The coronal lateral collateral ligament sign in the anterior cruciate ligament-injured knees was observed regardless of the knee laxity based on the quantitative measurements

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Abstract

Purpose: The coronal lateral collateral ligament (LCL) sign has been reported to be associated with deviated position of the tibia on MRI due to anterior cruciate ligament (ACL) injuries. However, the relationships between LCL sign and clinical knee laxity evaluations are still unclear. The purpose of the study was to investigate the relationship between the coronal LCL sign and knee laxity measurements.

Methods: A retrospective review of unilateral ACL injured patients who underwent ACL reconstruction was performed. The coronal LCL sign was determined using magnetic resonance imaging (MRI). Clinical grading of the pivot-shift test, KT-1000 measurements, and quantitative measurements of the Lachman test and the pivot-shift test using an electromagnetic system, were compared between patients with positive and negative coronal LCL sign. A subgroup analysis of different age groups was then performed, dividing patients to adolescent (age ≤ 18 years) and adult (age > 18 years) groups.

Results: A total of 85 patients were enrolled, of which 45 patients had coronal LCL signs. The coronal LCL sign was not associated with the pivot-shift test clinical grading (n.s), KT-1000 measurement (n.s), the tibial translation during the Lachman test (n.s), or with tibia acceleration (n.s) and translation (n.s) during the pivot-shift test. The subgroup analysis also showed that the aforementioned parameters were not associated with the coronal LCL sign in either adolescent or adult subgroups.

Conclusion: The occurrence of coronal LCL sign in MRI did not implied greater clinical knee laxity evaluations in patients with ACL tears. The knee laxity should routinely be evaluated regardless the coronal LCL sign.

Keywords: anterior cruciate ligament; coronal lateral collateral ligament sign; magnetic resonance imaging; pivot-shift; rotational instability

Level of Evidence: Level III

Introduction

Primary signs on magnetic resonance imaging (MRI), such as discontinuity and increased signal intensity of ACL fibers, are commonly used for the diagnosis of ACL tears [30]. In addition to direct findings, several supplementary signs have been introduced, such as anterior tibial translation [4, 32] and internal rotation of the tibia [39]. Furthermore, the lateral femoral notch sign [33, 37] and bone kissing contusion [27, 34, 37] in MRI have also been considered special presentations in patients with ACL tears.

Recently, a new complementary sign, called the coronal lateral collateral ligament (LCL) sign, was suggested to be correlated with an ACL-deficient knee [24]. A coronal LCL sign is considered positive when the entirety of the LCL (from the origin to the insertion) can be observed on a single coronal slice on an MRI, where the presence of the coronal LCL sign is associated with anterior displacement and internal rotation of the tibia [24]. Mitchell et al. reported that the coronal LCL sign is predictive of ACL graft failure in adolescents [25]. Therefore, the coronal LCL sign could be suggestive of abnormal knee laxity.

Dynamic rotatory knee laxity, or the pivot-shift, has been shown to be correlated with patient dissatisfaction and inferior functional outcomes [3, 20]. Furthermore, a large pivot-shift prior to ACL reconstruction is known as a risk for postoperative residual knee joint laxity [38, 40] and is associated with revisions of ACL reconstruction [22]. Although it has been reported that the coronal LCL sign could be another indicator for ACL re-rupture [25], it is still unclear how the coronal LCL sign is associated with knee laxities, including anterior laxity and rotatory knee laxity. Therefore, the purpose of the study was to investigate the relationship between the coronal LCL sign and knee laxity measurements. It was hypothesized that the presence of the coronal LCL sign would be an indication of greater knee laxities. The clinical relevance of this study is that clinicians would understand the potential of an MRI finding, the coronal LCL sign, for detecting the knee laxity.

