Decrease in valgus stiffness after medial knee ligament injury

A 4-year clinical and mechanical follow-up study in 38 patients

Magnus Lundberg and Karola Messner

The clinical outcome after partial rupture of the medial collateral knee ligament is reported to be good, but there is a lack of objective assessment of persistent valgus laxity. We prospectively followed 38 consecutive patients with an isolated partial medial ligament rupture. After diagnostic arthroscopy, all patients were treated by early functional rehabilitation. At 4 years, besides clinical routine laxity tests, varus/valgus rotation, internal/external tibial rotation, initial and endpoint valgus stiffnesses, initial and endpoint internal/external rotational stiffnesses were measured by instrumented computerized passive motion analysis (Genucom). Most patients had normal knee function and muscle strength as early as 3 months after injury and returned to their pre-injury activity level without problems. At 4 years, 2 knees had minor residual valgus laxity at the manual examination, all other knees appeared stable. The instrumented tests also showed equal varus/valgus rotations and internal/external rotational stiffnesses in injured and healthy knees, but a decrease in the initial valgus stiffness and a decrease in the internal/external tibial rotation of the injured knee.

Department of Orthopedics and Sports Medicine, University Hospital, S-581 85 Linköping, Sweden.
Tel +46 13-222 000. Fax -101045
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The diagnosis of the extent of medial collateral ligament (MCL) injury is usually based on a graded classification of valgus laxity on manual examination (Marshall and Rubin 1977). Various attempts including stress radiographs (Derscheid and Garrick 1981) and instrumented testing (Lowe and Saunders 1975, Balkfors 1982) have been made to assess more objectively valgus instability after MCL rupture. Instrumented laxity tests, as commonly used today for the evaluation of sagittal knee translation after anterior cruciate ligament injury, are not routinely employed for the assessment of valgus laxity at follow-up evaluations after MCL injuries.

The objective of this study was to assess knee function and to measure varus/valgus (V/V) and internal/external (I/E) tibial rotations, and varus, valgus, internal and external rotational stiffnesses, using instrumented computerized passive 6-degrees-of-freedom motion analysis 4 years following conservative treatment of isolated grade I and II MCL injuries.

Patients and methods

38 consecutive patients, 27 men and 11 women, with a mean age of 24 (13–41) years and with no previous knee injury, had sustained an acute unilateral isolated partial rupture of the MCL, as diagnosed by manual examination under general anesthesia and acute arthroscopy. All injuries, except 4, were sports-related, soccer (18) and alpine skiing (10) being the most prominent causes. On the manual examination under anesthesia immediately prior to arthroscopy, a grade-I valgus injury, according to the classification of Marshall and Rubin (1977), was present in 16 of the patients. The remaining 22 patients had a grade-II injury. A grade-I injury is considered when there is tenderness over the MCL and a slight increase in valgus laxity at 20° of knee flexion during manual tests compared to the normal knee. A grade-II injury shows a moderate increase in valgus laxity with a definite endpoint.

All patients were treated by early functional rehabilitation with weight bearing and ambulation as soon as tolerated. Except for functional bracing or elastic wrapping, no special protection was used. All patients followed a similar program. At 3 months, most patients had regained full muscle strength compared to the uninjured leg during testing in the Cybex II dynamometer, and had returned to sporting activities.

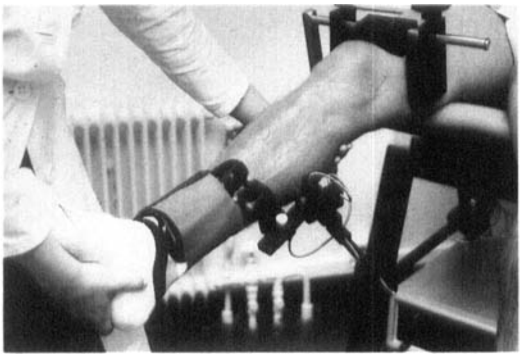

Figure 1. V/V rotation test with the Genucom knee analysis system. The patient is seated on a force plate, an electrogoniometer chain is attached to the lower leg. The test is performed manually.

