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ORIGINAL ARTICLE

Laxity measurements using stress radiography to assess anterior cruciate ligament tears

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KEYWORDS
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Laxity measurement;
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Summary

Introduction: The clinical diagnosis of the anterior cruciate ligament (ACL) tear is based on demonstrating anterior subluxation of the tibia on the femur. In any of the following perspectives, diagnostic (cutoff value confirming rupture), prognostic (treatment efficacy), and therapeutic (laxity influencing the treatment), this laxity can be measured on stress X-rays.

Working hypothesis: The diagnostic value of dynamic radiographs is low for ACL rupture. Passive Telos® X-rays have better diagnostic value, better radiologic quality, and are easier to carry out than active Franklin-type X-rays.

Material and methods: A cohort of 112 patients (28 females, 84 males; mean age, 33.7 years [range, 18—72 years]) with an indication for knee arthroscopy were studied prospectively. Before undergoing the arthroscopic treatment, two series of images of both knees were taken: one series of passive anterior drawer dynamic X-rays on a Telos® device at 250 N and a series of active anterior drawer dynamic X-rays according to Franklin (contraction of the quadriceps against 7 kg of weight at the ankle). The arthroscopic evaluation of the ACL (reference status) was compared to the anterior laxity measurements (absolute and differential) of each knee compartment (medial, lateral, and average) to determine the diagnostic value of the two radiological tests.

Results: We found 70 patients with an ''arthroscopically ruptured ACL'', 32 with an ''arthroscopically healthy ACL'', and 10 with a ''partial rupture''. The measurement of the anterior drawer values on the dynamic X-rays (active and passive) by two independent observers was reliable and reproducible (ICC > 0.80), particularly when using the medial compartment (ICC = 0.96) and the differential values eliminating the interobserver measurement error and interindividual laxity variations. In terms of X-ray technique, the active images were more frequently painful and the radiographic result showed less good quality than the Telos images. The anterior drawer values in the ''healthy ACL'' group were significantly less than in the ''ruptured ACL'' group for the Telos® images, whether the measurements were

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absolute or differential. For the Franklin images, this difference was only significant for the absolute values. Used for diagnosis (4-mm differential on the medial compartment), the passive dynamic images had lower diagnostic values (Se = 59% and Sp = 90%) than the series reported in the literature, which were marked by great heterogeneity.
Conclusion: The measurement of anterior drawer values on Telos® and Franklin dynamic X-rays is a reliable and reproducible measurement, particularly when using the medial compartment and differential measurements. This small series did not demonstrate a diagnostic value for the Franklin images, contrary to the Telos® X-rays. Used for diagnostic purposes, the Telos® images had a low sensitivity; consequently, they should be used preferentially for prognostic or therapeutic purposes.
Level of evidence: Level III, prospective case-control study.

Introduction

The anterior cruciate ligament (ACL) is a primary brake to anterior dislocation of the tibia. Sectioning this ligament is a necessary but sufficient condition to observe an increase in anterior tibial translation [1,2] and medial displacement of the center of rotation, disturbing the knee's biomechanics and kinematics. This results in increased, dangerous loading for other components of the knee (meniscus, cartilage, capsule, and other ligaments).

The clinical diagnosis of an ACL lesion is well founded when searching for abnormal movements produced by the deficit in this braking of anterior tibial translation. However, manual assessment of the anterior tibial translation is imprecise, subjective, and nonreproducible [3,4]. Several authors [5—8] have therefore proposed using arthrometers for measuring laxity (for clinical use) or dynamic X-rays to objectively quantify these displacements. Determining these laxity values can have a diagnostic (cutoff value confirming rupture), prognostic (treatment efficacy), and therapeutic (laxity influencing treatment) value.

The advantage of dynamic radiographs is in measuring the actual displacement of the tibia in relation to the femur, without consideration of the soft tissues, which can account for more than 50% of the anteroposterior displacement [9]. These dynamic X-rays can be passive or active [8].

The objective of the present study was to compare two types of dynamic knee X-rays (one active, the other passive) and determine the statistical values for the diagnosis of ACL rupture based on these values.

This study was registered as biological research (CRB, *recherche et collections biologiques*) of the *Association française de sécurité sanitaire des produits de santé* (Afssaps; French Association of Health Product Safety) No. 2009-A00309-48, and was approved by the *Comité de protection des personnes Nord-Ouest I* (CPP Nord-Ouest I; Committee for the Protection of Persons), No. CPP-SC 2009/009.

