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DEMONSTRATION OF ROTATORY INSTABILITY IN INJURED KNEES BY STRESS RADIOGRAPHY

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Rotatory instability of injured knees may be demonstrated by stress radiography by recording the different movements of the medial and lateral tibial condyle at pull or push with the knee in 90 degrees flexion. The displacements of the condyles are expressed in millimetres, not degrees. Comparison with the healthy knee is always used. The displacement of a tibial condyle has to exceed 3.0 mm in relation to the healthy knee to be defined as pathological. If the movements of both condyles exceed the movements in the healthy knee by more than 3.0 mm in the same direction a drawer sign is present – if only one of them moves, an abnormal rotation is present. When a drawer sign is present there may still be a greater displacement of one of the tibial condyles which means a rotatory instability added to the drawer sign, designated a complex rotatory instability. All types of rotatory instabilities, simple and complex, are defined and discussed, in relation to the classification of Nicholas, Trickey and Slocum & Larson. Forty-one cases of abnormal rotation were demonstrated in this series by stress radiography. The direction of rotation and the type of instability are described and compared with the operative findings. The findings are in agreement with those of the above-mentioned authors and the experimental work of Warren et al.

Key words: complex instability; gonylaxometry; knee rotatory instability, complex, simple; stress radiography

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Meyer (1853) was the first to measure the rotation in healthy knee joints of living human subjects. The measurements were made at different degrees of knee flexion, using a ruler fixed on the sole of the foot, the ankle joint being immobilized by a tight bandage. Ross in 1932 published a thorough study of 100 subjects with healthy knee joints, also using an externally placed ruler and measuring in degrees. Ouellet et al. (1969) have suggested a method for investigation of rotatory stability in 90° flexed knee joints by means of measurements on serial radiographs. In this method the measured distances on the radiographs are transformed (by a cosine relationship) to degrees of rotation. As this method presumes a knowledge of the centre of rotation, only an approximate calculation is possible and furthermore it is only practicable in the healthy knee, while in the injured knee, in which the centre shifts to an unknown position, it is of no value. So far there have been no publications of measurements of rotation in injured knee joints. It is the purpose of this paper to show that gonylaxometry (Jacobsen 1976) offers a practical possibility for obtaining such measurements.

Definitions

In this paper internal and external rotation refer to the movement of the tibia in relation to the fixed femur. *Internal rotation* means that the tibial tuberosity rotates medially, the posterior parts of the tibial condyles moving laterally around an axis in the direction of the tibial shaft. *External rotation* indicates the reverse movement.

Medial instability (or valgus laxity) is defined as a movement in the frontal plane by which the knee joint is opened medially to a greater extent than normally. The patient's uninjured knee is used for comparison. In the gonylaxometer the measurement is done in 20 degrees knee flexion (angle between thigh and lower leg 160 degrees). The medial gap on the film is used as defined (Jacobsen 1976).

Lateral instability is defined analogously.

Drawer signs are defined as contemporary antero-posterior displacements of both tibial condyles in relation to the respective femoral condyles. The knees are flexed 90 degrees, the feet pointing straight forwards and parallel to the direction of the pulling or pushing force. In gonylaxometry a certain critical level of anterior or posterior displacement must be exceeded to establish a drawer sign as distinct from a normal antero-posterior displacement (a mean value exceeding 3.0 mm is used as a critical level, Jacobsen 1977).

Rotatory instability is defined in accordance with the remarks on internal or external rotation. It is measured in the gonylaxometer in 90 degrees knee flexion using the same method and stress forces as when measuring drawer signs. The term *simple rotatory instability* is used in circumstances where only the movement of one tibial condyle exceeds the critical level (no drawer sign present); in *complex rotatory instability* the movement of both tibial condyles exceeds the critical level but the one moves further than the other, which means a rotation in addition to a drawer sign. The diagram of the classification of complex rotatory instability is shown in Figure 1. The direction of the rotatory movement cannot be deduced from the names of the different types of instability in this classification. The names are derived from the unstable structures. For example, antero-medial complex rotatory instability derives its name from the injured anterior cruciate and medial ligaments. The direction of the rotation is external. From this it follows that rotatory instabilities as well as medial, lateral and antero-posterior instabilities are measured in millimetres and not converted into degrees.

