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Diagnostic Tools for Acute Anterior Cruciate Ligament Injury: GNRB, Lachman Test, and Telos

Seung Min Ryu, MD, PhD, Ho Dong Na, MD, and Oog Jin Shon, MD

Department of Orthopedic Surgery, Yeungnam University Medical Center, Daegu, Korea

Purpose: The purpose of this study is to compare the accuracy of the GNRB arthrometer (Genourob), Lachman test, and Telos device (GmbH) in acute anterior cruciate ligament (ACL) injuries and to evaluate the accuracy of each diagnostic tool according to the length of time from injury to examination.
Materials and Methods: From September 2015 to September 2016, 40 cases of complete ACL rupture were reviewed. We divided the time from injury to examination into three periods of 10 days each and analyzed the diagnostic tools according to the time frame.
Results: An analysis of the area under the curve (AUC) of a receiver operating characteristic curve showed that all diagnostic tools were fairly informative. The GNRB showed a higher AUC than other diagnostic tools. In 10 cases assessed within 10 days after injury, the GNRB showed statistically significant side-to-side difference in laxity (p<0.001), whereas the Telos test and Lachman test did not show significantly different laxity (p=0.541 and p=0.413, respectively).
Conclusions: All diagnostic values of the GNRB were better than other diagnostic tools in acute ACL injuries. The GNRB was more effective in acute ACL injuries examined within 10 days of injury. The GNRB arthrometer can be a useful diagnostic tool for acute ACL injuries.

Keywords: Knee, Anterior cruciate ligament, Injury, Diagnosis, GNRB Arthrometer, Telos

Introduction

The anterior cruciate ligament (ACL) plays an important role in the stability of the knee joint, and ACL injuries are increasing with the recent increase in athletic activities and traffic accidents[1]. An ACL injury increases instability of the knee joint and causes damage to the cartilage and meniscus, leading to early arthritic changes[2]. Therefore, early diagnosis and treatment of an ACL rupture is important for improving prognosis. The early diagnosis rate of ACL ruptures was found to be 19.2%, which is higher than 9.2% reported in the past but still very low[2,3]. This is because it is difficult to measure knee joint laxity owing to pa-

tients' pain and physicians' inexperience[4].

For the diagnosis of an ACL rupture, the Lachman test (30° stress physical examination) (Fig. 1) and stress radiography using a Telos device (GmbH, Hungen, Germany) (Fig. 2A) are commonly used[5,6]. Since the Lachman test is a manual test, it is subject to errors depending on the applied strength and posture and thus has a low degree of reproducibility[7,8]. The Telos test is more reproducible and objective than the Lachman test, but it has the disadvantage of exposing the patient to radiation and potentially damaging the ACL during test. Recently, the GNRB arthrometer (Genourob, Laval, France) was introduced to solve these problems, and it is now possible to measure laxity of the knee joint quickly and accurately without exposure to radiation or application of an excessive force (Fig. 2B)[9]. There have been some reports that the GNRB is a useful tool for evaluation and follow-up of patients with ACL injuries[10,11]. However, to the best of our knowledge, no previous study comparing the diagnostic accuracy of the GNRB with that of other diagnostic tools used for acute ACL injury has been reported.