Hypothesis

The diagnostic value of dynamic X-rays for ACL rupture is low. Passive Telos® images provide a better diagnostic value, better radiologic quality, and are easier to carry out than active Franklin images.

Material and methods

This prospective cohort study conducted at the Rouen University Hospital over 18 months (August 2008 to February 2009) studied 112 patients (84 males and 28 females; mean age, 33.7 years [range, 18—72 years]). Two series of dynamic X-rays of both knees and an arthroscopy were taken for each patient. The mean time from symptom onset to surgery was 20.3 months (Table 1).

The clinical exam of the symptomatic knee included Lachman, anterior drawer, and pivot tests, scored by the International Knee Documentation Committee (IKDC). At the same time that surgical treatment was proposed, the surgeons (XR, JMA, BL, or FM) explained the protocol to the patient and collected oral consent. The inclusion and exclusion criteria (Table 2) took into account the exposure of ionizing radiation and the requirement that the contralateral knee be healthy. Frontal laxity in extension at the time of the clinical examination was an exclusion criterion.

Dynamic X-rays of both knees (symptomatic knee and contralateral healthy knee) were taken by the department's radiology technicians following two methods (Fig. 1): one series of dynamic passive anterior drawer X-rays on a Telos® device (Telos GmbH® Laubscher, Holstein, Switzerland) at 250 N.

A series of dynamic active anterior drawer X-rays with no load according to the method reported in Franklin et al. [10] (generating, depending on the authors, an anterior force of 154.8 ± 28.5 N). This is a simple and inexpensive method for taking X-rays in the Lachman test position. The anterior drawer of the tibia is produced by contraction of the quadriceps (extension of the leg on the thigh, with 7 kg weight on the ankle), with the knee at 20° flexion. We preferred this method to that described by Lerat et al. [8], which differed only in the weight on the ankle (9 kg for Lerat), because our preliminary study found that patients experienced pain and difficulties lifting this weight on the injured knee.

The dynamic X-rays were read by two operators (JB and SB), independent of the surgeons, with no knowledge of the arthroscopic status of the ACL or the symptomatic knee. Each operator independently measured the anterior

Table 1 Demographic data.

	Total population	Normal ACL	Ruptured ACL	Partial rupture
Number of patients	112	32	70	10
M:F sex-ratio	86/26	22/10	56/14	8/2
Age at surgery (years) (mean ± SD) (range)	38 ± 14.7(18—72)	45.7 ± 14.6(18—72)	34.3 ± 13.5(21—64)	39.9 ± 14.5(20—59)
Time from symptom onset to surgery (weeks)	95.5 ± 144.8	107.3 ± 149.9	94.8 ± 148.6	55.57 ± 75.5

Table 2 Inclusion and exclusion criteria.

Inclusion criteria	Patients symptomatic with surgeon's indication for arthroscopic knee surgery Oral consent for the protocol as current treatment Contralateral knee (vs symptomatic) presumed healthy
Exclusion criteria	History of injury or surgery to contralateral knee Patient pregnant or not on contraception Patient refusing to participate in study Frontal laxity in extension

drawer of both of the patient's knees on tracing paper using a graduated ruler (precision, 0.5 mm). Tibial drawer was measured based on the tangent of the medial plateau—the reference—from which perpendicular lines were drawn from the different bone landmarks (Fig. 2). The drawer measurement used for statistical analysis was the mean of the two operators' measurements. These measurements were taken on: (1) the anterior drawer of the medial compartment (ADMC), (2) the anterior drawer of the lateral compartment (ADLC), and (3) the mean anterior drawer (MAD) (corresponding to the mean of the medial and lateral condyles in relation to the mean medial and lateral plateaux), using the bone landmarks described by Jacobsen [11,12]. These absolute measurements were completed by differential measurements, the difference (in absolute value) of the right and left translations per compartment in the same patient, such that: dif(ADMC) = absolute value (right ADMC − left ADMC), dif(ADLC) = absolute value (right ADLC − left ADLC), and dif(MAD) = absolute value (right MAD − left MAD).

