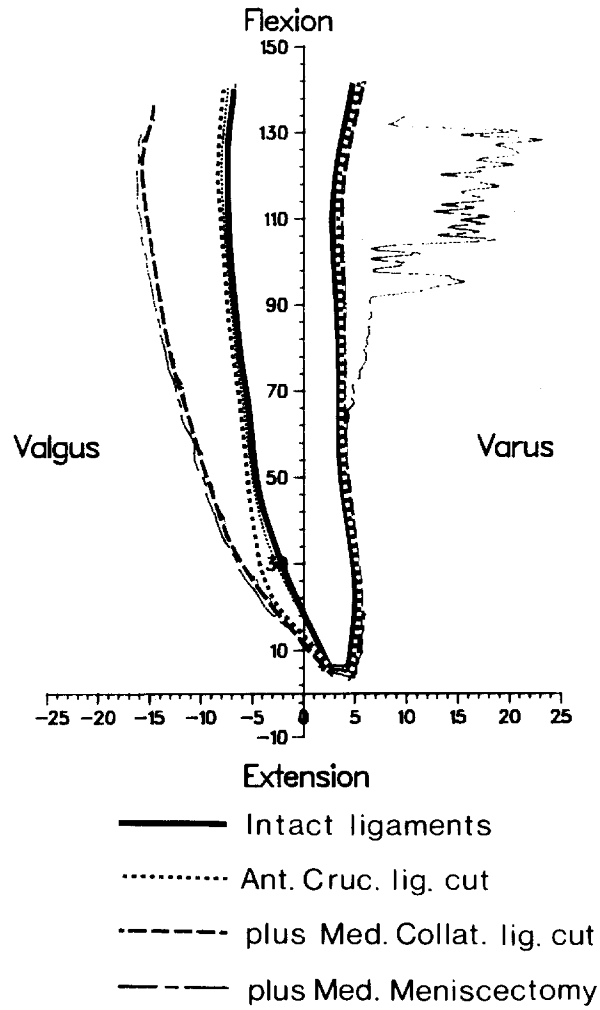

Fig. 1. Mobility pattern from the first series showing valgus-varus instability after successive cutting of the ACL and MCL plus medial meniscectomy. The apparent varus instability is due to "medial pivot shift"

some cases, even anteromedial subluxation of the tibia was seen when it was subjected to varus torque (Fig. 1).

Second Series

Combined injuries of the ACL and LCL caused varus instability of 5°–10°, maximal at about 60° of flexion (Fig. 3). In all five preparations, pivot shift (anterolateral subluxation of the tibia) was produced at about 30° of flexion when the tibia was submitted to valgus torque. Moderate posteromedial instability (5°–10°) was found, increasing with the amount of flexion, but apparently with a localized decrease at about 80° of flexion (Fig. 4). We had earlier demonstrated [11a] that isolated injury of the LCL does not cause posterolateral instability, but results in anterolateral looseness of about 5°. We now found that this instability did not increase, when the ACL was included in the transection (Table 2, Fig. 4). On lateral meniscectomy, however, there was a slight increase in the varus instability and an even slighter increase in posterolateral instability.