The purpose of this study was to compare the accuracy of the GNRB, Lachman test, and Telos test in acute ACL injuries. The hypothesis of this study was that the diagnostic accuracy of the
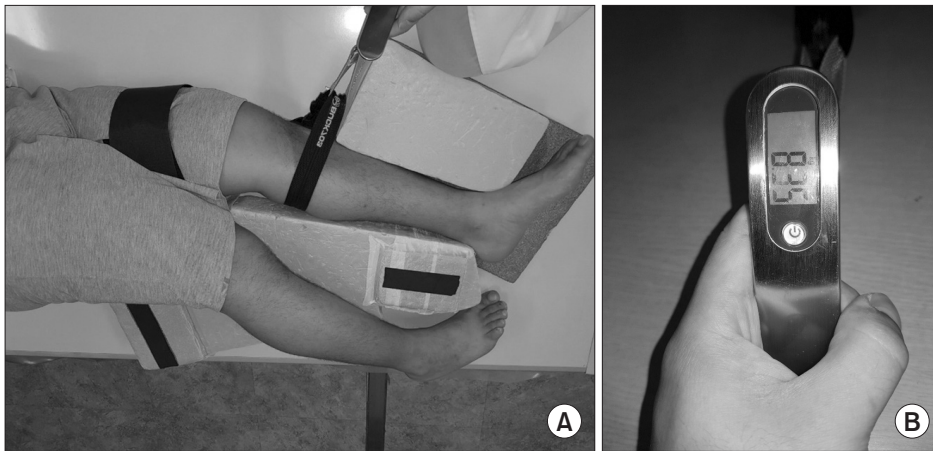
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Fig. 1. (A) Lachman test. A 23-year-old male was lying on a radiolucent table with the knee positioned in 30° of knee flexion and drawn anteriorly. (16 days after injury). (B) We conducted the Lachman test at the power of 80 N approximately.
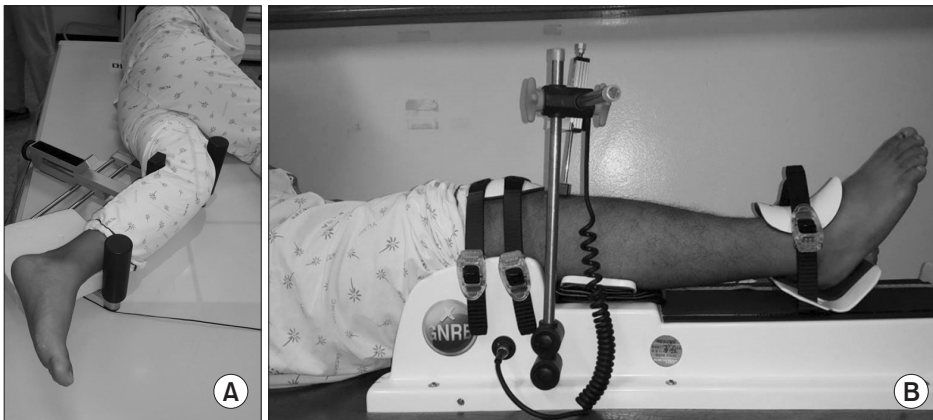

Fig. 2. (A) Telos (GmbH) device. A 19-year-old male was lying on a radiolucent table with the knee in 30° of flexion. The tibia was pressed anteriorly. We could measure the displaced distance by radiographic imaging. (20 days after injury) (B) GNRB arthrometer (Genourob). The 19-year-old male was lying on the GNRB arthrometer. The patient's leg was fixed on the arthrometer at 30° of knee flexion. The patient's tibia was pressed anteriorly and we could check the displaced distance.
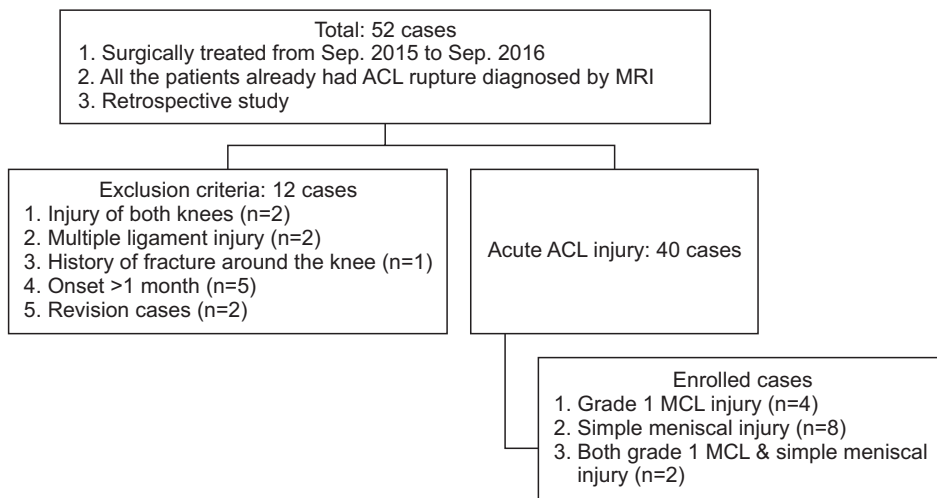
Fig. 3. Flow diagram of inclusion and exclusion of the study participants. ACL: anterior cruciate ligament, MRI: magnetic resonance imaging, MCL: medial collateral ligament.