Materials and Methods

After Institutional Review Board approval (ID No. B190055), charts were retrospectively reviewed for all patients treated surgically with ACL reconstruction in any age at a single institution between July 2017 and July 2020. While informed consents which allow us to use medical records with de-identification in future studies were obtained from all patients, informed consents from patients for this particular study were waived to the retrospective study design. Patients were excluded if the data were incomplete or if there were any concomitant fractures, cartilage injuries, posterolateral corner injuries, or other knee ligament injuries in the ipsilateral or contralateral knee. Patients were treated according to the clinical standard of care at the institution. ACL injury was diagnosed clinically and confirmed by MRI. ACL reconstruction was performed using an anatomic reconstruction technique.

Patients' data, including sex, laterality, sport played, time from injury to MRI, and time from injury to surgery, were collected from the chart review. MRI scans were obtained using the GE Discovery MR450 1.5T Scanner (GE Healthcare) with the patient in the supine position with the knee in 10º to 15º of flexion and neutral rotation. Coronal image slices were reviewed on the MRI for the coronal LCL sign. The coronal LCL sign was considered positive when the LCL could be observed entirely from the femoral origin to the fibular insertion in a single coronal slice on the MRI (**Figure 1**) [24, 25]. During the review process, three orthopedic surgeons (C-K H, HY and SW) blindly evaluated the images twice at a 2-week interval, and intra- and inter-observer repeatability was assessed by calculating intra-class correlation coefficients (ICCs).

The laxity of knee joint was routinely evaluated for each patient scheduled for ACL reconstruction, and these tests were performed under general anesthesia before ACL reconstruction in the operation room. Two evaluations of the pivot-shift test, clinical pivot-shift grading and the quantitative pivot-shift test, were conducted simultaneously. The standard clinical grading was determined by the examiner based on the International Knee Documentation Committee (IKDC) guidelines [15]: none (−), glide (+), clunk (++), and gross (+++). Grading was performed by a single examiner who was blinded to the results of quantitative evaluation and the coronal LCL signs in the MRI. Anterior knee laxity was measured with a KT-1000 knee ligament arthrometer (MEDmetric, San Diego, CA) at 30º of knee flexion in both the injured and contralateral knee with maximum manual force. The electromagnetic system (JIMI Kobe, Tokyo, Arthrex Japan) was used in accordance with previous studies [1, 2, 10-14, 26, 29, 31, 36], and the tibial translation and acceleration were calculated as quantitative measurements (**Figure 2**) [13]. The system consisted of three electromagnetic receivers and an electromagnetic transmitter. A transmitter that produces electromagnetic fields in this electromagnetic system was placed on the side of the operating table. Two receivers were firmly attached to the thigh and calf with plastic braces and were used to track femoral and tibial motions respectively, whereas the other receiver was used to register seven anatomic landmarks on the femur and the tibia, including the greater trochanter, medial epicondyle, lateral epicondyle, the intersection of the medial collateral ligament and knee joint line, the fibula head, the medial malleoli, and the lateral malleoli. The three-dimensional positions of the femur and the tibia were then recognized in a virtual space based on the registered landmark locations, and the anatomic coordinates of the knee were then set to provide 6 degree-of freedom of knee kinematics [8]. The tibial anteroposterior translation during the Lachman tests were recorded according to the previous literature [1]. The tibial anteroposterior translation during the pivot-shift test was captured with a sampling rate of 240Hz and used to calculate the tibial acceleration by secondary derivative in terms of time. The posterior tibial translation, or reduction, during the pivot-shift test was identified as the pivot-shift, and the tibial acceleration at the time of the tibial posterior reduction was utilized as a quantitative pivot-shift measurement [12, 13].

Since the coronal LCL sign was only utilized in adolescent populations in previous studies [24, 25], the present study further separated the patients into two age groups for the subgroup analysis: adolescent (age ≤ 18 years) and adult (age > 18 years) groups. KT-1000 measurement, tibial translation during the Lachman test, tibial acceleration and tibial translation during the pivot-shift test, were compared in the positive and negative coronal LCL sign groups in the different age subgroups.