A radiographic quality score for the dynamic X-rays was established (Fig. 3): the Telos® X-rays were scored on a 5-point scale and the Franklin images on a 4-point scale. This quality score was completed by the measurement of the posterior intercondylar distance (normally equal to 0 on a strict lateral image).

The arthroscopic surgical treatment concluded the protocol. Whatever treatment was used (meniscus procedure, ligament procedure, synovial biopsy, etc.), the ACL was systematically assessed with visual inspection and palpation using a surgical hook. Each ACL was classified as an arthroscopically normal ACL, an arthroscopically ruptured ACL, or a partially ruptured ACL on the arthroscope.

The arthroscopic evaluation of the ACL, representing the reference status, was compared to the laxity measurements of the compartments on the two series of dynamic X-rays.

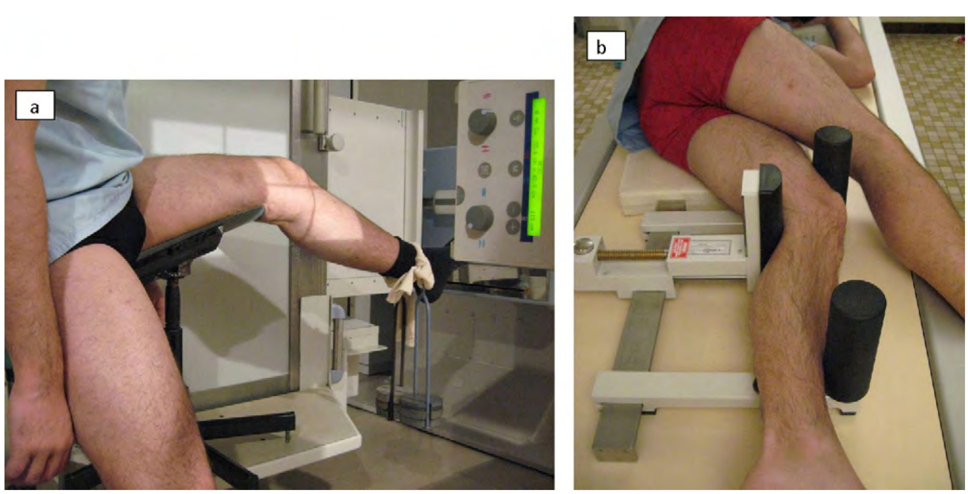

Figure 1 a: X-rays according to Franklin et al. [10], a simple and inexpensive method for taking X-rays for patients in the Lachman position; b: the Telos® device is used on a standard X-ray table, and reproduces the Lachman test position.

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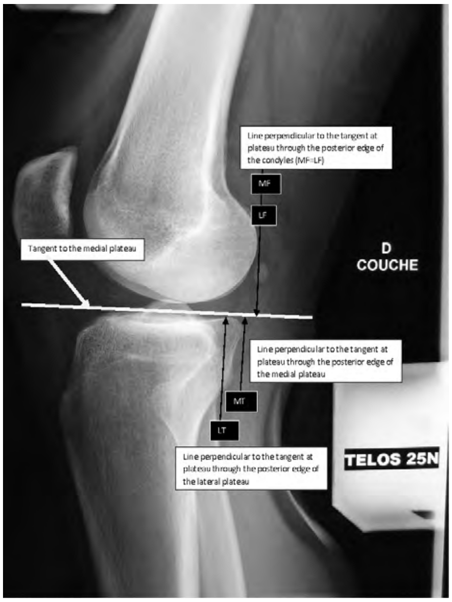

Figure 2 Anterior drawer measurement method. ADMC: distance from MF to MT; ADLC: distance from LF to LT; MAD: mean of ADMC and ADLC. The positive (+) or negative (−) value of the measurement is determined in relation to the femur considered to be fixed: a medial tibial compartment in front of the medial femoral compartment is noted ''+'' and conversely.

The statistical analysis was done using the NCSS software (Kaysville, UT, USA). The Fisher test was used to compare the qualitative variables and the Kruskal-Wallis (with Bonferroni correction) and the Mann-Whitney tests were used to compare the quantitative variables.

Results

One hundred and twelve patients were included in the study. All underwent arthroscopic exploration of the central pivot, which found 70 patients with an arthroscopically normal ACL (62.5%), 32 patients with an arthroscopically ruptured ACL (28.5%), and 10 patients with a partially ruptured ACL (9%).