GNRB arthrometer is better than that of the Lachman test and Telos test. We also planned to evaluate the accuracy of each diagnostic tool according to the time from injury to examination, presence of an accompanying injury, sex, and age.

Materials and Methods

1. Patient Selection

This study was approved by the Institutional Review Board of our hospital. The medical records of all patients (n=52) who

were diagnosed with total ACL ruptures by magnetic resonance imaging from September 2015 to September 2016 were reviewed. An ACL rupture was diagnosed when fibers of the ligament were completely ruptured (grade III injury). Exclusion criteria included injury to both knees (n=2), multiple ligament injury (n=2), history of fracture around the knee (n=1), elapsed time of more than 1 month after injury (n=5), and ACL re-rupture (n=2). However, cases with grade I medial collateral ligament (MCL) injuries (n=4)[12], simple meniscal injuries (n=8), or both (n=2) were included. Finally, 40 patients were selected. The mean age of the patients was 29.6 years (range, 16 to 57 years), and the sex distribution was 26 males and 14 females. The mean time from injury to test was 19.1 days (range, 2 to 30 days). Clinical details of the patients are described in Fig. 3.

2. Laxity Measurement Protocol

All diagnostic tests were performed preoperatively. The Lachman test and the Telos test were done at 80 N with 30° knee flexion, and the GNRB test was performed continuously from 0 N to 134 N. All patients were examined on both the injured and uninjured knees by two observers independently. To determine the inter-observer reliability, the two observers independently measured laxity using all diagnostic tools. The inter-observer reliability was analyzed using intraclass correlation coefficients (ICCs) with 95% confidence intervals (CIs).

The Lachman test and Telos test confirmed anterior laxity of

the knee by radiographically measuring displacement of the midpoint between the tangents to the posterior contours of the tibial condyles drawn perpendicular to the tibial plateau and relative to the corresponding midpoint between the 2 posterior aspects of the femoral condyles (Fig. 4)[9]. The results of the GNRB were confirmed with a graph (Fig. 5). When performing the Lachman test and Telos test, the examiner did not exert more force on a patient if the patient complained of severe pain. We created standards for the two tests such as strict lateral radiography (posterior intercondylar distance <1 mm), knee flexion of 30°, and matching of the two tibial plateau lines.

3. Evaluation of Factors Affecting Diagnosis

We divided the time from injury to test into three 10-day intervals and analyzed the tools for ACL injury diagnosis according to the time frame (time≤10 days, n=10; 10 days<time≤20 days, n=12; and 20 days<time≤30 days, n=18). In addition, we compared the effects of the presence of accompanying injuries such as a simple meniscal tear or a grade I MCL rupture on the ACL injury examination. Sex and age were also evaluated for their effects on ACL injury examination.

4. Statistical Analysis

The means and ranges were calculated for all continuous variables and all statistical analyses were performed using IBM SPSS ver. 23.0 (IBM Co., Armonk, NY, USA). All dependent variables were tested for distribution normality and equality of variances was assessed using the Kolmogorov Smirnov test. The paired *t*-test and Wilcoxon rank-sum test were used to determine statistical significance in the Lachman test, Telos test, and GNRB