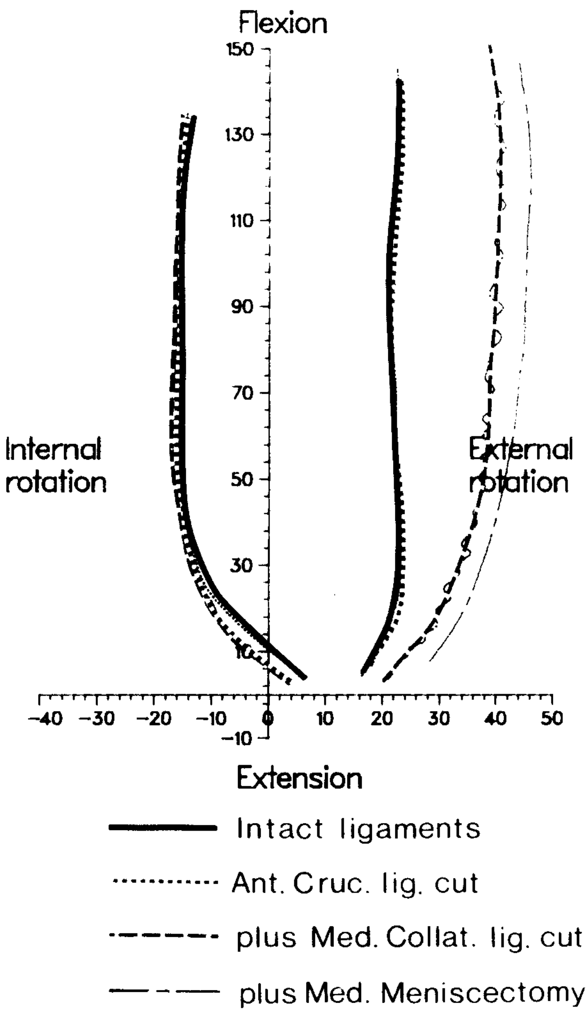

Fig. 2. Mobility pattern from the first series showing axial rotation instability. Internal and external rotation correspond to posteromedial and anteromedial rotation respectively

Discussion

Various authors have studied the function of the two parts of the ACL. Wang et al. [16] showed that the AMP had longer fibers than the PLP, and that the former was tense in flexion, the latter in extension. Their observations were later confirmed by Crowninshield et al. [2] and Girgis et al. [6]. Thus, an isolated injury of the AMP should cause some instability in the flexed knee, while damage to the PLP should render the joint unstable in extension. In 11 knee preparations, Furman et al. [3] found that isolated cutting of either AMP or PLP increased both internal and external rotation in the extended position but did not alter the stability of the flexed knee. Our investigations show that such partial transections of the ACL do not cause any instability, except for a minimal increase of internal rotation in the semiflexed position. The discrepancy between the results may be due to the fact that Furman et al. provoked the knee movements by exerting maximal manual pressure, i.e., they used a torque considerably greater than ours. However, it is essential not to use a torque which is so great that the intact ligaments undergo irreversible lengthening, as this would result in greater mobility than they would normally allow. Also after combined injury of the two parts of the ACL, Furman et al. found increased internal and external rotation at extension and in 45° and 90° of flexion, while under these circumstances we found that only internal rotation increased, and this only if the knee was stretched or slightly flexed (Figs. 2, 4). Our results are supported by those of Norwood and Hughston [12], Trent et al. [15], and Kennedy et al. [9], who clarified that the ACL was particularly effective in restraining internal rotation, while its fibers were relaxed in external rotation. Thus, one can conclude that theoretically, isolated rupture of the ACL may occur in internal rotation trauma in extension or

Table 1. The increase in instability (mean ± SD) in the first series at 30° and 70° of flexion

Injury	Flexion	Increase in instability		
		Valgus	Internal rotation	External rotation
AMP	30°	0.4° ± 0.5°	1.6° ± 1.0°	0.4° ± 0.5°
	70°	0.6° ± 0.5°	0.6° ± 0.8°	0.4° ± 0.5°
Entire ACL	30°	2.2° ± 1.6°	2.4° ± 1.9°	1.0° ± 1.1°
	70°	2.0° ± 1.5°	0.6° ± 0.8°	0.8° ± 1.2°
ACL + MCL	30°	6.0° ± 1.8°	4.0° ± 2.1°	11.4° ± 1.0°
	70°	9.4° ± 2.8°	4.0° ± 1.8°	20.8° ± 3.7°
ACL + MCL + medial meniscectomy	30°	7.8° ± 2.6°	4.6° ± 2.3°	13.4° ± 1.6°
	70°	12.6° ± 4.6°	5.4° ± 2.9°	23.8° ± 3.6°