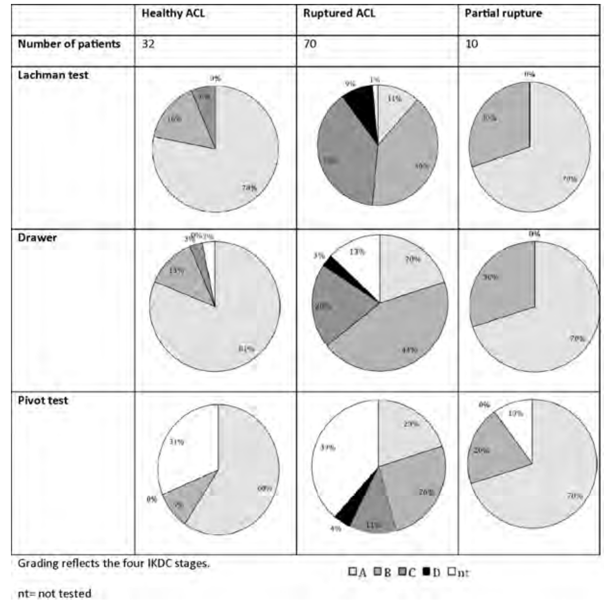

Figure 4 Clinical exam data by the five operators in relation to ACL status.

The data from the clinical examination, collected by five operators, are reported in Fig. 4. Comparing IKDC laxity, grade A versus B, C, and D, we determined the sensitivity and specificity of the three clinical tests. The Lachman test was the most sensitive (88.4%), whereas the pivot test was the most specific (Sp = 86.3%). The Lachman test was a painless test, nearly always realizable ($n = 1$), in contrast to the anterior drawer measurement requiring at least 90° flexion ($n = 12$) or the pivot test, which was very demanding in terms of patient muscle relaxation ($n = 38$). This difference for unrealizable tests was significant (Fisher test, $P < 0.05$).

For the dynamic X-rays (Table 3), all the Telos® X-rays taken were usable (two X-rays/patient; 224 images). Of the Franklin X-rays, only 160 images could be measured (71.4%): 36 images (16%) could not be used (oversight or insufficient time in radiology); for 16 X-rays (7.1%), the maneuver

	Good quality criteria	Number of points per criterion
Telos® passive anterior drawer. **(Figure 3a)**	- strict lateral x-ray (posterior intercondylar distance < 5 mm).	1
	- knee joint angulation between 10° and 30°.	1
	- incident ray at the height of the joint space linking the two tibial plateaux.	1
	- x-ray radiographically clear.	1
	- well-adapted piston position (behind the proximal epiphysis of the tibia).	1
		Total of 5 points
Franklin unloaded active anterior drawer **(Figure 3b)**	- strict lateral x-ray (posterior intercondylar distance < 5 mm).	1
	- knee joint angulation between 10° and 30°.	1
	- incident ray at the height of the joint space linking the two tibial plateaux.	1
	- x-ray radiographically clear.	1
		Total of 4 points

Figure 3 Radiographic quality score for dynamic X-rays: the Telos® images are graded on a 5-point scale; the Franklin images are graded on a 4-point scales.

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Table 3 Radiological quality score for dynamic X-rays.

Quality criteria for dynamic X-rays	Telos® X-rays	Franklin X-rays	Fisher test
	224/224 (100%)	160/224 (71.4%)	
Quality score(Beldame-Bertiaux score)	4.62/5 points ± 0.57(92.4/100)	2.49/4 points ± 0.82(62/100)	$P<0.05$
Posterior intercondylar distance	3.09 ± 2.63	8.65 ± 7.22	$P<0.05$
Exams not done	0	36 (16%)	$P<0.05$
Exams could not be done	0	16 (7.1%)	$P<0.05$
Exams that could not be used	0	12 (5.3%)	$P<0.05$

Posterior intercondylar distance perpendicular to the tangent of the medial plateau.

Table 4 Interobserver reproducibility.