Fig. 4. The Lachman test and the Telos test were performed at 80 N with 30° knee flexion. The anterior laxity of the knee joint is measured by displacement of the midpoint between the tangents to the posterior contours of the tibial condyles drawn perpendicular to the tibial plateau and relative to the location of the corresponding midpoint between the 2 posterior aspects of the femoral condyles.
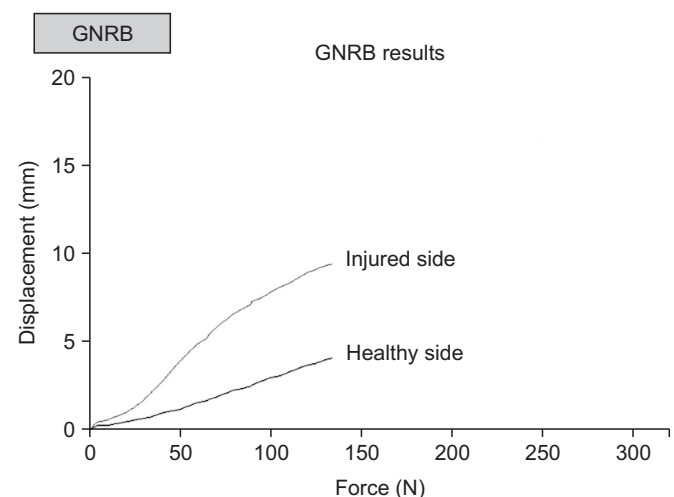

Fig. 5. GNRB (Genourob) results graph. The GNRB test was performed continuously from 0 N to 134 N in both knees.

test between the injured knee and the uninjured knee. Correlations between the possible influencing factors and the diagnostic tools were also evaluated by Pearson correlation coefficient. The diagnostic value of each diagnostic tool was evaluated by analysis of the area under the curve (AUC) of a receiver operating characteristic (ROC) curve: null (AUC=0.5), poorly informative (0.5≤AUC<0.7), fairly informative (0.7≤AUC<0.9), highly informative (0.9≤AUC<1), or perfect (AUC=1)[13]. All statistical analyses were done using IBM SPSS ver. 23.0 (IBM Co.), and p<0.05 was considered statistically significant.

Results

1. General Accuracy of Each Diagnostic Tool

All diagnostic tools detected differences in laxity between the two sides at statistically significant levels (Table 1). The mean laxities measured by the GNRB arthrometer with three testing forces of 67 N, 89 N, and 134 N (GNRBs) were 3.83 mm, 4.95 mm, and 7.00 mm, respectively, in the injured knees, and 1.87 mm, 2.58 mm, and 4.18 mm, respectively, in the uninjured knees (all p=0.000). In the Lachman test, the mean laxity was 2.52 mm in injured knees and –0.26 mm in uninjured knees (p=0.000). Using the Telos device, the mean laxity was 3.13 mm in injured

knees and 0.72 mm in uninjured knees (p=0.003).

The AUC analysis showed that all diagnostic tools were fairly informative. The GNRBs had higher AUCs than did the Telos and Lachman tests, so GNRBs were more reliable than the other diagnostic tools.

2. Accuracy of Each Diagnostic Tool according to Possible Influencing Factors

In the 10 cases examined within 10 days after injury, the GNRBs showed statistically different laxity between the two sides (all p=0.000), but the Telos and Lachman tests did not show statistically significant differences in laxity (p=0.541 and p=0.413, respectively) (Table 2). In the 12 cases examined between 10 and 20 days after injury, the GNRBs and Lachman test showed statistically significant differences in laxity between the two sides (p=0.000, p=0.005, and p=0.033 for the GNRB at 67 N, 89 N, and 13 N, respectively and p=0.006 for the Lachman test), but the Telos test did not show a statistically significant side-to-side difference in laxity (p=0.122). In the 18 cases examined from 20 to 30 days after injury, all diagnostic tools showed statistically significant differences in laxity between the two sides (p=0.026, p=0.015, and p=0.009 for the GNRB at 67 N, 89 N, and 13 N, respectively, p=0.002 for the Lachman test, and, p=0.018 for the

Table 1. Side-to-Side Difference in Laxity and AUC on All Diagnostic Tools in All Cases