Statistics Analysis

A priori sample size calculation was performed with G*Power, version 3.1.3 software (Heinrich Heine-University of Dusseldorf, Dusseldorf, Germany). The results showed that at least 36 subjects were required in order to detect a 0.5 m/s^2 difference in tibial acceleration, assuming a power of 0.80, a significance level of 0.05, and a common variance of 0.5 m/s^2 was obtained in the two-tailed Mann-Whitney U test. These parameters were based on data from previous reports [29]. Also, when tibial translation was used for the calculation, at least 34 subjects were required in order to detect a 2.5mm difference in tibial translation, assuming a power of 0.80, a significance level of 0.05, and common variance of 4 mm in the two-tailed Mann-Whitney U test. These parameters were based on data from previous reports [12, 13].

All statistical analyses were conducted using IBM SPSS Statistics (version 20; IBM SPSS Inc., Chicago, IL, USA). Side-to-side differences between the injured knee and contralateral knee were calculated for the results from the KT-1000 measurements, tibial translation during the Lachman test, and tibial translation during the pivot-shift test. Descriptive statistics, including means and standard deviations, were obtained for each group. The intraclass correlation efficient (ICC) was calculated to determine interobserver and intraobserver repeatability for the coronal LCL sign. A chi-square test was used for comparing categorical data between groups. A Mann-Whitney U test was used for between-group comparisons of the non-parametric variables. A Spearman correlation was used to evaluate the correlations among the non-parametric variables, where $p \leq 0.05$ was considered statistically significant.

Results

After initial screening, 94 patients were considered eligible. Three patients with multiple ligament tear and four patients with contralateral knee ligament injuries were excluded, whereas two patients were excluded due to incomplete data. Finally, a total of 85 patients with a mean age of 26.1 ± 11.9 years were enrolled. The mean time from injury to MRI was 8.7 ± 11.5 days, ranging from 0 to 63 days, whereas the mean time from injury to surgery was 77.3 ± 55 days, ranging from 6 to 285 days. Forty-five patients had positive coronal LCL signs, whereas the others had negative signs. A significantly greater proportion of male patients had positive LCL signs as compared to the female patients ($p = 0.04$). Interobserver repeatability for the coronal LCL sign was 0.89, where intraobserver repeatability ranged from 0.87 to 0.94. The patient demographics and the findings for the coronal LCL sign are detailed in **Table 1**.

Results of the preoperative clinical grading of the pivot-shift test were summarized in **Table 2**. The time from injury to surgery was not correlated to the clinical pivot-shift grading (n.s). There were no differences in the clinical grading of the pivot-shift tests between patients with the positive coronal LCL sign and negative coronal LCL sign (n.s). The subgroup analysis also showed no between-group differences in adolescent and adult patients (n.s).

The side-to-side difference (SSD) in tibial translation during the Lachman test and KT-1000 measurement were similar in the positive and negative coronal LCL sign groups (n.s) (**Table 3**) . The time from injury to surgery was not correlated to the SSD in tibial translation during the Lachman test and KT-1000 measurement (n.s). The subgroup analysis showed that the tibial translation during the Lachman test SSD and KT-1000 measurement SSD were not related to the presence of the coronal LCL sign in either adolescent patients or adult patients (**Table 3**).

The tibial acceleration during the pivot-shift test was similar in the positive and negative coronal LCL sign groups (n.s) (**Table 3**) . The time from injury to surgery was not correlated to the tibial acceleration during the pivot-shift test (n.s). The subgroup analysis also showed no between-group differences in tibial acceleration during the pivot-shift test in adolescent and adult groups (n.s). The SSD of tibial translation during the pivot-shift test was similar in the positive and negative coronal LCL sign groups (n.s), and was not correlated to the time from injury to surgery (n.s) (**Table 3**). The subgroup analysis also showed no between-group differences in side-to-side differences in tibial translation during the pivot-shift test in adolescent and adult groups (n.s) (**Table 3**).