METHOD

From gonylaxometry measurements on normal subjects in a neutral position it can be shown that when a straight pull in the anterior direction is applied to the upper end of the tibia the displacement of the medial and lateral tibial condyles is of different amplitude. The mean anterior displacement of the medial condyle is 2.3 mm (rounded off 2 mm) in 34 subjects, while the mean for the lateral condyle is 4.4 mm (4 mm) or nearly twice as much as the medial condyle. This means an internal rotation of the tibia as shown in Figure 2. When an opposite force is applied the posterior displacement in the normal knee is also found to be nearly twice as much on the lateral condyle as on the medial (mean values 3.1/1.6), i.e., external rotation takes place.

If any *abnormal* rotation is to be demonstrated the method of choice is to compare the same parameters of the patient's healthy and injured knee. In the following all instabilities mentioned are defined as "movement in the injured knee minus movement in the healthy knee". The 97½ per cent upper confidence limit of the difference between the two knees of a healthy subject for the above-mentioned parameters (anterior or posterior displacement of each condyle) is about 3 mm and ranges from 2.5 to 3.1 mm. A critical level of 3.0 mm is chosen for practical clinical use. The displacement of a tibial condyle has to exceed the critical level to be defined pathological. If both condyles move beyond this level in the same direction a drawer sign is present. If only one of the condyles moves enough to exceed this level an abnormal rotation must be present. The following criteria for a positive finding of rotatory instability are suggested: (a) the rotating condyle must be displaced minimally 3.0 mm and (b) if both

