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Original articles

Quantitative stress radiography for diagnosis of anterior cruciate ligament deficiency

Comparison between manual and instrumental techniques and between methods with knee flexed at 20° and at 90°

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Summary. A portable stress-applying device for stress radiography was developed for daily clinical use. Using this device, stress radiography for the diagnosis of the anterior cruciate ligament (ACL) deficiency was performed with the knee flexed at 20° and at 90°. A 100-N force was chosen as a standardized stress. The subjects were classified into four groups: the manually tested ACL-deficient group (32 knees), the manually tested control group (80 knees), the instrumentally tested ACL-deficient group (14 knees), and the instrumentally tested control group (34 knees). There was no statistical difference in the reliability (sensitivity, specificity, and accuracy) of stress radiography between the manual technique and the instrumental technique. When stress radiography with the knee flexed at 20° and that at 90° were compared, the former was more reliable than the latter. As the manual technique is compromised by a lack of standardization in applied force, a mechanical device is required in quantitative stress radiography. The reliability of stress radiography with the knee flexed at 20° is considered high enough to warrant dispensing with further stress radiography with the knee flexed at 90° for diagnosing ACL deficiency.

Many devices have been used in stress radiography for the diagnosis of cruciate ligament deficiency [8, 11, 17–19]. However, these devices are rather expensive, time consuming, and technically demanding to use and are not necessarily suitable for routine clinical examination. A new, less complicated, and less costly stress-applying device was developed and used in the present study.

Patients and methods

A portable stress-applying device for stress radiography was developed for daily clinical use. It weighs 650 g, and its length is 34 cm. It is shown in Fig. 1. With this device both compressive and tensile forces can be applied to the knee joint. Stress radiography for the diagnosis of anterior cruciate ligament (ACL) deficiency was performed with the knee flexed at 20° and at 90°.

For stress radiography with the knee flexed at 20°, a support is placed under the proximal tibia of the patient lying in the supine position to produce the desired degree of flexion. The height of the support can be varied from 12 to 15 cm depending on the patient's physique. A 2-kg sandbag is placed on the ankle joint. A 100-N, posteriorly directed force is applied on the distal end of the femoral shaft with the stress-applying device via its rubber pad, and a lateral radiograph is taken with a roentgen cassette placed vertically adjacent to the medial side of the knee joint at a film focus distance of 100 cm (Fig. 2). The method of measurement is depicted in Fig. 3.

For stress radiography with the knee flexed at 90° the foot of the patient is fixed with the tibia in neutral rotation by having the examiner sit on the tip of the foot. A 100-N, anteriorly directed force is applied on the proximal end of the tibia with the stress-applying device via a loop sling around the tibial condyles, and a lateral radiograph is taken (Fig. 4). Anterior tibial displacement is measured with the midpoint displacement ratio of Murase et al. [13], which is the ratio of the mean position of the femoral condyles relative to the proximal tibia (Fig. 5).

The subjects were classified into two groups: the manually tested group and the instrumentally tested group. Each group was subdivided into two subgroups: the ACL-deficient subgroup whose ACL ruptures were diagnosed by arthroscopy or arthrotomy, and the control subgroup which included intact knees in patients whose contralateral knees were suspected of having a ligament injury. The manually tested ACL-deficient subgroup consisted of 32 knees in 30 patients (10 knees in 10 patients were

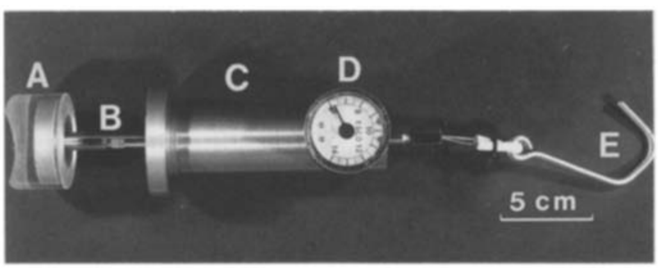

Fig. 1. A portable stress-applying device for stress radiography. It is composed of a concave rubber pad *(A)*, a piston rod *(B)*, a cylinder having a spring within *(C)*, a force gauge *(D)*, and a hook *(E)* with a steel wire loop which is connected to the piston rod