Discussion

The most important findings of the present study were that the coronal LCL sign in patients with ACL tear was not associated with greater knee laxities, neither anterior nor rotatory knee laxity. The vertically orientated fibular collateral ligament, named as the coronal LCL sign in the recent literature, was considered as a secondary sign of anterior cruciate ligament rupture on magnetic resonance imaging [16]. The coronal LCL sign was reported to indicate anterior displacement and internal rotation of the tibia on MRI [24, 25]. Due to a lack of evidence of the relationship between the coronal LCL sign and knee laxities, a comparison was made using both Lachman test and the pivot-shift test. Furthermore, quantitative measurements were utilized for both tests, since the tibial translation and acceleration for the pivot-shift test have been validated for clinical ACL trials [28]. Further studies will be needed to elucidate how the coronal LCL sign leads to a greater risk of ACL reconstruction graft failure [25].

Increased anterior tibial translation is common in patients with anterior cruciate ligament (ACL) tear [18] and potentially alters lower extremity kinematics [19, 21, 23]. Since the potential impact of the coronal LCL sign on the anterior knee laxity was suggested by previous report [24], the present study evaluated the association of the coronal LCL sign and the anterior tibial translation during Lachman test and the pivot-shift test. The results in the present study showed no difference between the positive and negative coronal LCL sign groups in KT-1000 measurement and tibial translations during the Lachman test and the pivot-shift test. This might be due to the difference of evaluating condition between the coronal LCL sign and knee laxities. The coronal LCL sign is evaluated on the MRI which is taken without any external stress on the knee joint [24, 25], whereas knee laxity evaluations, either Lachman test or the pivot-shift test, include external stress on the knee joint that elicit abnormal translation or instability. The coronal LCL sign could indicate an abnormal tibial position under stress-free condition similarly to the report of Hardy A et al. [9] and might affect knee kinematics regardless of knee laxities.

Detecting dynamic instability in the knee is clinically important since it may lead to osteoarthritic changes [5, 7, 17], postoperative residual knee joint laxity [38, 40] and the need for revisions to ACL reconstruction [22]. A pivot-shift is a combination of anterior subluxation of the lateral tibial plateau and its posterior reduction [6]. The LCL sign could indicate anterior subluxation of the tibial plateau during the MRI, and it therefore could have the potential to inflate the pivot-shift. In the present study, however, we failed to find between-group differences in tibial acceleration and tibial translation during the pivot-shift tests in the positive and negative coronal LCL sign groups. On the other hand, the effect of ACL insufficiency on knee laxity may also vary depending on age since the joints become stiff with age in general [35]. Subgroup analysis was then performed for adolescent and adult patients, but the results showed that the tibial acceleration and tibial translation during the pivot-shift tests were similar in the positive and negative coronal LCL sign groups. Therefore, it is suggested that the static knee displacement sign found in stress-free MRI could not predict the present of dynamic rotatory knee laxity in either adolescent or adult patients with ACL tears.

The results of the present study showed that the period from the time of injury to the MRI was not correlated with the coronal LCL sign. A previous study also demonstrated that the chronicity of an ACL tear did not affect the presence of the coronal LCL sign [24]. Despite the fact that the MRI images collected in the current study were relatively in the acute stage, the findings supported the premise suggesting early occurrence of the coronal LCL sign in the acute stage. It should also be noted that the coronal LCL sign has also been found in some ACL-intact knees [24]. There is thus a possibility that the coronal LCL sign is a predisposing factor for an ACL tear, rather than a resultant change due to an ACL injury.

Although the data from different studies could not be compared directly, the data acquired in the present study were generally consistent with those of previous studies. It was found in the present study that 53% of ACL-deficient patients have positive coronal LCL signs, while previous studies reported the rate to be 69% in their cohort [24, 25]. Meanwhile, it was also found in the present study that male sex was significantly associated with the presence of the coronal LCL sign, which was also reported in a previous study [24]. The positive rate of coronal LCL signs in the male and female groups in the present study (63% and 41%, respectively) were also similar to those in a previous study (62% and 38%, respectively) [24]. Our results for the inter- and intra-observer reliabilities for the coronal LCL sign were also in agreement with those of a previous study [24].