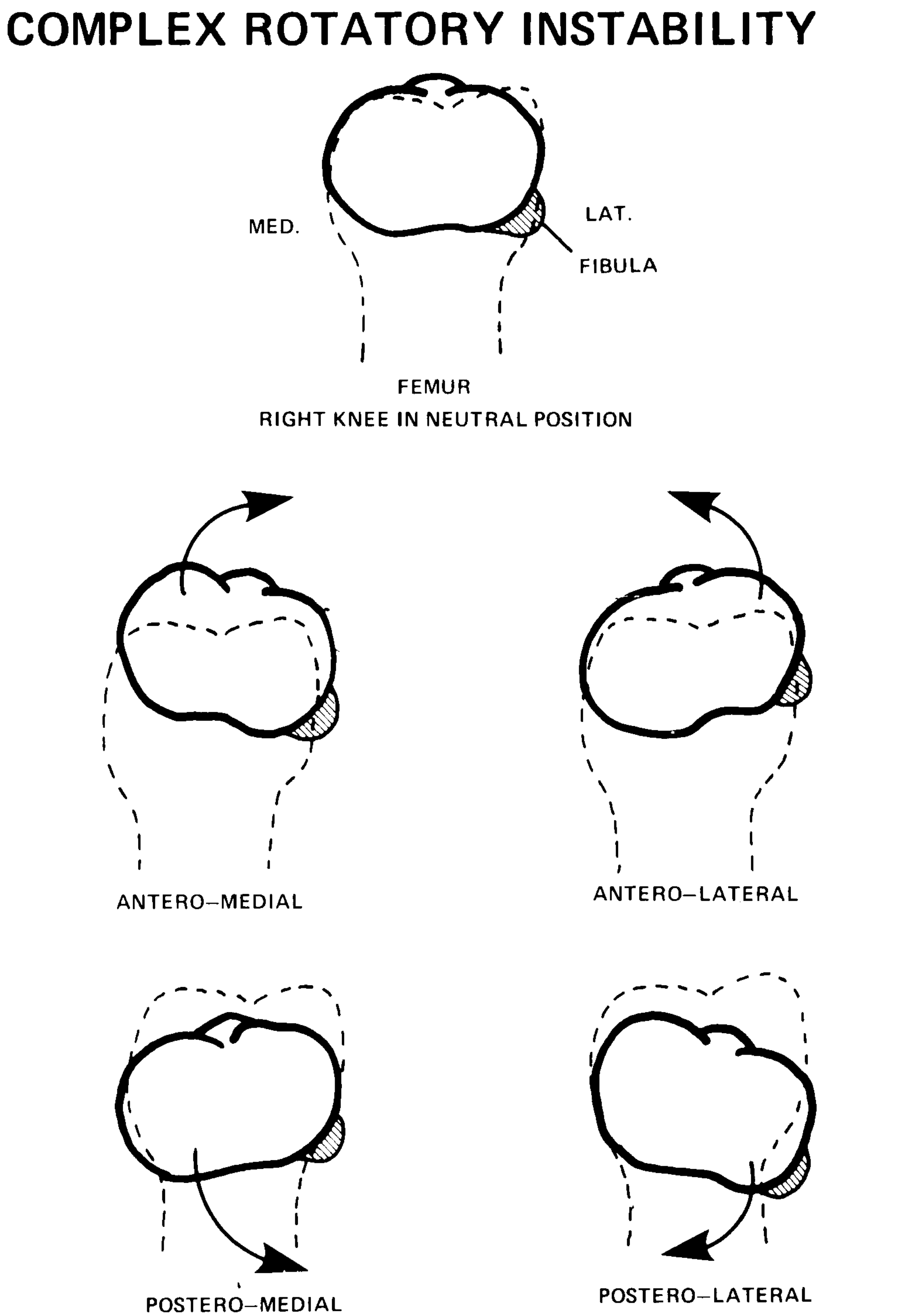


Figure 1. Complex rotatory instability. Right knee seen from above in 90° flexion. The tibia shown with unbroken lines. The shifting centres of rotation in injured knees are in reality unknown. External rotation is found in antero-medial and postero-lateral instability. Internal rotation in antero-lateral and postero-medial instability. A contemporary drawer movement is noted in the four pathological conditions.

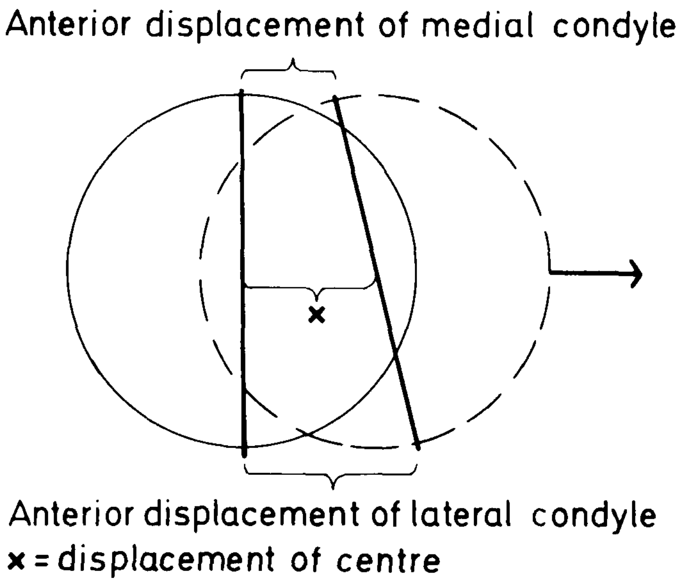


Figure 2. Tibial head (right, seen from above) diagramatically shown as a circle. During application of a pulling force (arrow) the medial condyle moves less than the lateral. On the radiograph straight linear distances are measured to represent the movement of each condyle. The landmarks used for the measurements are on the posterior part of the circle but in the same way points on the middle of the medial and lateral sides move. A chord at the posterior part of the circle, through the landmarks, will move parallel to the diameter shown and thus show the same angle of rotation. The movement of the centre shows the anterior displacement. The diagram may represent a normal knee *if the braces represent the total movement in a normal knee. On the other hand it may represent* complex rotatory instability, *if the braces represent differences between an injured and a healthy knee of the same patient.*

condyles of the injured knee are displaced to some degree the difference between the two condyles must exceed 2.0 mm (2 SD in healthy knees).