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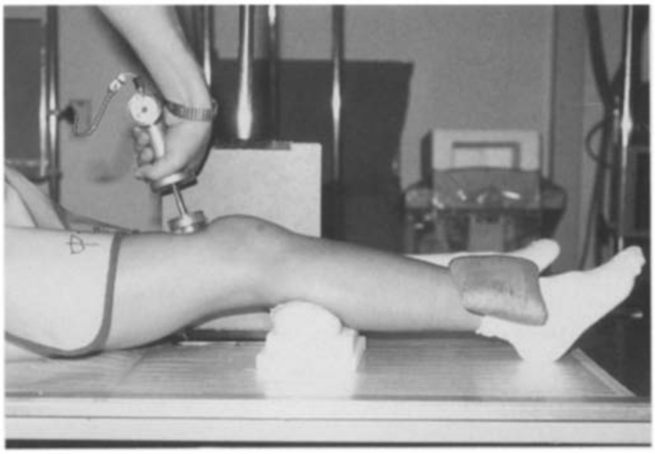

Fig. 2. Stress radiography for the diagnosis of ACL deficiency with the knee flexed at 20°

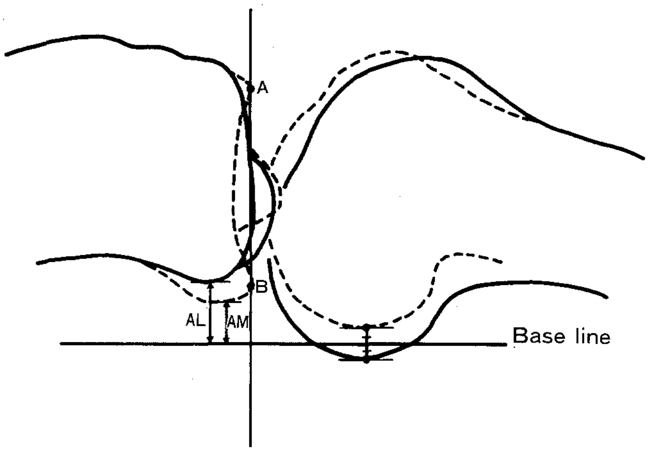

Fig. 3. The measuring method in stress radiography with knee flexed at 20°. *Dashed lines,* medial femoral condyle and medial tibial plateau. A joint line *(AB)* is drawn tangential to the medial tibial plateau, and a base line is drawn perpendicular to the joint line through the midpoint of the posterior peaks of the femoral condyles. The anterior distances of the posterior peaks of both the lateral and the medial tibial condyles from the base line (*AL*, *AM*, respectively) are measured

Fig. 4. Stress radiography for the diagnosis of ACL deficiency with knee flexed at 90°

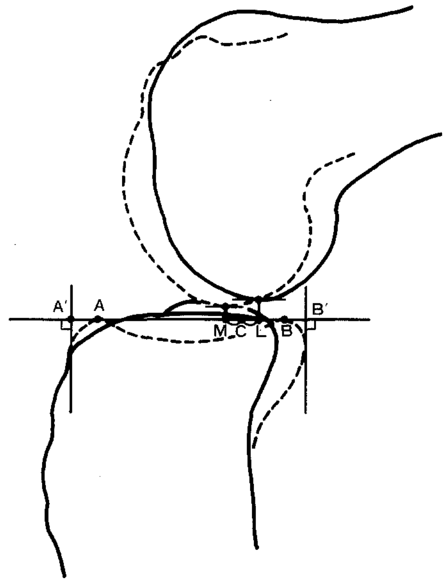

Fig. 5. The measuring method in stress radiography with knee flexed at 90°. *Dashed lines*, medial femoral condyle and medial tibial plateau, *AB* and *A'B'*, anteroposterior widths of the lateral and medial tibial plateaus, respectively. A base line *(A'B')* is drawn tangential to the medial tibial plateau. Straight lines are drawn parallel to the base line and tangential to the femoral condyles. From the points of contact on the femoral condyles, perpendicular lines are drawn to the base line, and the midpoint *(C)* of their feet *(M, L)* on the base line is obtained. The percentage of the maximum anteroposterior width of the tibial plateaus occupied by the distance between the anterior end of the tibial plateaus and the midpoint C defines the midpoint displacement ratio [13]. The midpoint displacement ratio is calculated by $A'C/A'B' \times 100$ in this figure