Clinical follow-up evaluation

At an average of 4 years (46 [36–54] months) after injury, all patients were re-examined. Knee function was assessed with the Lysholm score (Lysholm and Gillquist 1982). The pre-injury and present activity levels were graded with a scoring scale (Tegner et al. 1985). Knee stability was evaluated by manual tests, including the Lachman, drawer, and V/V laxity tests. Signs of meniscal injury or patellofemoral disorder were recorded. V/V and I/E tibial rotational laxities, varus and valgus stiffnesses and internal and external rotational stiffnesses were assessed in 36 of the 38 patients by instrumented measurements, using the Genucom Knee Analysis System (Faro Medical Technologies Inc., Montreal, Canada).

Instrumented evaluation

The testing was performed by the first author who at this time was an approved and licensed Genucom examiner. The patient was positioned on the seat containing the force plate, the upper leg was fixed above the knee joint in a thigh-holder, and the electrogoniometer chain was attached to the lower leg (Figure 1). The healthy knee was always tested first. After the necessary soft tissue compensation and digitalization procedures, including zeroing of knee position at full extension, the following passive manual tests were performed according to the users' manual, as described by Oliver and Coughlin (1987):

V/V rotation at full knee extension (zero-position)
V/V rotation at 20° of knee flexion
I/E tibial rotation at 20° of knee flexion
I/E tibial rotation at 80° of knee flexion.

All tests were repeated a minimum of 2 times.

For testing of V/V rotation, the lower leg was lifted and the knee positioned in the desired flexion angle (Figure 1). A valgus and, immediately following, a varus moment of over 20 Nm were applied to the knee joint through the lower leg which was forced medially and laterally against the resistance of the thigh-holder. Knee flexion angle, femoral and tibial rotations, and applied torques were directly controlled and adjusted with reference to simultaneous computer readings on the screen display. The computer registered a force-moment (torque) curve. Only tests with sufficient and even torques and with involuntary tibial or femoral rotations of less than 5° were accepted. The knee flexion angle was held constant within ± 1°.

For testing the I/E tibial rotation the knee was positioned in the desired flexion angle. The lower leg was then rotated internally and externally against the resistance of the thigh-holder until a 10 Nm moment was reached at the knee joint level. Simultaneously, slight traction was applied manually through the lower leg to avoid interference from the joint surfaces. Tibial and femoral rotations, traction forces, tibial torques and knee flexion angles were displayed simultaneously. The force-moment curves were registered in tests with an even and sufficient torque and with less than 5° of change in knee flexion angle or femoral rotation.

Calculations

V/V rotation: V/V rotation was calculated by the computer program from the angular reading at 12 Nm torque which corresponds to 60 percent of the V/V torque required for an accepted test. Because the neutral position of the knee joint is difficult to identify (Shoemaker and Markolf 1985, Strobel and Stedtfeld 1990), the numerical values of valgus and varus rotations at 12 Nm were added together to give the total V/V rotation (degrees) of the joint.

I/E tibial rotation: The curve with the lowest change in flexion angle during the test was used for the calculations. The values of internal and external rotations (degrees) at an 8-Nm torque were added together to give the total I/E tibial rotation.

Varus and valgus stiffnesses and internal and external rotational stiffnesses: For the stiffness calculations the force-moment curves were used. Stiffness was calculated separately for varus, valgus, internal and external rotational measurements. On the respective curves, 2 segments around arbitrarily chosen midpoints were defined. The segment closer to origo was chosen to represent initial stiffness (IS) and the other segment to represent endpoint stiffness (ES) (Figure 2). For varus and valgus stiffnesses, a segment at around 4 Nm (± 2 Nm) was chosen for IS and at 16 Nm (± 2 Nm) for ES. Corresponding seg-

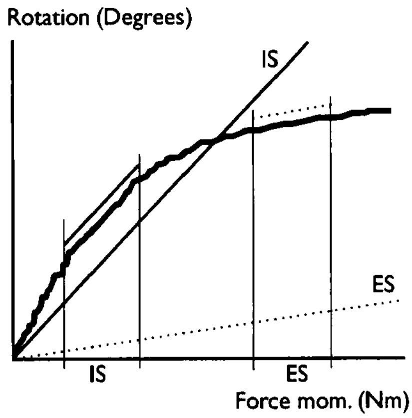

Figure 2. Calculations of the initial (IS) and endpoint (ES) valgus stiffnesses from the graphical output of the Genucom. For further explanations, see text.

