

STRESS RADIOGRAPHICAL MEASUREMENTS OF POST-TRAUMATIC KNEE INSTABILITY

A Clinical Study

KLAUS JACOBSEN

Department of Orthopaedic Surgery T3 and Department of Diagnostic Radiology,
The Gentofte Hospital, Copenhagen, Denmark.

In a prospective, consecutive, clinical and stress radiographical study, comprising 153 traumatic knee injuries, the value of stress radiographical measurements, gonylaxometry, was studied. Clinical evaluation, gonylaxometry and preoperative evaluation under general anaesthesia were carried out in that order. Then the operative findings were recorded as drawings on standard diagrams. These were used as a basis for evaluation of the preoperative tests. Of all the methods evaluated, gonylaxometry was found to provide the most accurate information regarding the knee injury. Very close to this result were the findings under general anaesthesia. Anterior drawer sign was measured gonylaxometrically when damage to the anterior cruciate ligament was present; posterior drawer meant damage to the posterior cruciate ligament. Partial ruptures of cruciate ligaments did not allow antero-posterior displacements exceeding the critical levels of the test. Small positive medial instability was found with ruptures of profound medial structures, higher values with total rupture of the long superficial collateral band, and still higher values when cruciate ligament ruptures were also present. The predictive values of a positive radiographical test were 100 per cent as regards medial instability and 98 per cent for drawer looseness. The predictive values of a negative test were 96 per cent for drawer and 92 per cent for medial instability. These figures are based on the total material. 95 per cent confidence limits are given.

Key words: knee instability; gonylaxometry; predictive values; prospective clinical evaluation; stress radiography

Accepted 9.ii.77

A method for stress radiographical measurement of anterior, posterior and

medial and lateral stability in the knee joint has been described by the author (Jacobsen 1976). A series of subjects with healthy knees were used to investigate the accuracy and upper limits of the normal standard values of the

Aided by grants from the Danish Medical Research Council, the Danish Council for Sports Research, and the Foundation for the Handicapped.

parameters mentioned. A logical next step is an investigation of the clinical value on a clinical material. A prospective study is presented below comprising preoperative stress-radiographical measurements compared with 1) operative findings, 2) a preoperative clinical evaluation and 3) a preoperative evaluation under general anaesthesia.

PATIENTS

The material comprises a prospective, consecutive, series of 151 patients with 153 traumatic knee injuries. Two patients have been examined and operated upon twice (in the same knee). The investigation took place from January 1974 to November 1975. The age and sex distribution is shown in Table 1; the precipitating activity or cause of the injury is shown in Table 2. There are a great number of young people in the age group 17 to 30 years as the material comprises largely sports injuries. The preponderance of men is explained by the great number of soccer injuries.

All the patients were referred with a suspicion of ligamentous injury to the knee and all were examined and operated upon. They were divided into three groups on the basis of the duration of time from trauma to operation.

Group 1: duration 14 days or less (recent injuries).

Group 2: duration from 15 days to 3 months.

Group 3: duration exceeding 3 months.

The group of recent injuries comprised 90 knee joints. Local anaesthesia (Lidocaini chloridum) was necessary during the measurements. It was combined with noradrenaline for the collateral ligaments and the capsule, but used alone intra-articularly (5 ml, ½ per cent, after aspiration of hyarthrosis or haemarthrosis). In

Table 2. *Precipitating activity or cause of the injury.*

Precipitating cause	Total	Men	Women
Soccer	79	76	3
Handball	11	6	5
Other ball games (basketball, volleyball, badminton)	5	4	1
Skiing	17	7	10
Other sports	11	10	1
All sports total	124	103	21
Work, traffic and holiday accidents	29	22	7
Total	153	125	28

recent injuries observation of the damage to ligaments and capsular structures is facilitated by the absence of scar tissue. On the other hand, pain may be violent and so in three of the 90 injuries measurement of anteroposterior instability could not be carried out.

Group 2 comprised only 26 knee injuries. The use of local anaesthesia was also necessary during stress radiography in this group. During operation the patho-anatomy of the injuries was blurred by scar tissue and atrophy of the cruciate ligaments.