Table 1. Complications in the ACL-deficient knees

Complicated tissue	Manually tested group (32 knees) [%]	Instrumentally tested group (14 knees) [%]
Medial meniscus	38	29
Lateral meniscus	25	36
Posterior cruciate ligament	6	21
Medial collateral ligament	13	0
Lateral collateral ligament	6	14
Arcuate ligament	13	14
Lateral tibial condyle	3	0
Peroneal nerve	3	0
None	22	14

tested in the acute stage within 3 weeks after injuries), the manually tested control subgroup of 80 knees in 80 patients, the instrumentally tested ACL-deficient subgroup of 14 knees in 14 patients (one knee was tested in the acute stage), and the instrumentally tested control subgroup of 34 knees in 34 patients. Complications in the tested ACL-deficient knees are listed in Table 1. Isolated ACL tears accounted for 22% of the manually tested group and 14% of the instrumentally tested group.

Statistical comparison was performed between manual stress radiography and instrumental stress radiography, and between stress radiography with the knee flexed at 20° and that at 90°.

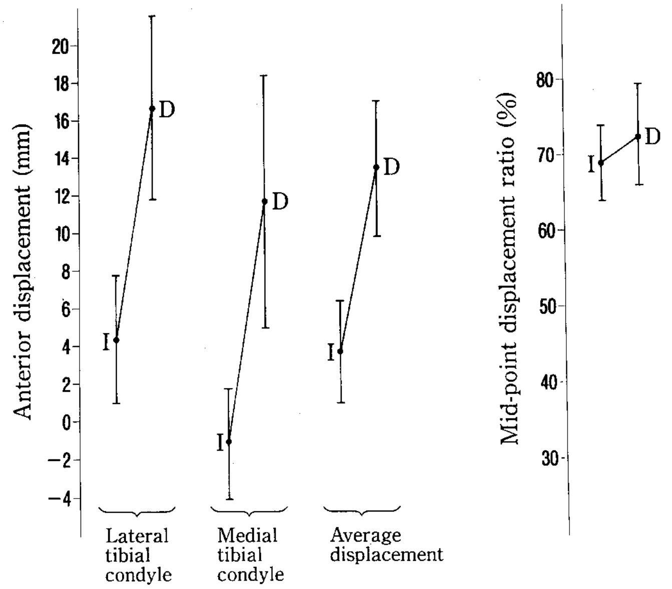

Fig. 6. Graphic representation of averages and standard deviations of the manually tested group. Results of stress radiography with knee flexed at 20° *(left)* and those at 90° *(right)*. *I*, 80 intact knees; *D*, 32 ACL-deficient knees

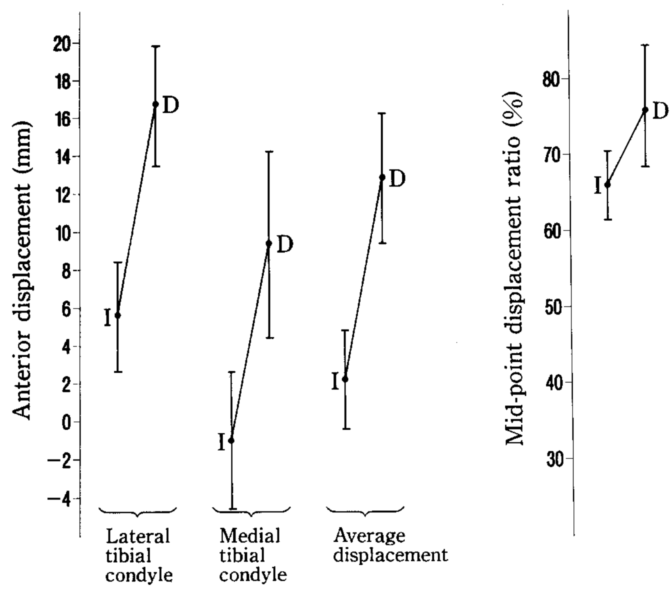

Fig. 7. Graphic representation of averages and standard deviations of the instrumentally tested group. Results of stress radiography with knee flexed at 20° *(left)* and those at 90° *(right)*. *I*, 34 intact knees; *D*, 14 ACL-deficient knees

Results

Results (averages and standard deviations) of the manually tested group are shown in Fig. 6 and those of the instrumentally tested group in Fig. 7. Both in the manual and in the instrumental stress radiographs with the knee flexed at 20° the following critical values for diagnosis of ACL deficiency were the most appropriate for producing the lowest numbers of both false-positive and false-negative results: 10 mm for the anterior distance of the lateral tibial condyle from the base line, 4 mm for that of the medial tibial condyle, and 7 mm for the average anterior distance of both tibial condyles.