Interobserver reproducibility	ICC [95% CI]	Mean of the errors	Standard deviation	Significant interobserver difference?
Posterior intercondylar distance	0.953 [0.940–0.964]	0.141	0.75	No, $P>0.05$
Dif (ADMC)	0.963 [0.948–0.975]	0.197	1.27*	No, $P>0.05$
Dif (ADLC)	0.815 [0.744–0.870]	0.118	3.15*	No, $P>0.05$

All measurements are expressed in millimetres.
ICC: intraclass correlation coefficient; 95% CI: 95% confidence interval.
*dif(ADLC) > dif(ADMC) with $P<0.05$ on Fischer test.

requested could not be carried out by the patient (pain or muscle deficit) and for 12 images (5.3%) the quality of the radiographs was insufficient for the measurements. These differences were significant for these three items (Fisher test, $P<0.05$). There was also a significant difference in terms of X-ray quality: image quality as well as the intercondylar distance (guarantee of good technical conditions when taking the X-ray) were better for the Telos® than the Franklin X-rays (Fisher test, $P<0.05$): 4.62 points out of 5 (Telos®) versus 2.49 points out of 4 (Franklin) for radi-

Table 5 Anterior translation measurements of each compartment by arthroscopic status of ACL.

Dynamic X-rays	Healthy ACL[a] (1)	Arthroscopically ruptured ACL (2)	Partial rupture (3)	Statistical test[b]
Number of patients	144	70	10	
Telos® X-rays (absolute value)				
ADMC	0.53 ± 3.37	4.87 ± 6.14	−1.17 ± 3.48	1 ≠ 2
ADLC	2.40 ± 5.23	7.46 ± 6.79	−0.38 ± 2.77	2 ≠ 3
MAD	1.64 ± 3.49	6.30 ± 6.06	−0.13 ± 2.48	1 vs 3: ns
Franklin X-rays (absolute value)				
ADMC	−0.22 ± 6.01	2.77 ± 5.76	−2.18 ± 7.04	1 ≠ 2
ADLC	0.22 ± 7.80	2.94 ± 7.01	1.71 ± 6.58	2 vs 3: ns
MAD	0.25 ± 3.33	2.77 ± 4.64	−0.22 ± 2.59	1 vs 3: ns
Number of patients	32	70	10	
Telos® X-rays (differential)				
Dif (ADMC)	2.17 ± 1.28	5.90 ± 5.25	3.07 ± 1.89	1 ≠ 2
Dif (ADLC)	2.88 ± 2.09	6.69 ± 5.66	3.38 ± 2.16	2 vs 3: ns
Dif (MAD)	2.08 ± 1.46	5.90 ± 5.20	2.66 ± 3.15	1 vs 3: ns
Number of patients	32	69	10	
Franklin X-rays (differential)				
Dif (ADMC)	3.98 ± 4.22	5.09 ± 3.95	3.58 ± 2.63	1 vs 2: ns
Dif (ADLC)	6.90 ± 5.48	5.60 ± 4.26	4.83 ± 2.57	2 vs 3: ns
Dif (MAD)	2.66 ± 1.79	3.84 ± 3.45	2.37 ± 1.33	1 vs 3: ns

The data are the mean of two operators (SB and JB). The values are the means indicated in millimetres followed by standard deviation. ADMC: anterior drawer medical compartment; ADLC: anterior drawer lateral compartment; MAD: mean anterior drawer; Dif(*): differential of both knees in the same patient; ns: non-significant.
[a] ''Healthy ACL'' groups arthroscopically healthy ACLs and control presumably healthy contralateral knees (versus symptomatic knee).
[b] Statistical test: 2 × 2 Kruskal-Wallis comparison test with Bonferroni correction.

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Table 6 Example of sensitivity and specificity value of Telos® X-ray in relation to several threshold values.

Variable	Cutoff value (mm)	Se (%)	Sp (%)
ADMC	4	52.0	83.8
ADLC	4	72.0	55.5
Dif (ADMC)	4	59.4	90.6
Dif (ADLC)	4	60.8	81.2
Dif (MAD)	4	55.0	93.7

ological quality, and a posterior intercondylar distance of 3.09 mm ± 2.63 (Telos®) versus 8.65 ± 7.22 mm (Franklin).