Group 3 comprised 37 knees. Here no pain interfered with the measurements and local anaesthesia was not utilized. The original patho-anatomy of the injuries to collateral ligaments and capsule was totally blurred by scar tissue, and injuries to the cruciate ligaments could be graded only as partial or total atrophy. Per-operative judgement of any "healing with elongation" of injured cruciate ligaments is very difficult and uncertain, and has been avoided.

Table 1. *Age and sex of the 153 patients.*

Age in years	Total	Men	Women
13-20	39	35	4
21-30	69	58	11
31-40	27	23	4
41-50	13	7	6
51-60	3	1	2
61-67	2	1	1
13-67	153	125	28 (18.3 %)

METHOD

The preoperative stress radiographical measurements were carried out as described previously (Jacobsen 1976), viz., medial and lateral instability was measured on a-p radiographs with the patient's knees flexed 20° ("neutral position 160°") with a 9 kg stress (abduction or adduction) on both knees at the same time. Only the gap in the frontal plane was measured, this being used as a definition of medial and lateral instability. The foot and femur were fixed to avoid rotation. The drawer signs were measured

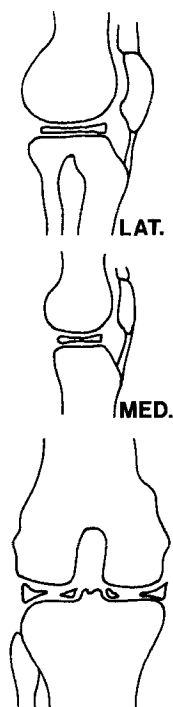


Figure 1. Diagram for routine drawings of ligament and capsule ruptures found at operation.

at 90° of knee flexion with the foot fixed pointing anteriorly (starting from "neutral position 90°") a force of 30 kg being applied. (Measurement of rotation will be dealt with in a following publication.) Medial and lateral instability as well as anterior and posterior displacements were measured on the radiographs and recorded before operation.

Preoperative clinical evaluation was carried out on admission (before gonylaxometry) in 122 of the cases by another senior surgeon (chief or senior registrar) and the results were sealed; in 31 cases the clinical evaluation was performed by the author and became the first entry in the patients record. Preoperative evaluation under general anaesthesia was carried out, after gonylaxometry, in all cases by the author. Operative findings were recorded in detail and drawings were made of the findings on standard diagrams (Figure 1).

The clinical evaluation was simplified to include only a description of whether or not instability was present. If an attempt was made to use three degrees: 1) no instability, 2) a little instability, 3) gross instability, the clinical evaluation became very uncertain.

The stress radiographical findings were corre-

lated with the operative findings. The preoperative clinical findings and the preoperative findings under anaesthesia were also correlated with the findings at operation. As expressions of these correlations, the predictive value of a positive test, PV_{pos} , and the predictive value of a negative test, PV_{neg} , are used, as described by Vecchio (1966) and in Scandinavia by Wulff (1976). The PV_{pos} is defined as the probability of a certain ligament injury if the test is positive. The PV_{neg} is defined as the probability of non-injury if the test is negative.

FINDINGS

Group 1.

The stress radiographical measurements of group 1 can be seen in Figure 2. Instabilities were measured on the radiographs in millimetres with one decimal and are shown and defined throughout this paper as the differences between the patient's injured and healthy knee. In accordance with the earlier measurements on healthy subjects, 2.0 mm is used as the upper normal limit (critical level) for medial and lateral instability and 3.0 mm as the critical level for abnormal anterior or posterior displacement.

Patients nos. 1 to 11 showed, at stress radiography, no collateral looseness at all, and the measurements were true negative as the operations showed no injuries to the collateral ligaments, but revealed other injuries (of the meniscus or dislocations of the knee cap). Patients nos. 1, 2 and 3 had small tears of isolated fibres anteriorly in the superficial medial collateral ligament, this nevertheless being intact in more than two-thirds of its breadth, thus not allowing any looseness in the frontal plane. Nos. 12 to 57 represent isolated injuries to the medial collateral ligaments. At gonylaxometry they all showed true positive values as they exceeded the critical level of 2 mm and true negative values for antero-posterior displacement (< 3 mm). Among these, nos. 12 to 24 had the smallest