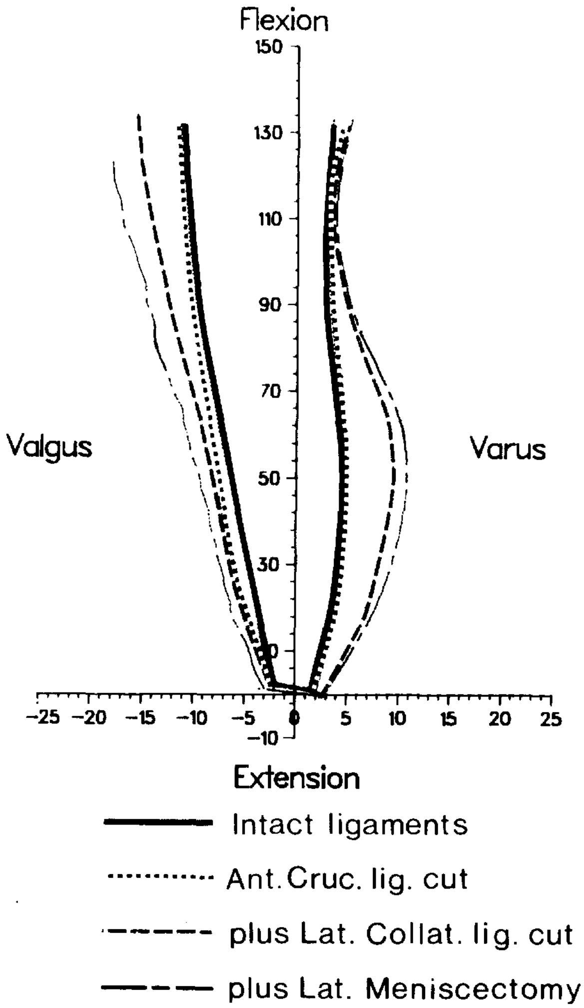

Fig. 3. Mobility pattern from the second series showing valgus-varus instability after successive cutting of the ACL and LCL plus lateral meniscectomy. The apparent valgus instability is due to pivot shift

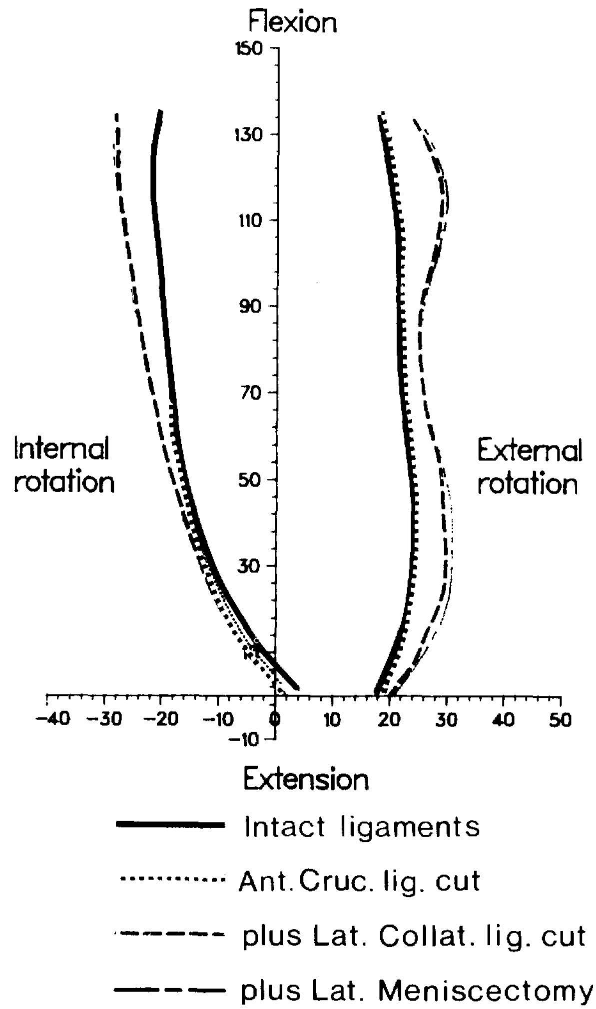

Fig. 4. Axial rotation curves from the second series. Internal and external rotation correspond to anterolateral and posterolateral rotation respectively