Table 2. Reliability of stress radiography in diagnosing ACL deficiency

	Manually tested group (112 knees) [%]	Instrumentally tested group (48 knees) [%]
With knee flexed at 20°		
Sensitivity	100	100
Specificity	100	94
Accuracy	100	97
With knee flexed at 90°		
Sensitivity	72	71
Specificity	69	76
Accuracy	71	74

The reliability of stress radiography in distinguishing ACL-deficient knees from ACL-intact knees was evaluated for sensitivity, specificity, and accuracy (Table 2). The reliability values of both manual and instrumental stress radiographs with the knee flexed at 20° were higher than 93%, while those with the knee flexed at 90° were lower than 77%. The χ^2 test showed no statistical difference of any kind in reliability of stress radiography between the manual technique and the instrumental technique ($P > 0.05$). When stress radiography with the knee flexed at 20° and that at 90° were compared, the former was more sensitive (no false-negatives), more specific (fewer false-positives), and more accurate than the latter ($P < 0.01$).

Discussion

The Lachman test has been found to be more sensitive in detecting ACL tears than the anterior drawer test performed at 90° of flexion [10, 14]. The inaccuracy of stress radiography with the knee flexed at 90° for the diagnosis of ACL deficiency has been pointed out [20]. Recently, new methods of stress radiography with the knees flexed at various smaller angles has been reported [7, 9, 15]. After considering the reported flexion angles at which maximum anterior tibial displacement occurred in ACL-deficient knees [2, 4, 12], we chose 20° as the flexion angle for use in stress radiography. In this study, the method with the knee flexed at 20° proved superior to that with the knee flexed at 90° in diagnosing ACL deficiency. The reasons that the reliability of the method with the knee flexed at 90° was low were as follows: less anterior displacement occurred in ACL-deficient knees at 90° of flexion than at around 20° [2, 4, 12]; anterior tibial displacement decreased 30% when tibial rotation was constrained [4]; and large erros in measurement were found when rotational motions were not accounted for [20]. In spite of these facts, in stress radiography with the knee flexed at 90° tibial rotation was semiconstrained with foot fixation, and rotation was neglected in measurement. Stress radiography performed at 90° knee flexion is preferably not used as the sole diagnostic criterion. The reliability of stress radiography at 20° of knee flexion was considered high enough to warrant not performing further stress radiography at 90° knee flexion for diagnosing ACL deficiency.

In the present study there was no statistically significant difference between the manual technique and the instrumental one. However, the manual technique is compromised by a lack of standardization of the applied force, which is examiner dependent and might be affected by subjectivity on the part of the examiner, especially in the case of postoperative evaluation. Therefore, standardized stress radiography requires a mechanical device to apply stress accurately. The comparatively inexpensive stress-applying device used in this study provided a measure of sagittal laxity of the knee joint, which was useful in diagnosing ACL deficiency. This device could also be used in stress radiographies for assessing ligaments other than ACL.

Forces used in previous studies of stress radiography ranged from 29.4 to 294 N for anteroposterior examination. Jacobsen [8] adopted 294 N, Torzilli et al. [1] 67 and 134 N, Hede et al. [6] 294 N, Hooper [7] 29.4 N, Harilainen et al. [5] 147 N, Rijke et al. [15] 147 N, Stäubli [17] 178 N, and Strobel and Stedtfeld [18] 147 N. The stress force should be large enough to be useful without causing intolerable pain. Harilainen et al. [5] found a stress force of 147 N to be the upper limit which was tolerated. We chose a 100-N force for stress radiography.

Various kinds of arthrometers have been developed to diagnose ACL deficiency [1–3, 12, 16]. One problem affecting their validity is the difficulty in defining the neutral position of the knee joint, and the results obtained are not very useful in discriminating between ACL and posterior cruciate ligament deficiencies [1, 3]. Another disadvantage of arthrometers is a soft-tissue effect, not only upon applying force but also on measuring displacement. As stress radiography is free from those faults, we prefer it to arthrometer measurement in diagnosing ACL deficiency.

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