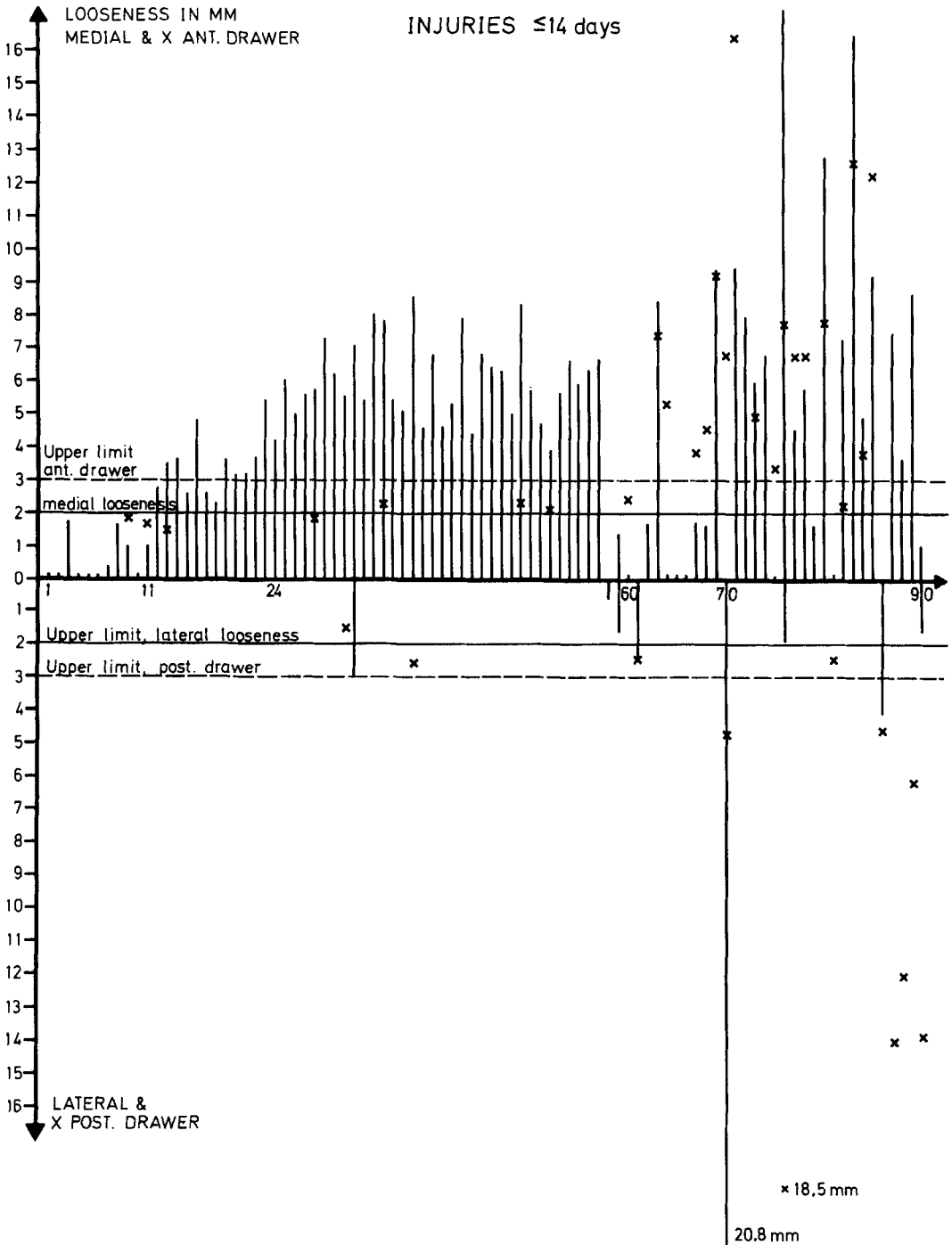


Figure 2. Diagram showing stress radiographically measured instabilities in group 1. Differences between the patient's injured and healthy knee. Medial collateral instability: columns above the axis of the abscissa. Lateral instability: columns below the axis. Anterior displacement or drawer as an x above the axis and posterior drawer as an x below the axis (values below the axis are thus also positive). Every column and cross show measurements on one patient, the patient number being the abscissa.

Table 3. Predictive values in knee injuries ≤ 14 days. Medial instability.