Table 1. Evaluation of manual valgus laxity at trauma, at 3 months and at 4 years (number of patients)

		Instability grade	
	Stable	I	II
Trauma	0	16	22
3 months	30	7	1
4 years	36	2	0

Table 2. V/V and I/E tibial rotations (degrees, n 36). Mean *SD*

Test	Knee flexion	Injured knee	Healthy knee
V/V rotation	0°	3.0 *1.5*	3.2 *2.0*
V/V rotation	20°	8.0 *2.3*	8.1 *2.7*
I/E tibial rotation	20°	35 *8*	37 *8*
I/E tibial rotation	80°	30 *6*[a]	32 *9*

[a] Decrease compared to the healthy knee (*P* 0.04)

ments for calculations of internal and external rotational stiffnesses were chosen at 2 Nm (± 1 Nm) and 8 Nm (± 1 Nm), respectively. The stiffness of the segments was calculated after linear approximation of the slope of the curve using the formula [Stiffness (Nm/°) = 2 cosα/3 cosα] where α is the angle between the x-axis and the slope. Further, the ratios between IS and ES were calculated.

Repeatability of the measurements: The tests for V/V rotation were repeated in 14 of the original patients after a 4-month interval. The coefficient of variation was calculated for V/V rotation, varus and valgus stiffnesses (IS and ES), and varus and valgus stiffness ratios (IS/ES).

Statistics

All calculated differences were normally distributed. Accordingly, differences in stiffness and rotations between injured and healthy knees were calculated with the Student's paired *t*-test. A significance level of 5 percent was used.

Results

Clinical examination at 4 years

2 patients had sustained further knee injuries since the 3-month evaluation, one had an ipsilateral anterior cruciate ligament (ACL) tear and the other an ACL tear in the contralateral knee. Another 2 patients had knee pain resulting in a Lysholm score of 71 and 66, respectively. The other 34 patients had a Lysholm score of 95 points and above (mean 100, range, 95–100), which indicates normal knee function. 32 patients were able to perform on their preinjury and desired activity level (mean 7, SD 2).

In 2 patients with initial grade-II valgus instability, manual laxity assessment showed an increase in valgus laxity compared to the normal side (Table 1). All other patients were stable, except for the patient with an ACL deficiency, who had a positive drawer and Lachman sign.

Instrumented evaluation

At full extension, V/V rotation was around 3°, similar for injured and healthy knees. At 20° of knee flexion, V/V rotation was larger ($P < 0.01$), but similar in both knees (Table 2).

At 20° of knee flexion I/E tibial rotation was similar in both legs. At 80° of knee flexion, however, a decrease in tibial rotation was noted in the injured knee compared to the healthy knee ($P < 0.05$; Table 2).

At full extension, no differences in varus and valgus stiffnesses or stiffness ratios (IS/ES) were detected, comparing the injured and healthy knees. At 20° of knee flexion, initial and endpoint varus and valgus stiffnesses were similar in both knees (Table 3). However, comparing the ratios IS/ES of injured to healthy knees, a decrease was noted in the injured knee. This indicates a lower initial valgus stiffness, compared to the endpoint stiffness in the injured knee (Table 3). Internal and external rotational stiffnesses and corresponding ratios were equal in

Table 3. Varus and valgus stiffnesses. Nm/degree and ratio of initial and endpoint stiffnesses at 20° of knee flexion (n 36). Mean *SD*

Stiffness	Injured knee		Healthy knee	
Varus				
Initial	2.4	*1.3*	2.4	*1.0*
Endpoint	2.8	*0.9*	3.0	*1.0*
Ratio	0.8	*0.4*	0.9	*0.5*
Valgus				
Initial	2.0	*0.6*	2.2	*0.8*
Endpoint	3.6	*1.4*	3.6	*1.4*
Ratio	0.6	*0.2*[a]	0.7	*0.2*