If both condyles can be displaced more than 3.0 mm and added to this one condylar displacement exceeds the other by 2.0 mm a drawer sign plus a rotation is present or in other words a complex rotatory instability exists (refer to Figure 2 and its legend).

Rotatory movements were studied both in the normal position for examination for drawer sign "neutral position 90 degrees" with the feet pointing straight anteriorly and in positions with the feet externally or internally rotated 15 degrees and 30 degrees. The fastening gear may also be fixed in these positions in the gonylaxometer.

PATIENTS

The material comprises 153 injured knees; 90 were examined 2 weeks or less after the injury (group 1), 26 from 15 days to 3 months after the injury (group 2) and in 37 a period of more than 3 months had elapsed since injury (group 3). For further details of the material, the various pathoanatomical features, medial and lateral instability, drawer signs, etc. refer to Jacobsen (1977). In many cases small differences in antero-posterior displacement of the medial and lateral condyles of the injured knee, not exceeding the above defined critical levels, were found radiographically. They are not discussed further in this report. Measurements with the feet in 15 and 30 degrees rotation as mentioned above were carried out in 63 cases.

FINDINGS

Simple rotatory instability may be demonstrated in two different ways. Firstly the test of Slocum & Larson (1968) may be performed with the feet fixed in 15 degrees external rotation and the knees flexed to 90 degrees, in the gonylaxometer. Prior to this a clinical test of the lateral collateral ligaments as described by Slocum & Larson and a test for lateral stability at stress radiography are performed. If an external rotation is to be demonstrated as a result of injury to the medial collateral ligaments alone the following criteria must be fulfilled: provided the lateral structures are intact an anterior drawer test at gonylaxometry in neutral position must be negative, and in the position with the feet fastened in 15 degrees external rotation it should be positive. The subsequent surgical operation would then show intact cruciate ligaments, intact lateral structures and injury to the medial collateral ligaments alone. Two such cases were found in group 2. Both of them showed a mean anterior displacement of the tibial condyles of 4.4 mm in the position with 15 degrees external rotation of the feet. Furthermore in one of them with 30 degrees external rotation of the feet there was an anterior displacement of 6.6 mm. Thus stress radiography demonstrated a positive Slocum & Larson test. The menisci were intact in both patients.

Secondly simple rotatory instability may be shown by stress radiographical measurements also in the neutral position of the foot. In a third case the medial tibial condyle at pull starting from "neutral position 90 degrees" moved 3.2 mm (criterion a) which exceeded the movement of the lateral condyle by 2.1 mm (criterion b), which shows external rotation, while the mean of the two condylar movements (2.2 mm) did not exceed the critical level of 3.0 mm for anterior drawer sign. With the feet fastened in 15 degrees external rotation the difference between medial and lateral condylar movement was even greater. Intact menisci were found at operation. These three cases from group 2 had soft scar tissue after rupture of medial ligaments. A further seven simple medial rotatory instabilities from group 1 and two from group 3 are shown in Table 1 and Figures 3 and 4, making a total of 12 cases.

Simple lateral rotatory instability was found in two cases.

Complex rotatory instabilities of all the types shown in Figure 1 were found in 25 cases in 24 knees; *antero-medial* in 19 cases (Table 2). The pathoanatomy in all these cases consisted of anterior cruciate ligament rupture combined with medial collateral ligament rupture. This was clearly visible in group 1, but less obvious in the other groups where scar tissue had developed at the site of the medial structures.

Postero-medial complex rotatory instability was demonstrated by gonylaxometry in three cases. One case is shown in Figure 5. In the second case anterior drawer (7.7 mm) was found coupled with a posterior drawer (18.5 mm) and postero-medial instability at push (difference between posterior displacement of the tibial condyles 2.1 mm). Subsequent operation showed total rupture of both cruciate ligaments, the medial collateral ligaments and the capsule, as well as the postero-medial part of the capsule. The third case with total rupture of the medial structures and posterior cruciate ligament showed external rotation at pull and posterior drawer sign at push.