Table 2. The increase in instability (mean ± SD) in the second series at 30° and 70° of flexion

Injury	Flexion	Increase in instability		
		Varus	Internal rotation	External rotation
PLP	30°	0.0° ± 0.0°	0.4° ± 0.5°	0.4° ± 0.5°
	70°	0.0° ± 0.0°	0.2° ± 0.4°	0.6° ± 0.5°
Entire ACL	30°	0.4° ± 0.5°	2.2° ± 1.2°	0.4° ± 0.5°
	70°	0.4° ± 0.5°	0.4° ± 0.8°	0.6° ± 0.5°
ACL + LCL	30°	4.2° ± 2.7°	4.0° ± 2.1°	6.2° ± 2.5°
	70°	6.0° ± 3.5°	3.6° ± 1.9°	6.4° ± 3.8°
ACL + LCL + lateral meniscectomy	30°	5.4° ± 2.1°	4.2° ± 1.9°	6.8° ± 2.8°
	70°	7.0° ± 4.1°	3.8° ± 1.8°	6.8° ± 4.5°

slight flexion, but can hardly be caused by external rotation trauma.

Combined transection of the ACL and the MCL produced anteromedial rotatory instability which was about twice as pronounced as that after isolated cutting of the MCL, but smaller than that found previously after transection of the MCL and the posterior medial part of the joint capsule [11a], especially in the extended knee. This further confirms that the ACL is not primarily essential in the control of external rotation. These findings are confirmed by Slocum and Larson [14], who found that in external rotation traumas the MCL will rupture before the ACL, but contradicted by Seering et al. [13], who found that the ACL and the MCL play no part in the control of external rotation, but instead limit internal rotation. However, Seering et al. used considerably greater torque to produce movements than we did, and their results were based upon examination of only four knees. The posteromedial instability after transection of the ACL was not increased by additional cutting of the MCL. This instability was pronounced after combined injuries of the MCL and the posteromedial capsule, which shows that the posteromedial capsule plays a major role in preventing posteromedial instability. We deduce from our results that in external rotational traumas, not only the MCL but also the posterior medial capsule will rupture before the ACL. In internal rotational traumas in extension or a semiflexed position, the ACL and the posteromedial capsule will rupture before the MCL.

We tried to combine transections of the ACL and the MCl with cutting of the posterior medial joint capsule, but the knee preparations became so instable that they could not be examined by our method. Instead, we combined the transections with medial meniscectomy. This type of injury usually caused a "medial pivot shift" (Fig. 1), as simultaneous flexion and varus torque made the medial part of the tibia subluxate anteriorly.

Combined transections of the ACL and the LCL always resulted in a pivot shift, i.e., anterolateral subluxation, when the tibia was forced into valgus. Hughston et al. [7, 8] are of the opinion that an injury of the intermediate third of the lateral capsule may cause such anterolateral subluxation of the tibia, but as our experience that this instability never occurs as long as the ACL is intact confirms the statement of Galway and co-workers [4, 5] that pivot shift cannot be found unless the ACL is ruptured. Lipke et al. [10] found an increase in internal rotation after injury of the ACL, further increasing when the LCL was also damaged. We agree with this, but the instability that we found was no more pronounced than after isolated cutting of the LCL. In opposition to Lipke et al. we found posterolateral rotatory instability after cutting of the ACL and LCL together, but not so pronounced as after combined transection of the LCL and the posterior lateral joint capsule [11a]. We thus agree with Lipke et al. [10] and Hughston et al. [7, 8] that the posterolateral ligament complex is of major importance in the maintenance of posterolateral stability. In internal and external rotation traumas one usually focuses upon the state of the ACL, but as seen, greater rotatory instability can be found after combined lesions of the collateral ligaments and the posterior joint capsule than after injury of the ACL alone or even the ACL together with one collateral ligament.

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