[a]Decrease compared to the healthy knee (*P* 0.03)

Table 4. Internal and external rotational stiffnesses. Nm/degree and ratio of initial and endpoint stiffnesses at 80° of knee flexion (n 36). Mean *SD*

Stiffness	Injured knee		Healthy knee	
Internal rotational				
Initial	0.3	*0.2*	0.3	*0.2*
Endpoint	0.7	*0.5*	0.8	*0.5*
Ratio	0.5	*0.1*	0.5	*0.1*
External rotational				
Initial	0.4	*0.1*	0.4	*0.1*
Endpoint	1.0	*0.3*	1.0	*0.2*
Ratio	0.4	*0.1*	0.4	*0.1*

injured and healthy knees at 20° and 80° of knee flexion (Table 4). No differences were found for any of the calculated parameters between the 2 test occasions. The coefficient of variation (CV) was a mean of 27 percent for total V/V rotation, a mean of 21 percent for initial varus and valgus stiffnesses and 17 percent for endpoint varus and valgus stiffnesses. The CV was 18 percent for the varus stiffness ratio (IS/ES) and only 7 percent for the valgus stiffness ratio.

Discussion

As in previous studies (Holden et al. 1983, Indelicato 1983), we observed excellent short- and medium-term results after partial isolated MCL injuries. Apparently, the minor decrease in initial valgus stiffness did not impair knee function during recreational sports. There is also evidence from experimental studies (Inoue et al. 1987) that a decrease in valgus stiffness after MCL rupture may be compensated for by the remaining structures, especially by the ACL.

V/V rotation and stiffnesses have not been measured previously after partial MCL injury, using a comparable method of evaluation. Moore et al. (1976) used stress radiographs to measure V/V rotation after tibial plateau fractures and reported a 5° rotation at slight knee flexion for normal knees using an unknown V/V moment. Markolf et al. (1976) found similar values in normal cadaver knees. In their test set-up, the specimens were mounted with screws to the testing device, thus avoiding femoral rotation or soft-tissue errors. This may explain their somewhat lower V/V rotation values at a similar torque, compared to our results. They also reported less I/E tibial rotation (24°) than in the present study. In contrast, Grood et al. (1981) tested cadaver knees at 20° of knee flexion and found values for initial and endpoint stiffnesses comparable to our results. No clinical data exist on patients with MCL rupture. Only Bryant and Cooke (1988) measured V/V rotation and stiffnesses at 20° of knee flexion in healthy volunteers. They found somewhat higher values (mean 14°) for total V/V rotation than in the present study (mean 8°), but reported almost similar values for varus (mean 2.9 Nm/°) and valgus (mean 3.5 Nm/°) stiffnesses. In their test set-up, femoral rotation was less controlled than in the present set-up, which may lead to increased V/V rotational readings. Apparently, the method of fixation of the upper leg may influence the results, and may account for part of the variation found between 2 test occasions. In this respect, the calculation of stiffness ratios seems more reliable, because it does not depend on absolute values, but on the shape of the curve. The similarity in the values of these parameters in various studies and the low CV between different test occasions tend to confirm this finding.

In rabbit experiments, a recovery to normal V/V laxity from initially increased values was observed between 6 and 12 weeks after MCL transection (Woo et al. 1987). Further, in the same rabbit experiment, valgus stiffness which was decreased during the early period after MCL transection, was found to be normalized later. The recovery of the structural properties and valgus laxity to normal values was attributed to the size of the healed ligament, which showed an increase in cross-sectional area compared to a normal MCL. However, the tensile strength of this ligament scar never reached more than 50 percent of normal tissue (Frank et al. 1983), suggesting that the impairment of mechanical tissue properties was compensated for by an increase in the ligamentous mass. In our material, we still noted a decrease in initial valgus stiffness 4 years after MCL rupture. The simultaneous decrease in rotational laxity, without apparent change in rotational stiffness, may be attributed to scar tissue formation in the medial structures which are the primary restraints to rotational forces (Grood et al. 1981). It is not known whether the slight mechanical changes found at 4 years have any significance for long-term knee performance or for the development of arthrosis.

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