In one case *combined antero-lateral and postero-lateral complex rotatory instability* was demonstrated. The findings at operation were: Total rupture of the anterior and posterior cruciate ligament, lateral collateral ligament, popliteus and biceps femoris tendons, posterior and lateral capsule and partial rupture of the iliotibial tract and the medial collateral ligament. In another case of postero-lateral complex rotatory instability the operative findings were total rupture of the posterior cruciate ligament and the lateral collateral ligament.

In six patients external rotation in the injured knee occurred in the unloaded knee during rotation of the foot from the neutral to the 15 degrees externally rotated position. Only two of them were not further rotated by stress (external rotation – medial instability). The same criteria of rotation were used as in loaded knees.

Totally 41 instances of abnormal rotation in 40 knees were shown by stress radiography in the series.

DISCUSSION

Slocum & Larson (1968) describe the clinical test position "with the foot and leg in 15 degrees external rotation". This has caused some practical difficulty, as the head of the tibia rotates less than half the rotation of the foot. Nevertheless the position of 15 degrees

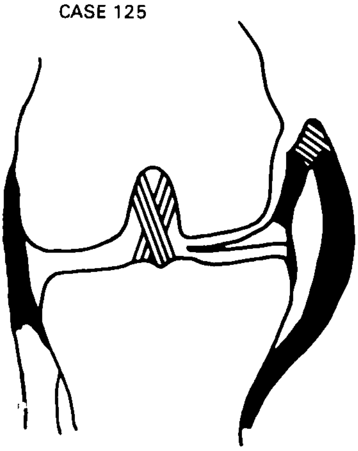
Table 1. Simple medial rotatory instability (groups 1 and 3). Measured in mm.

Pt. no. and type of rotation	Medial instability	Ant. displ. med. cond.		Ant. displ. lat. cond.	Ant. drawer mean of med. and lat. cond.	Ligament injury	Meniscus injury
1 ext. rot. at pull	none	neutral:	3.2	−1.4	1.4 = none	Partial rupt. (ant. fibres) of long, superficial med. coll. lig. (Figure 3)	none
2 ext. rot. at pull	none	neutral: 15° ext.:	3.0 3.1	−4.1 −4.1	−0.6 = none −0.5 = none	Ant. and middle sup. fibres – same lig.	none
28 ext. rot. at pull	5.7	neutral:	3.6	0.1	1.9 = none	Total rupt. of med. collateral both superf. and deep	none
38 int. rot. at push	8.5	post. displ. neutral:	4.0	post. displ. 1.3	post. displ. 2.7 = none	Total rupt. of med. collateral superf. Deep intact	none
43 ext. rot. at pull	7.9	neutral: 15° ext.:	0.3 = none 3.2	−0.3 0.1	0 1.7 = none	Total rupt. of med. coll. Superficial and deep oblique intact	none
49 ext. rot. at pull	8.3	neutral:	3.9	0.8	2.4 = none	Total rupt. of all med. ligaments	none
50 ext. rot. at pull	5.7	neutral: 15° ext:	2.0 = none 2.9	−0.5 0.8	0.8 = none 1.9 = none	Total rupt. superf. and deep	none
127 ext. rot. at pull	none	neutral:	5.0	0.2	2.6 = none	Plate of scar tissue at site of med. ligaments	Medial meniscus loosened along circumference and dislocated to intercond. space

In the third column "neutral" or 15° external rotation or internal rotation refers to the position of the foot during stress radiography; the figures refer to displacement in millimetres of the medial tibial condyle. In patient number 38 reference is made to posterior displacement (with the foot in a neutral position) instead of anterior displacement. The difference between the movements of the medial and lateral tibial condyles is found by subtracting the values in column four from those in column three.

Figure 3. Operative findings in case no. 1: Isolated partial rupture of the superficial medial collateral ligament—long anterior fibres ruptured. In extension or slight flexion the middle and posterior fibres prevent medial instability (valgus laxity). At flexion to 90° and pull applied to the head of the tibia the posterior and middle fibres are slack and inverted anteriorly, the anterior fibres ruptured and distended thus allowing an abnormal anterior displacement of the medial tibial condyle only—i.e. external rotation (refer to discussion).