	Injured knee (mm)	Uninjured knee (mm)	p-value[a]	AUC	95% CI
GNRB 67 N	3.83±2.09	1.87±0.70	0.000	0.826	0.700–0.953
GNRB 89 N	4.95±2.39	2.58±0.90	0.000	0.833	0.708–0.957
GNRB 134 N	7.00±2.59	4.18±1.24	0.000	0.840	0.714–0.966
Lachman test	2.52±4.71	–0.26±3.63	0.000	0.779	0.620–0.937
Telos	5.13±4.55	0.72±3.50	0.003	0.736	0.566–0.906

Values are presented as mean±standard deviation.
AUC: area under the curve, CI: confidence interval.
[a]Paired *t*-test.

Table 2. Side-to-Side Difference in Laxity (mm) on All Diagnostic Tools according to Time of Examination

	Within 10 days (n=10)			10 to 20 days (n=12)			20 to 30 days (n=18)		
	Injured knee	Uninjured knee	p-value	Injured knee	Uninjured knee	p-value[a]	Injured knee	Uninjured knee	p-value
GNRB 67 N	4.04±1.79	1.62±0.57	0.000[a]	3.03±0.86	2.06±0.80	0.000	3.95±0.99	1.76±0.24	0.026[a]
GNRB 89 N	5.36±2.11	2.30±0.71	0.000[a]	4.03±1.13	2.91±1.03	0.005	5.05±1.12	2.40±0.30	0.015[a]
GNRB 134 N	7.64±2.30	3.76±1.01	0.000[a]	5.91±1.52	4.66±1.42	0.033	7.16±1.20	4.01±0.45	0.009[a]
Lachman test	1.04±5.65	0.30±3.76	0.541[b]	2.50±2.68	–1.48±2.68	0.006	2.49±1.13	–0.99±0.39	0.002[b]
Telos	6.85±2.52	5.48±3.12	0.413[a]	5.06±6.02	2.24±3.36	0.122	4.30±1.17	1.34±1.13	0.018[a]

Values are presented as mean±standard deviation.
[a]Paired *t*-test.
[b]Wilcoxon rank sum test.

Telos test).

Regardless of the presence of a combined injury, all diagnostic tools showed significant differences in laxity between the two sides (Table 3). The AUC analysis showed that the diagnostic tools were fairly to highly informative in patients with combined injuries, and poorly to fairly informative in patients with isolated ACL injuries.

Regardless of sex, all diagnostic tools showed statistically significant differences in laxity between the two sides, and knee joint relaxation tended to be greater on both the injured and the uninjured sides in women (Table 4). The AUC analysis showed that the diagnostic tools were fairly to highly informative in female patients and only fairly informative in male patients.

On the correlation analysis between age and diagnostic tools, only the GNRBs showed statistically significant correlation for detection of ACL injuries (for testing forces of 67 N, 89 N, and 134 N, the correlation coefficients were 0.551, 0.523, and 0.501, respectively and p=0.012, p=0.018, and p=0.025, respectively). However, the Lachman test and Telos test showed no statistically significant correlations with age in the injured knees. In addition, in the uninjured knees, no statistically significant correlations were found between the diagnostic tools and age.

3. Inter-Observer Reliability

The ICCs for inter-observer reliability in the assessment of laxity using all five diagnostic tools are summarized in Table 5. ICCs ranged from 0.853 to 0.972. The GNRBs showed slightly higher ICCs than did other diagnostic tools.

Discussion

The most important objective of this study was to compare the accuracy of the Lachman test, Telos test, and GNRB test in acute

Table 5. Intraclass Correlation Coefficients (ICCs) for Inter-Observer Reliability in the Assessment of Laxity Using All Diagnostic Tools

	Injured knee		Uninjured knee	
	ICC	95% CI	ICC	95% CI
GNRB 67 N	0.924	0.797–0.972	0.939	0.790–0.983
GNRB 89 N	0.987	0.966–0.995	0.936	0.834–0.975
GNRB 134 N	0.972	0.922–0.990	0.941	0.780–0.984
Lachman test	0.872	0.782–0.951	0.853	0.793–0.945
Telos	0.891	0.803–0.958	0.882	0.821–0.957

CI: confidence interval.