The present study had some limitations. First, although the total sample size was greater than the required sample size calculated from the priori power analysis, the sample sizes in the subgroups were relatively small. Second, the study was a retrospective design, and the quality of the MRI could not be fully controlled. The positioning inconsistencies possibly existed due to 5% of images being obtained at an outside facility, despite the fact that these images were obtained from the MRI scanner with the same product specification and that the position of the knee was in accordance with a standardized protocol. Third, some patients enrolled in the present study acquired MRI early but underwent surgeries several months later. The discrepancy in time points possibly affected the results. Forth, concomitant soft tissue injuries were not evaluated in the present study. The present study was aimed toward confirming the relationship between the coronal LCL sign and the dynamic instability of the knee, but the actual cause of knee dynamic instability could not be confirmed in this study. Despite the aforementioned limitations, the results of the present study provide new insights into the clinical roles of the coronal LCL sign.

The clinical relevance of this study is that clinicians should acknowledge low potential of the coronal LCL sign for detecting the knee laxity. Clinicians should assess the knee laxity in every patient independently of image findings.

Conclusion

The coronal LCL sign in MRI did not imply greater knee anterior and rotatory laxities which were quantitatively measured in patients with ACL tears. The knee laxity should routinely be evaluated regardless the coronal LCL sign.

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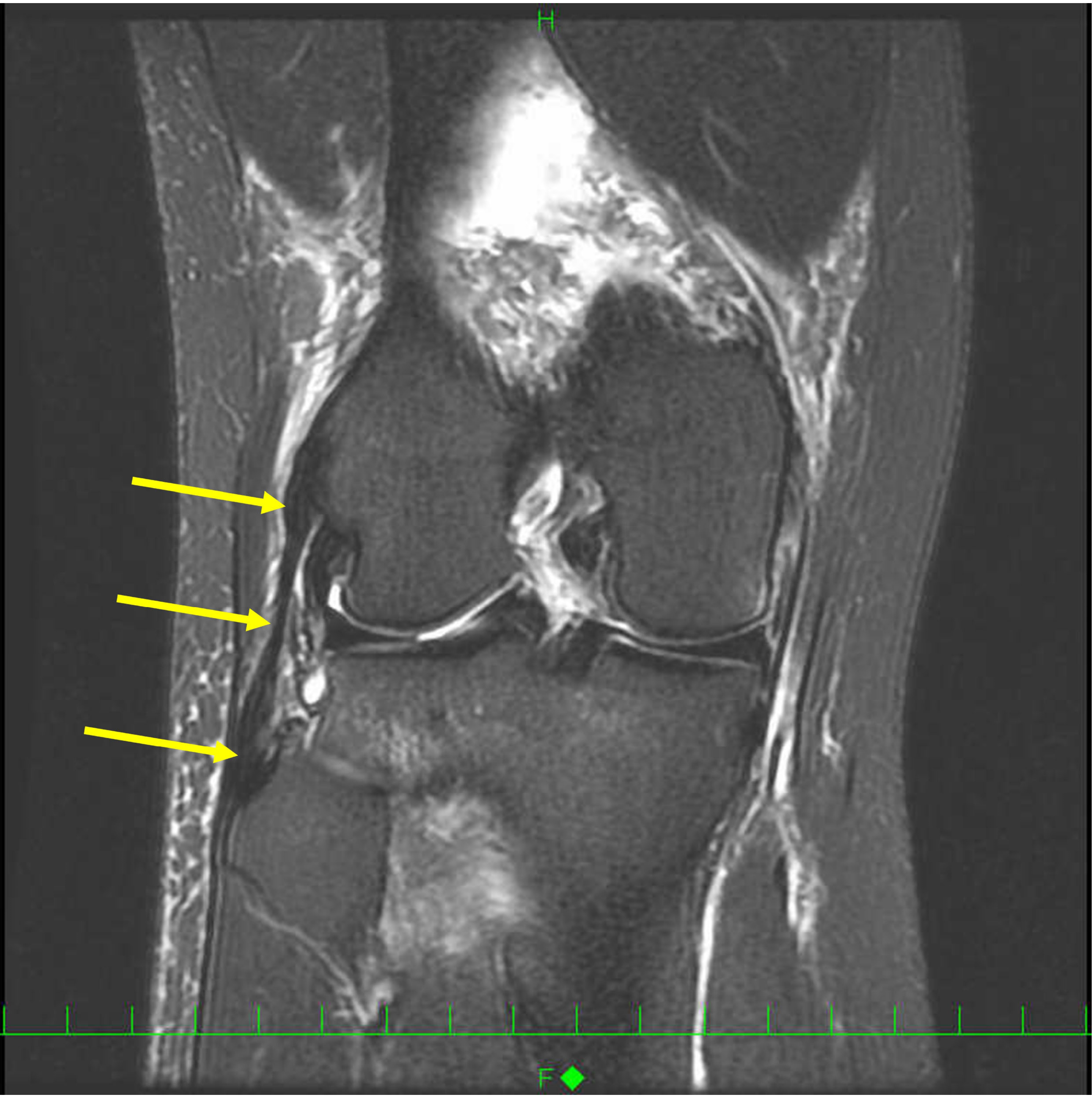
Legends