CASE 125



ISOLATED MEDIAL RUPTURE

GONYLAXOMETRY:

MEDIAL LOOSENESS: 4.6 mm
ANTERO-POSTERIOR DISPLACEMENTS:
IN NEUTRAL POS.:

ANT. DISPL. LAT. CONDYLE:	1.2 mm
ANT. DISPL. MED. CONDYLE:	3.0 mm
POST. DISPL. LAT. CONDYLE:	0.5 mm
POST. DISPL. MED. CONDYLE:	3.0 mm
ANT. DRAWER: (2.5 = neg.)	
POST DRAWER: (1.8 = neg.)	
TOTAL ANT.-POST. DISPL. LAT: COND.	2.5
TOTAL ANT.-POST. DISPL. MED. COND.	6.0

WITH FOOT 15° OUTW. ROTATED THIS IS INCREASED TO 7.1

Figure 4. Isolated rupture of medial structures: superficial and deep medial collateral as well as oblique posterior ligament and medial capsule. Simple medial rotatory instability.

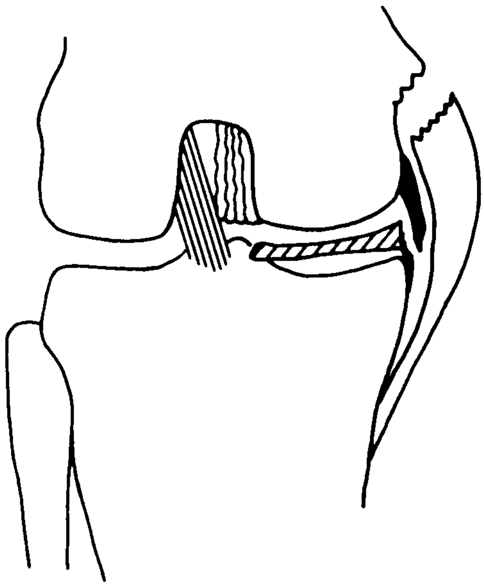


Figure 5. Recent injury: Case no. 89. Postero-medial complex rotatory instability (posterior drawer plus rotation).

Table 2. Examples of antero-medial complex instabilities. Measured in mm.

Pt. no.	Medial instability	Ant. displ. med. cond.		Ant. displ. lat. cond.	Difference = measure of rot.	Ant. displ. (mean of med. and lat. cond.)	Meniscus injury
71	9.3	neutr.	18.7	13.4	5.3	16.1	none
80	12.7	neutr.	7.8	7.6	0.2	7.7	none
		15° ext.	16.8	13.3	3.5	15.2	
84	4.8	neutr.	5.4	2.2	3.2	3.8	none
		15° ext.	5.9	2.8	3.1	4.4	
85	9.1	neutr.	13.9	10.2	3.7	12.1	medial
115	none	neutr.	3.6	0.9	2.7	2.3 (none)	both med. and lat. removed
		15° ext.	6.2	3.1	3.1	4.7	earlier
116	5.9	neutr.	8.4	6.3	2.1	7.4	none
		15° ext.	7.9	4.9	3.0	6.4	
		30° int.	3.7	2.4	1.3	3.1	
129	none	neutr.	7.2	3.3	3.9	5.3	med. + lat.
130	none	neutr.	8.5	4.4	4.1	6.5	med.
133	none (1.9)	neutr.	12.1	8.7	3.4	10.4	med. removed earlier

The difference between the movement of the two tibial condyles is calculated in column five; anterior drawer in column six.

external rotation of the foot was chosen as a standard position, when examining for rotatory instability *ad modum* Slocum & Larson but in nine cases the knee was tested also with the foot fixed in 30 degrees external rotation (which forces the proximal end of the tibia closer to 15 degrees external rotation as measured by an externally fixed pointer). As seen from the first-mentioned cases with simple medial rotatory instability the latter position may give an even better outcome of the test in favour of the theory of Slocum & Larson.