Table 3. Side-to-Side Difference in Laxity (mm) and AUC on All Diagnostic Tools according to Accompanied Meniscus or MCL injury

	Isolated anterior cruciate ligament injury (n=26)					Combined injury (n=14)				
	Injured knee	Uninjured knee	p-value[a]	AUC	95% CI	Injured knee	Uninjured knee	p-value[a]	AUC	95% CI
GNRB 67 N	3.66±2.23	1.93±0.71	0.000	0.790	0.614–0.966	4.12±1.85	1.74±0.70	0.000	0.918	0.772–1.000
GNRB 89 N	4.80±2.60	2.66±0.95	0.000	0.805	0.635–0.974	5.22±2.00	2.44±0.81	0.000	0.918	0.772–1.000
GNRB 134 N	6.98±2.90	4.31±1.32	0.000	0.822	0.656–0.989	7.04±2.00	3.94±1.08	0.000	0.878	0.689–1.000
Lachman test	0.88±4.58	−1.64±3.09	0.012	0.760	0.559–0.961	5.56±3.32	2.28±3.22	0.000	0.861	0.634–1.000
Telos	4.72±4.65	2.22±4.23	0.023	0.674	0.450–0.897	5.90±4.41	1.50±0.91	0.012	0.931	0.768–1.000

Values are presented as mean±standard deviation.
AUC: area under the curve, MCL: medial collateral ligament, CI: confidence interval.
[a]Paired *t*-test.

Table 4. Side-to-Side Difference in Laxity (mm) and AUC on All Diagnostic Tools according to Sex Distribution

	Male (n=26)					Female (n=14)				
	Injured knee	Uninjured knee	p-value[a]	AUC	95% CI	Injured knee	Uninjured knee	p-value[a]	AUC	95% CI
GNRB 67 N	2.89±1.36	1.65±0.71	0.003	0.796	0.625–0.967	5.57±2.14	2.27±0.51	0.000	0.970	0.940–1.000
GNRB 89 N	3.90±1.68	2.28±0.91	0.002	0.814	0.649–0.978	6.91±2.31	3.14±0.54	0.000	0.970	0.940–1.000
GNRB 134 N	5.96±2.04	3.79±1.31	0.002	0.814	0.647–0.980	8.92±2.46	4.91±0.64	0.000	0.970	0.937–1.000
Lachman test	1.11±4.44	−1.65±2.53	0.000	0.785	0.585–0.985	1.17±4.91	−0.59±4.85	0.001	0.847	0.603–1.000
Telos	2.27±4.17	−0.66±3.81	0.005	0.747	0.540–0.953	2.97±5.73	0.47±3.27	0.028	0.708	0.393–1.000

Values are presented as mean±standard deviation.
AUC: area under the curve, CI: confidence interval.
[a]Paired *t*-test.

ACL injuries. The main result of this study was that all diagnostic values of the GNRBs were better than those of the Lachman test or Telos test in acute ACL injuries.

Recently, the GNRB arthrometer has been introduced to improve accuracy and reproducibility in the diagnosis of ACL injuries[11]. The patient lies on a standard examination table in the supine position for comparative testing of both knees that starts with the healthy side. The GNRB test starts from about 25°–30° of knee flexion as in any other tests. During the test, the lower limb is placed in a rigid adjustable leg support with the knee placed at 0° of rotation so that the inferior pole of the patella corresponds to the lower border of the patellar support. The joint line is palpated and should be located between the support and a linear jack that exerts gradually increasing anterior translation thrust forces from 0 N to 250 N[14]. A displacement transducer records relative displacement of the anterior tibial tubercle with respect to the femur. Unlike previous tests, the GNRB has the advantage of being able to control the force applied to the patella and calf and to limit the impact of hamstring muscles on the knee[15]. Therefore, it was theorized that the GNRB could overcome the shortcomings of radiographic stress tests.