Gonylaxometry: TN = 21, FN = 5, TP = 63, FP = 0, N = 89.

$$\text{Predictive value of pos. test} = PV_{\text{pos}} = \frac{TP}{TP + FP} = \frac{63}{63 + 0} = 100 \%. \\ (95 \% \text{ confidence limits: } 94\text{--}100 \%)$$

$$\text{Predictive value of neg. test} = PV_{\text{neg}} = \frac{TN}{TN + FN} = \frac{21}{21 + 5} = 81 \%. \\ (95 \% \text{ confidence limits: } 61\text{--}93 \%)$$

Clinical test: TN = 10, FN = 2, TP = 66, FP = 12, N = 90.

$$PV_{\text{pos}} = \frac{TP}{TP + FP} = \frac{66}{66 + 12} = 85 \% (75\text{--}92 \%)$$

$$PV_{\text{neg}} = \frac{TN}{TN + FN} = \frac{10}{10 + 2} = 83 \% (52\text{--}98 \%)$$

Test under general anaesthesia: TN = 20, FN = 3, TP = 65, FP = 2, N = 90.

$$PV_{\text{pos}} = \frac{TP}{TP + FP} = \frac{65}{65 + 2} = 97 \% (90\text{--}100 \%)$$

$$PV_{\text{neg}} = \frac{TN}{TN + FN} = \frac{20}{20 + 3} = 87 \% (66\text{--}97 \%)$$

TN = true negative, TP = true positive, FN = false negative, FP = false positive, N = number of patients tested.

amount of positive medial instability, nearly all of them less than 4 mm, and the operative findings revealed ruptures of the deep medial structures, i.e., the profound medial collateral and oblique posteromedial ligaments, sometimes together with smaller tears in the superficial medial collateral ligament but never a total rupture of this structure. On the contrary, patients nos. 25 to 57 all (except one) showed greater medial instability (> 4 mm) and they all had a total rupture of the superficial medial collateral ligament, which Warren et al. (1974) have called "the prime static stabilizer of the medial side of the knee". Moreover, it can be seen that gross medial and lateral instabilities are found in combination with gross drawer signs (to the right in the diagram, Figure 2).

The main purpose of the development of the gonylaxometer has not been for diagnostic use in acute injuries but for

scientific use (follow-up investigations and investigations of old painless unstable knee joints). However, an evaluation of the method for acute cases ought to be made and so the predictive values, PV_{pos} and PV_{neg} , were calculated (Table 3).

Lateral instability: In two cases (nos. 58 and 59) with operatively proven small, incomplete ruptures of the lateral collateral ligament there was no instability. The four other cases had grave injuries and positive measurements (Figure 2).

Drawer symptoms in group 1: Anterior drawer range at gonylaxometry was up to 16 mm (difference from the healthy knee) and posterior drawer up to 21 mm. The amount of anterior and posterior displacement was evenly spread from the critical levels to the top of the rank. Cruciate ligament injuries were found in nos. 60 to 90. Three cases with injuries to both cruciate ligaments were measured.

Two showed a marked drawer sign both anteriorly and posteriorly, while one was negative (see below). Injuries to the posterior cruciate ligament without injury to the anterior were found in five patients, all with true positive measurements of posterior drawer. *Anterior drawer* could not be measured radiographically in seven cases of partial rupture and in one case of intrasynovial rupture of the anterior cruciate ligament while partial rupture of the anterior cruciate ligament was demonstrated by small values in two cases.

Table 4. Predictive values. Total a-p displacement (drawer/no drawer). Injuries ≤ 14 days. 95 % confidence limits in brackets.

Gonylaxometry:

N = 87, FP = 0, TP = 21, FN = 10, TN = 56

PV_{pos} = 100 % (84–100 %)

PV_{neg} = 85 % (74–92 %)

Clinical test:

N = 90, FP = 7, TP = 18, FN = 14, TN = 51

PV_{pos} = 72 % (51–88 %)

PV_{neg} = 78 % (67–88 %)

Test under general anaesthesia:

N = 90, FP = 2, TP = 21, FN = 11, TN = 56

PV_{pos} = 91 % (72–99 %)

PV_{neg} = 84 % (73–92 %)

Two cases with total rupture (one of the anterior and one of the anterior plus posterior cruciate) did not show any drawer sign either at gonylaxometry or during examination under general anaesthesia. During operation the femoral condyle was found to be locked in a great bucket-handle-lesion of the meniscus. In the calculation of predictive values these 10 cases (including partial ruptures) are considered as false negative.