In case no. 78 with operatively proven total rupture of the medial collateral ligaments and the anterior cruciate ligament no rotation was shown with the foot in the neutral position, but a great increase of the anterior displacement with the foot in the 15 degrees externally rotated position gave evidence of medial rotatory instability. When the tibial condyles are rotated externally the tibio-fibular insertions of the lateral structures move posteriorly and, therefore, allow a greater anterior movement at pull even when intact. This movement, prevented when the medial ligaments are undamaged, occurs when they are damaged and to a still greater degree when the anterior cruciate ligament is ruptured also (still in agreement with the theory of Slocum & Larson).

Antero-medial instability was shown by Trickey (personal communication 1976) on cadaveric knees with totally cut medial collateral ligaments and intact cruciate ligaments, with the knee flexed 30 degrees, as a combined medial gap and external rotation. The present author agrees with this point of view, but prefers to analyse each of these movements (gap in frontal plane and rotation) separately.

In the case in Figure 4 nature has produced an injury so "clear cut" that it may easily be reproduced experimentally on knee specimens. In such a specimen Trickey demonstrated his "anteromedial instability". With the methods and definitions used by the present author it was possible to demonstrate both medial instability in the frontal plane in this case and external rotation (anterior displacement of the medial tibial condyle at 90 degrees knee flexion and pull) and internal rotation (posterior displacement of medial condyle at push) due to instability of the medial structures alone.

Rotatory instability at gonylaxometry was only demonstrated in cases where operation disclosed a total rupture of the long anterior fibres of the superficial medial collateral ligament, the exact pathoanatomy being only accessible in the recent injuries and a few other cases (as in Figure 4) with non-union and scanty scar tissue formation. No rotation exceeding the critical levels of the criteria were shown in injuries comprising only the deep and oblique posterior medial collateral ligaments. This is in agreement with Warren et al. (1974, p. 671 and charts IV and V) who write: "... relatively large increments in both medial joint space opening (valgus) and rotation are allowed by releasing the long fibres in an otherwise intact specimen. Conversely, cutting the deep ligament produces almost no change ... if the long fibres are intact".

As the middle and posterior fibres of the superficial medial collateral ligament are taut in extension and slight flexion but slack and inverted anteriorly in 90 degrees knee flexion [refer to Lanz & Wachsmuth (1938) p. 233, abb. 188 or Warren et al. (1974) p. 666], and the anterior fibres behave in the opposite way (slack in extension and taut in 90 degrees flexion) findings like those in case no. 1 (Table 1 and Figure 3) may occur. The middle and posterior fibres, intact in this case, prevent medial instability, when measured in 20 degree knee flexion (the 160 degrees position) as in the gonylaxometer. In the 90 degrees position in which they are slack and anteverted they allow anterior displacement of the medial tibial condyle – or external rotation. This movement should have been prevented by the anterior fibres of this ligament, but they have ruptured in this case. The injury was sustained in a skiing accident during flexion and external rotation of the knee. The same phenomenon occurred in case no. 2.

Complex instability was defined and

classified by Nicholas (1973) as contemporary instability in two or more planes. Referring to this definition Trickey's antero-medial instability is a kind of complex instability. The author of this article prefers to use the term complex instability only in connection with rotatory instability. Within this concept the terminology is defined in full agreement with Nicholas' nomenclature. Lastly attention must be drawn to the measuring technique with a force acting which tightens the intact structures. The rotation produced in this way is probably less than if a rotating force were applied directly with the knee in the neutral position (no antero-posterior stress on the ligaments). Some findings indicate this. In case no. 150 the feet were also rotated externally 30 degrees and then tested for anterior displacement—and no movement at all of the medial condyle was found. But unloaded the medial condyle had moved 7.4 mm more than the lateral from neutral position to the position with 30 degrees externally rotated feet, i.e., the rotation had taken place already before the pulling force was applied to the rotated leg. Such rotation of the unloaded knee was found in another five cases, but only two did not move further on traction.

It may be concluded that rotatory instability of the knee: simple, medial and lateral, as well as all the complex types discussed theoretically and the antero-medial type shown clinically by Nicholas—can be demonstrated and measured by stress radiography in a clinical material of injured knees. The findings are in agreement with the experimental work of Warren et al. (1974).

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