Interobserver reproducibility (JB versus SB) was evaluated based on the posterior intercondylar distance (PICD) as well as the differential of the ADMCs and the ADLCs (Table 4). The mean of the errors was 0.141 ± 0.75 mm for the PICD, 0.197 ± 1.27 mm for the dif(ADMC) and 0.118 ± 3.15 mm for the dif(ADLC). Studied statistically using the Bland and Altman curves, no significant difference was found between the two operators' measurements on these three items ($P > 0.05$). The PICD (not subjected to positioning error as the medial and lateral compartments could be) showed an excellent intraclass correlation coefficient (ICC) with the lowest standard deviation (SD = 0.75). The correlation coefficient of the dif(ADMC) and dif(ADLC) was also excellent; however, the standard deviation of the dif(ADMC) (SD = 1.27) was significantly lower than the dif(ADCL) (SD = 3.15) (Fisher test, $P > 0.05$).

As for the measurement of translation (Table 5) on the Telos® X-rays, the anterior drawer values in the ''healthy ACL'' group were significantly lower than the ''ruptured ACL'' group (Kruskal-Wallis test with Bonferroni correction) on the absolute drawer values ($n = 224$) and the differential values ($n = 112$). For the Franklin X-rays, this difference was only significant for the absolute values ($n = 224$) and not for the differential values with a lower number of patients ($n = 111$).

Partial ruptures ($n = 10$) comprised an intermediate group. On the Telos® X-rays, the absolute anterior drawer values (ADMC = −1.17 ± 3.48; ADLC = −0.38 ± 2.77; MAD = −0.13 ± 2.48) were significantly different from the total ruptures, but did not differ from the healthy ACLs. The differential drawer values made up a group that was significantly different from the healthy or ruptured ACLs (ADMC = 3.07 ± 1.89; ADMC = 3.38 ± 2.16; MAD = 2.66 ± 3.15). This independent and intermediate status of the partial ruptures did not appear on the Franklin images: the absolute and differential drawer values did not differentiate the two groups statistically.

The analysis of the ROC curves allowed us to define the drawer cutoff values in relation to sensitivity and specificity. These values were only defined for the Telos® method, because the curve of the Franklin X-ray differential values was not statistically different from the diagonal ($P > 0.05$). The differential measurements taken on the Franklin images did not demonstrate a diagnostic value compared to the arthroscopic value of the ACL. In contrast, the Telos® images provided absolute and differential curves that were significantly different from the diagonal. Thus, for a ADMC cutoff value of 4 mm, sensitivity was 59.4% and specificity was 90.4% (several values chosen are reported in Table 6).

Discussion

We compared and determined the diagnostic value of two broad families of dynamic knee X-rays, as Lerat et al. [8] had done but with different methods. For the passive X-rays, we chose the reference device that has been widely studied [13—16]: the Telos® device. For this method, like Bercovy and Weber [6], Boyer et al. [13], and Daniel et al. [7], we decided to use not a 150-N force (as indicated by the manufacturer), but rather 250 N so as to increase its diagnostic value (thus reducing false-negatives) [7] and measurement

Table 7 Series from the literature that only proved a diagnostic value for dynamic X-rays.

Authors	Number of ACLs	Method	Force (N)	Intact ACL	Injured ACL	Remark
Lerat et al. [8]	180 normal 125 ruptured 66 operated	Active drawer	9 kg at ankle	ADMC = 3.3 ± 2.0*	ADMC = 10.8 ± 3.1**	*NS/**NS
		Passive drawer	9 kg on thigh	ADMC = 3.1 ± 1.9*	ADMCM = 10.1 ± 3.1**	
Staubli et al. [15]	53 normal 85 ruptured	Passive drawer	Telos® 200 N	ADMC* = 3.4 ± 2.0 ADLC** = 4.0 ± 3.2	ADMC* = 12.8 ± 4.1 ADLC** = 15.8 ± 4.6	*$P < 0.05$ **$P < 0.05$
Hooper [22]	70 normal 70 ruptured	Passive drawer	3 kg on thigh	ADMC = 1.7* ADLC = 2.4**	ADMC = 8.3* ADLC = 11.8**	*$P < 0.05$ **$P < 0.05$
Bonnin [17]	281 ruptured[a]	Active drawer	One-leg standing	ADMC = 2.9 ± 3.2* ADLC = 8.9 ± 4.65**	ADMC = 6.4 ± 4.4* ADLC = 12.6 ± 5.7**	*$P < 0.05$ **$P < 0.05$
Franklin et al. [10]	60 ruptured	Active drawer	6.8 kg at ankle	ADMC = 1.0 ± 3.5* ADLC = 2.0 ± 4.0**	ADMC = 5.5 ± 4.0* ADLC = 8.5 ± 4.0**	*$P < 0.05$ **$P < 0.05$

[a] The population of healthy knees was made up of the contralateral knees (assumed to be healthy) of this population.