Table 4 gives the values for the patients with total a-p displacement exceeding critical levels. If anterior and posterior drawer are separated, the clinical test becomes more inaccurate while gonylaxometry and evaluation under

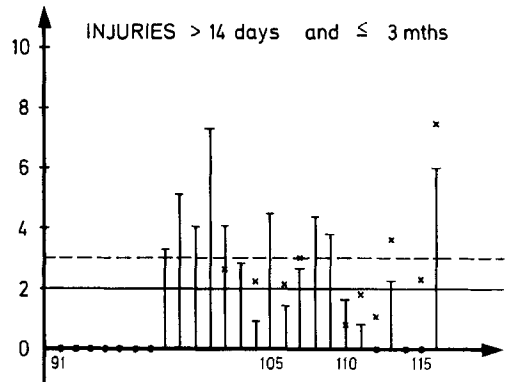


Figure 3. Stress radiographically measured instabilities in group 2. Medial instability: column above the axis. Anterior drawer, x above the axis. No lateral or posterior cruciate injuries in this group.

general anaesthesia remains unchanged. Table 4 shows the superiority of gonylaxometry also in the acutediagnostic field, but this is indeed very moderate compared with examination under general anaesthesia.

Group 2 (26 knee joints)

The stress radiographical measurements are shown in Figure 3. There were no cases of lateral collateral or posterior cruciate ligament injury. There were no cases of false negative or false positive medial instability, which ranged up to 7.3 mm. Four cases of peroperatively verified partial anterior cruciate ligament ruptures could not be demonstrated by gonylaxometry or by examination under general anaesthesia. Two out of three total ruptures of the anterior cruciate ligament showed measurements of anterior drawer exceeding the critical level and they were also estimated as positive during clinical examination and examination under general anaesthesia. The third case had a negative drawer sign at gonylaxometry as well as during the clinical examination and the examination under anaesthesia. This group by itself is too small for statistical analysis.

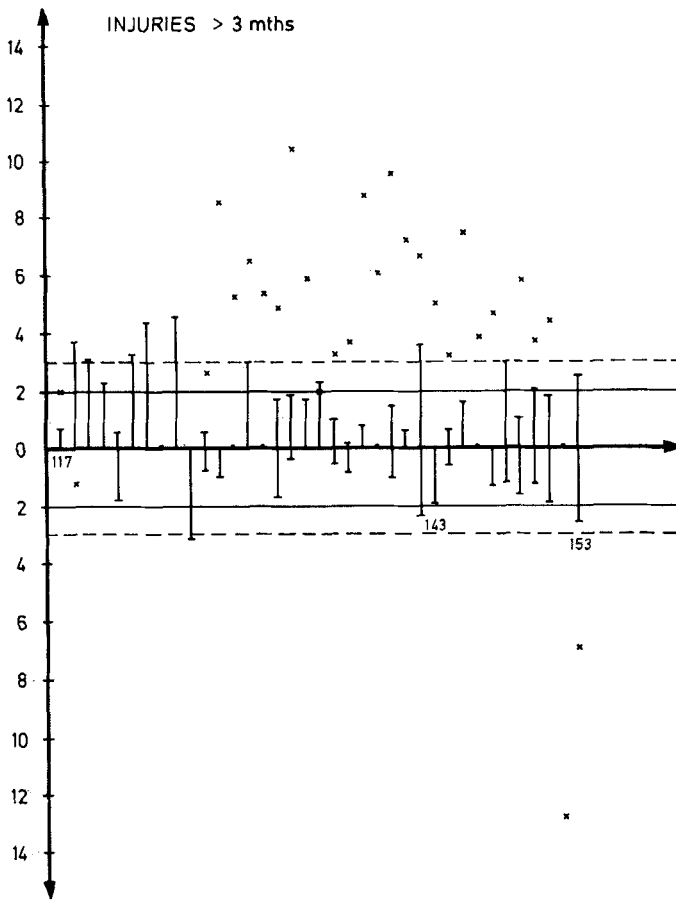


Figure 4. Stress radiographically measured instabilities in group 3. For explanation of indications refer to Figure 2.