Figure 1. A positive coronal LCL sign. The coronal LCL sign was considered positive when the LCL could be observed entirely from the femoral origin to the fibular insertion in a single coronal slice on the MRI (yellow arrows).

Figure 2. Quantitative assessment of the pivot-shift using an electromagnetic measurement system for the pivot-shift test. Two sensors were firmly attached on the thigh (not shown) and the calf with a plastic brace. An electromagnetic transmitter was placed within the range of the electromagnetic wave.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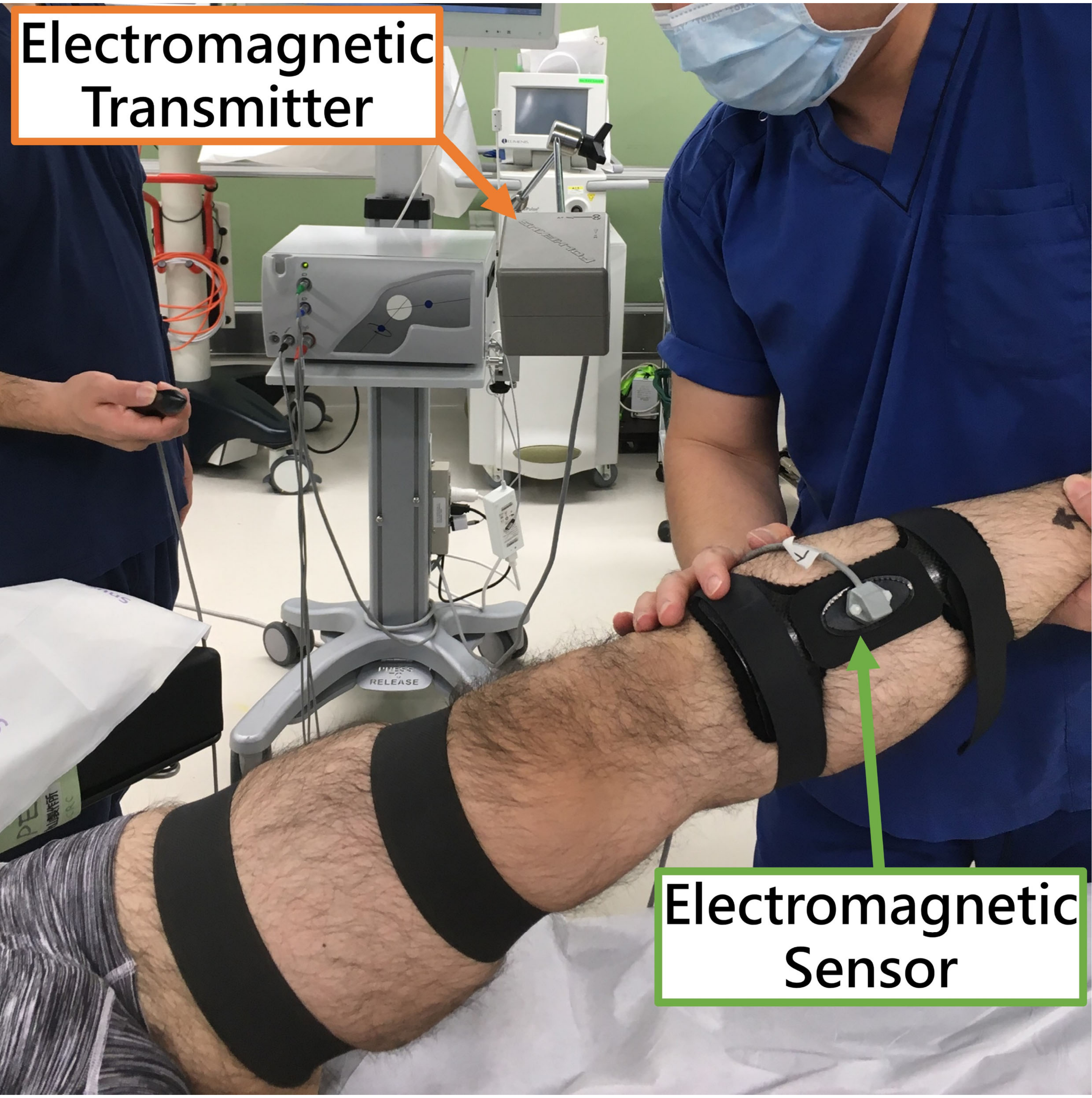
Electromagnetic Transmitter
Electromagnetic Sensor