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reproducibility [6]. For the active X-rays, we retained the Franklin method, identical to the method reported by Lerat et al. [8] but with 7 kg weight at the ankle instead of 9 kg as Lerat et al. used. The preliminary study that we conducted found that patients experienced pain and problems lifting 9 kg at the ankle on an injured knee (this problem had already been mentioned by other authors). The Bonnin method [17] (active one-leg-standing X-rays) was not retained because it adds axial compression forces, thus reducing drawer by 65—70% according to Uh et al. [18].

Like Garces et al. and Lerat et al. [19,20], we took the arthroscopic aspect as the reference status of the ACL. However, this description is not visual and does not take into account the mechanical state of the ACL, as clinical testing can attest. Furthermore, our arthroscopic description was deliberately simple, in three stages (healthy ACL, ruptured ACL, or partial rupture), even though Panisset et al. [21] had shown the great diversity of arthroscopic lesional aspects of the ACL (ACL disappeared, posterolateral preservation, scarring on the PCL, scarring on the femoral notch). The present study was not designed to investigate laximetry in relation to the different lesional aspects of the ACL.

We made the choice of measuring the drawer on both knee compartments (as well as their mean), as did Lerat et al. [20], Hooper [22], Staubli et al. [15], and Rijke et al. [23]. However, our reference was not the posterior cortex of the tibia as in Lerat et al. [20], Dejour et al. [24], and Staubli et al. [15] but rather the parallel of the medial tibial plateau as in Boyer et al. [13], Franklin et al. [10], and Hooper [22]. Given the irradiation generated by these bilateral X-rays, we deemed it wise to reduce the radiological window as much as possible and did not take the lower third of the leg segment.

To our knowledge, using a radiological quality index on dynamic X-rays is an original contribution of this study. We believe it to be pertinent, concordant with the posterior intercondylar distance, and it is easy to use because it is founded on simple criteria that require no measurements.

Interobserver reproducibility (calculated only on the Telos® X-rays) was excellent on the three markers chosen (intercondylar distance, dif(TACM) and dif(TACL)) with ICC greater than 0.80. The results are in agreement with those reported by Lerat et al., between 0.85 and 0.96 for the absolute medial and lateral drawer values [25], with inter- and intraobserver error evaluated at 1.5 ± 1.6 mm and 0.7 ± 0.9 mm [26]. Hooper et al. [22] found a mean intraobserver error less than 1 mm for the measurement of the two compartments; Bercovy and Weber [6] found an interobserver difference less than 1 mm and Staubli et al. [15] a measurement precision less than 0.5 mm. However, the standard deviation on the lateral compartment in the present study was double the medial compartment SD ($P < 0.05$, Fischer test). This can be explained by the greater difficulty identifying the posterior edge of the lateral tibial plateau (slight, with little cortical bone, and superimposed on the medial tibial structure), contrary to the posterior edge of the medial plateau (stopping in a steep slope, with cortical bone, and not superimposed on bone) [11,22]. Bercovy and Weber [6] also found this measurement variability to be greater on lateral than medial radiographs. These data, of better diagnostic value for the medial compartment, were also found by Lerat et al. [25], Dejour et al. [24], and Bonnin [17]. In the search for better reproducibility, the differential measurements seem more reliable [20,24], because they prevent potential tracing errors (by tracing the landmarks identically on both sides) and eliminate individual physiological laxity.

This study shows the superiority of the Telos® measurements in comparison to the Franklin X-rays from the technical point of view during image acquisition: the active images are more painful for the patient, more difficult to take, and lower quality than the passive images. These disadvantages have already been discussed by Lerat et al. [8], who found knee angulation and rotation more difficult to reproduce as well as greater difficulty for the patient. They also underscore the lack of reproducibility of the force generated (variable lever arm and quadriceps force). Doubts were raised on the dynamic X-rays by Howel in 1990 [27], who did not find more anterior translation with maximum contraction of the quadriceps than with the KT-1000 at 89 N.