In this study, GNRB measurements were similar to those of other studies in normal knees: 1.9±0.7 at 67 N, 2.6±0.9 at 89 N, and 4.2±1.2 at 134 N[15]. The Telos and Lachman tests had lower AUCs than did the GNRBs, indicating that they were less reliable than the GNRB arthrometer. Lefevre et al.[16] reported that the diagnostic value of GNRB arthrometer was better than the Telos device for the diagnosis of ACL partial thickness tears. Also Beldame et al.[9] reported that the GNRB arthrometer exhibited similar performance to the Telos device but was simpler to use. They concluded that the GNRB test can be performed repeatedly for diagnostic and monitoring purposes as it does not expose the patient to radiation.

There may be several reasons for this, one of which may be a measurement bias caused by pain and muscle tension the patient feels such that the examiner cannot apply enough force to the knee. Second, in radiographic tests, anterior translation of the knee is measured by displacement of the midpoint between the tangents to the posterior contours of the tibial condyles drawn perpendicular to the tibial plateau and relative to the position of the corresponding midpoint between the 2 posterior aspects of the femoral condyles. According to Bouguennec et al.[10], there is a limitation to the precise recognition of structures on simple knee lateral radiographs, and a slight degree of rotation may result in a difference of several millimeters. In this study, we also had difficulty in accurately recognizing structures on radiographs. By

contrast, the inter-observer ICC of the GNRB test was higher than that of other tests, so we think that it is possible to overcome the measurement bias with high reproducibility.

When we divided time from injury to examination into three intervals, the patients treated within 10 days after injury showed statistical differences between the results of the injured and the uninjured knees only on the GNRB test. Although, as far as we know, there have been no studies on this issue, we presume that the GNRB is more effective than the other tools in hyper-acute ACL injuries, which are seen within 10 days. Further studies are needed on this matter.

For all diagnostic tools, accompanying injuries such as simple meniscal tears or grade 1 MCL injuries did not affect distinction between the injured and uninjured knees. However, the patients in the combined injury group showed higher AUCs than did the patients in the isolated ACL injury group. We presume that damage to the meniscus and MCL affects laxity of the knee and therefore produces higher reliability in diagnosis.

For all diagnostic tools, sex did not affect the distinction between the injured and uninjured knees. The degree of knee laxity was higher in women than in men, which is consistent with the findings by Wojtys et al.[17]. We assume that this is because males have higher muscle strength than females. We also think that this difference in laxity caused a difference in the AUC values, which in turn caused greater diagnostic reliability of the GNRB test in females. In addition, in the female group, the AUC of the Telos test was very low compared to that of other tests. This is probably because pain was so severe in four patients in the female group that the examiner did not apply 80 N of power when performing the Telos test. However, this did not happen in the male group.

In elderly patients, laxity of the knees tends to increase, and the difference between the uninjured limb and the injured limb also tends to increase. This is consistent with the findings by Sharma et al.[18], and we think the reason is that elderly patients have reduced muscle strength. In the Telos test, it was not possible to distinguish the injured knee from the uninjured knee in patients in their early 20s, probably because the muscles were strong.

This study had several limitations. First, the sample size was small. Second, we did not address cases of acute partial ACL injury, so a further study is needed on acute partial ACL injuries. In addition, the GNRB test was performed in one trial, but the radiographic tests (Lachman test and Telos test) were performed several times to obtain accurate measurements, and this might have affected knee joint relaxation and muscle tension. Finally, we did not evaluate intra-observer reliability because patients received surgery immediately after diagnosis.

Conclusions

All diagnostic values of the GNRB test were better than those of the Lachman test or Telos test in acute ACL injuries. The GNRB test was more effective than the Lachman test or Telos test for diagnosing an acute ACL injury, which is seen within 10 days of injury, and it was more reliable than the other tests in elderly or female patients. The GNRB arthrometer can be a useful diagnostic tool for acute ACL injuries.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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