Table 1. Coronal LCL sign and Patient Characteristics

	Coronal LCL Sign		
	Negative (n= 40)	Positive (n= 45)	P value
Age (years)	24.2 ± 11.2	27.3 ± 12.4	(n.s)
Age subgroups			(n.s)
Age ≤ 18 years (n= 31)	16	15	
Age > 18 years (n= 54)	24	30	
Sex			0.04*
Male (n= 44)	16	28	
Female (n= 41)	24	17	
Laterality			(n.s)
Right (n= 41)	16	25	
Left (n= 44)	24	20	
Time from injury to MRI (day)	7.7 ± 10.8	9.5 ± 13.9	(n.s)
Time from injury to surgery (day)	86.8 ± 58	66.6 ± 50	(n.s)

*$P < 0.05$ with Chi-square test

Table 2. The coronal LCL sign and clinical pivot-shift grading

	Clinical pivot-shift grade				
	0	1	2	3	*P*-Value
Overall					(n.s)
LCL(+)	0	27	16	2	
LCL (-)	1	26	13	0	
Age ≤ 18 years					(n.s)
LCL(+)	0	8	5	2	
LCL (-)	0	9	7	0	
Age > 18 years					(n.s)
LCL(+)	0	19	11	0	
LCL (-)	1	17	6	0	

Table 3. The coronal LCL sign and quantitative evaluation with the KT-1000 knee arthrometer and the electromagnetic measurement system*

	KT-1000 SSD	Tibial translation during Lachman test SSD (mm)	Tibial acceleration during pivot-shift test (m/s^2)	Tibial translation during pivot-shift test SSD (mm)
Overall				
LCL (+)	5.2 ± 2.2	6.5 ± 5.0	1.4 ± 1.0	2.6 ± 3.6
LCL (-)	5.0 ± 2.4	6.4 ± 4.0	1.2 ± 0.8	2.6 ± 3.5
P value	(n.s)	(n.s)	(n.s)	(n.s)
Age ≤ 18 years				
LCL (+)	4.7 ± 2.2	6.1 ± 4.7	1.6 ± 1.2	3.7 ± 3.7
LCL (-)	5.7 ± 2.5	6.7 ± 4.6	1.5 ± 0.9	2.5 ± 3.2
P value	(n.s)	(n.s)	(n.s)	(n.s)
Age > 18 years				
LCL (+)	5.5 ± 2.1	6.6 ± 5.2	1.3 ± 0.9	2.0 ± 3.4
LCL (-)	4.5 ± 2.3	6.1 ± 3.7	0.9 ± 0.6	2.6 ± 3.8
P value	(n.s)	(n.s)	(n.s)	(n.s)

SSD, side-to-side difference

* Data were presented in mean ± standard deviation