Group 3 (37 knees)

There was no pain during stress radiography and local anaesthesia was not used. The measurements can thus be considered to be accurate. One bucket-handle lesion with locking of the femoral condyle and false negative measurement of drawer was found. Figure 4 shows the findings at gonylaxometry. Most remarkable is the medial instability which is slight in these chronic injuries (range up to 4.6 mm). In 22 cases no collateral instability at all was found either at gonylaxometry or at operation.

One false positive anterior drawer sign (5 mm) was found. The patient had a marked quadriceps atrophy following

arthrotomy and suture of the medial collateral ligament 2 years earlier, after a work accident. He had recurrent hyarthrosis, pain in the knee and a feeling of instability. The present operation showed normal structure of the cruciate ligaments, but they were loose.

The drawer signs in this group ranged from 3.3 to 15.1 mm, mean: 6.6 mm. The $PV_{pos} = 96$ per cent (80–100 per cent) and $PV_{neg} = 92$ per cent (67–100 per cent) are approximately the same as in group 1.

Finally an evaluation of the total material was made. As it is normally impossible to detect partial cruciate ligament rupture by this method, as pointed

out above, the negative measurements of these injuries are counted as true negative. For total anteroposterior displacements $PV_{\text{pos}} = 98$ per cent (89–100 per cent), $PV_{\text{neg}} = 96$ per cent (90–99 per cent), for medial instability $PV_{\text{pos}} = 100$ per cent (96–100 per cent) and $PV_{\text{neg}} = 92$ per cent (83–97 per cent).

DISCUSSION

The main purpose of this report was to show how collateral and anteroposterior instabilities in patients could be measured with relative accuracy by goniolaxometry. It was also important to discover if certain injuries to the ligaments showed certain patterns of instability at stress radiography.

The pattern of medial ligament injuries is shown by stress radiography to agree with that found by Warren et al. (1974). These authors investigated the medial structures in fresh human knee specimens. They have shown that the anterior long fibres of the superficial medial collateral ligament for a breadth of approximately 10 mm are the main stabilizing factors of the medial side of the knee. As mentioned above medial instabilities more than approximately 4 mm at stress radiography cannot be demonstrated unless this part of the ligament has been totally ruptured and if this is the case the instability is > 4 mm. Warren et al. (Chart II) found an increase in instability of 8 mm (mean) in this situation—with intact cruciate ligaments—which matches well with the findings in patients nos. 25–57 on Figure 2.

Positive findings from 2 to 4 mm indicate ruptures in the deep medial ligaments without total rupture of the superficial ligament (nos. 12–24). In agreement with Hallén & Lindahl (1965) the very large medial and lateral instabilities are found in ruptures of both cruciate

ligaments and the posterior joint capsule in connection with total rupture of the medial or lateral structures (nos. 70 and 76).

The most remarkable finding in the group of chronic injuries is that collateral instability is only slight, in 22 cases there was none at all. This is a fact for both patients with and patients without rupture of cruciate ligaments. This finding indicates that the medial collateral ligament and the capsular structures are capable of spontaneous restitution after trauma even if untreated or treated only by a plaster cast, as found by Jonasch (1958). He measured, at follow-up, the medial instability in the frontal plane using a simple radiographical technique and manual pressure (1200 plaster cast-treated patients). But it must be stressed that this fact tells nothing about rotatory instability and the role of a possible coincident a-p instability.

In the total material three cases of negative a-p measurements were found in which the subsequent arthrotomy showed a "locking" of the femoral condyle to the tibial by a bucket-handle lesion of the meniscus. These are all considered as false negative in the statistical calculations. This is justified from a diagnostic point of view but hardly from the point of view of the measuring technique.

The investigation reveals an even distribution of the measured values of all parameters on the scale from the critical levels and upwards. This also applies to the a-p displacements there being no "free interval" between the upper normal values (97.5 per cent border) and the pathological values. This is to be expected in a biological material with very complex injuries to different ligaments in the joint—the degree of a drawer sign also being dependent on the condition of the other ligaments and the capsule.

Generally it is not possible to measure partial ruptures of the anterior cruciate

ligament as positive drawer signs exceeding the critical levels used here. There may be an anatomical reason for this. The anterior cruciate ligament consists of a posterolateral part, which is taut at knee extension and more slack at 90° knee flexion, and an anteromedial part, which is taut at 90° knee flexion. This fact has been described in anatomical text books (Fick 1904, Lang & Wachsmuth 1972). It was not mentioned by Kennedy et al. in their biomechanical work (1974), but has been advanced again by Furman et al. (1976). In eight of the cases where measurement of partial anterior cruciate rupture was not possible, a rupture of the posterolateral fibres was found, leaving the anteromedial fibre bundle, which is taut in the position of drawer measurement in the gonylaxometer, intact. In this situation it is impossible to bring about any anterior drawer sign and these cases ought not to be designated false negative (neither do they offer an indication for operation—see below). Table 4 which counts these ruptures as false negatives thus represents an absolute minimum of the PV_{neg} at stress radiography.

Posterior drawer signs were only found coincident with ruptures of the posterior cruciate ligament and anterior drawer signs coincident with ruptures of the anterior cruciate ligament in agreement with the works of Palmer (1938) and numerous others, most recently Furman et al. (1976). Group 1 also comprises four isolated anterior drawer signs (true positive, all with true negative medial instability. They represent three total ruptures and one partial, and in agreement with Wang et al. (1975) contribute to the continuous controversy of whether an isolated injury of the anterior cruciate ligament may occur. It does.

Thus gonylaxometry in this clinical material shows patterns of instability in agreement with findings of other authors, also those who have been working experi-

mentally using fresh human knee specimens. Moreover, when used as a diagnostic test gonylaxometry must be evaluated in relation to its primary function: assessment for operation. Those patients in group 1 whose measurements of drawer looseness were false negative ought not to have been operated upon in 8 out of 10 cases as their cruciate ligament ruptures were partial or intra-synovial. With this background the PV_{neg} could be calculated to 97 per cent (and PV_{pos} 100 per cent). A similar consideration can be made for four out of five false negative measurements on fresh medial collateral ruptures, where total rupture of the superficial band not was found. Being also a diagnostic aid in acute and other knee injuries gonylaxometry is therefore evaluated as a method of high accuracy.

REFERENCES

- Fick, R. (1904) Handbuch der Anatomie und Mechanik der Gelenke. I-III. In: Handbuch der Anatomie des Menschen. Ed. von Bardeleben, K., Band II, Teil III p. 546. Gustav Fischer, Jena.
- Furman, W., Marshall, J. L. & Girgis, F. C. (1976) The anterior cruciate ligament. A functional analysis based on postmortem studies. *J. Bone Jt Surg.* **58-A**, 179-185.
- Hallén, L. G. & Lindahl, O. (1965) The lateral stability of the knee-joint. *Acta orthop. scand.* **36**, 179-191.
- Jacobsen, K. (1976) Stress radiographical measurement of the anteroposterior, medial and lateral stability of the knee joint. *Acta orthop. scand.* **47**, 335-344.
- Jonasch, E. (1958) Zerreissung des äusseren und inneren Knieseiten bandes. *Msschr. Unfallheilk.* Beiheft 59, 1-88.
- 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.
- Lang, J. & Wachsmuth, W. (1972) *Praktische Anatomie*. Band I, Teil IV. *Bein und Statik*, p. 242-252. Springer Verlag, Berlin.
- Palmer, I. (1938) On the injuries to the ligaments of the knee joint. A clinical study. *Acta chir. scand.* **LXXXI**, Suppl. LIII, p. 282.

- Wang, J. B., Rubin, R. M. & Marshall, J. L. (1975) A mechanism of isolated anterior cruciate ligament rupture. *J. Bone Jt Surg.* **57-A**, 411-413.
- Warren, L. F., Marshall, J. L. & Girgis, F. (1974) The prime static stabilizer of the medial side of the knee. *J. Bone Jt Surg.* **56-A**, 665-674 (Chart II).
- Vecchio, T. J. (1966) Predictive value of a single diagnostic test in unselected populations. *New Engl. J. Med.* **274**, 1171-1173.
- Wulff, H. R. (1976) *Rational diagnosis and treatment*. pp. 182. Blackwell, Oxford.

Correspondence to: Klaus Jacobsen, 58, Søndertoften, DK-2630 Tåstrup, Denmark.