This study also shows the superiority of Telos® stress X-rays compared to Franklin X-rays for its diagnostic value. For the absolute values, both methods demonstrated a difference between the two groups. However, for differential measurements in small groups of patients (32 healthy ACLs and 70 ruptured), only the passive images demonstrate a measurement difference. Yet it is these measurements, which, eliminating measurement errors and interindividual laxity differences, have diagnostic value.

This study provided a particular approach in that it researched the diagnostic value of dynamic X-rays, whereas the majority of studies to date only demonstrate a significant difference between populations of intact and ruptured ACLs [10,17,22,26,28] (Table 6). Few studies define the sensitivity and specificity of the test used [6,13,19,20,24,25] (Table 7).

The comparison of the anterior drawer values in the literature is unfortunately problematic: each study investigates the diagnostic characteristics of the test used, with a different translation force and different cutoff values, on a population whose epidemiological characteristics are unknown. None of the authors specifies the date of the initial injury or the time from injury to management, except for Panisset et al. [21]. Laxity increases with time, making it easier to obtain higher sensitivity values for a series of chronic ruptures as opposed to acute ruptures [21].

Lerat et al. [8] are the only ones to have compared an active drawer value method (9 kg at the ankle) with a passive method (9 kg on the thigh) on 371 knees. They found statistically identical measurements between the two techniques, but did not study the diagnostic values, while emphasizing the technical difficulties of the active method.

The studies using the Telos® X-ray for diagnosis are few and far between: Boyer et al. [13] and Garces et al. [19] only provide incomplete Telos® measurements at less than 150 N. Only Bercovy and Weber [6] used the Telos® device at 250 N, but only the radiological landmark of the medial compartment was identical to that used by Jacobsen [11], Staubli et al. [28], and Jacobsen and Rosenkilde [29] (and ours). Higher values than ours on this compartment result from differences in the population recruited in that more than one-third of the subjects in the Bercovy and Weber study [6] had potentially lax ACLs (chronic instability, anterolateral plasty, arthrotic knees before arthroplasty or osteotomy).

Table 8 Series from the literature studying the statistical characteristics of dynamic X-rays.

Authors	Number of ACLs	Method	Force in N	Intact ACL	Injured ACL	Cutoff value	Se (%)	Sp (%)	Comment
Dejour et al. [24]	281 ruptured[a]	Active drawer	*Appui monopodal*	ADMC = 2.9 ± 3.2* ADLC = 8.9 ± 4.6**	ADMC = 6.4 ± 4.4* ADLC = 12.6 ± 5.7**	2 mm	70		*P < 0.05 **P < 0.05
		Passive drawer	Lachman radio	ADMC = 3.4 ± 2.9 ADLC = 8.9 ± 4.0	ADMC = 9.0 ± 3.5 ADLCL = 15.0 ± 5.0	2 mm	92		
Boyer et al. [13]	147 ruptured[a]	Passive drawer	Telos® at 150 N		MAD = 7.7 ± 3.4	5 mm	72		28% false-negatives
Lerat et al. [25]	563 normal 487 ruptured	Passive drawer	9 kg at thigh	ADMC = 2.1 ± 2.6* ADLC = 10.5 ± 3.5**	ADMC = 10.4 ± 4.3* ADLC = 18.47 ± 5.1**	6 mm ADMC 11.5 mm ADLC	87 79	90 87	*P < 0.05 **P < 0.05
Bercovy et al. [6]	1502 patients	Passive drawer	Telos® at 0, 100, 150, 200, 250 and 300 N	ADMC = 0.72 MAD = 18.67 ADLC = 11.34	ADMC = [11.4—12.6] MAD = [28.39—29.87] ADLC = [18.44—21.24]	4 mm at 250 N	96	90	Heterogeneous series
Garces et al. [19]	69 normal 47 ruptured	Passive drawer	Telos® at 137 N	ADMC = 1.07 ± 3.5* ADLCL = 3.5 ± 4.7**	ADMC = 5.8 ± 4.9* ADLC = 10.21 ± 5.9**	3 mm	67	100	*P < 0.05 **P < 0.05
Lerat et al. [20]	100 ruptured[a]	Passive drawer	9 kg at thigh	ADMC = 2.9 ± 2.9* ADLC = 9.4 ± 5.2**	ADMC = 10.2 ± 4.8* ADLC = 17.3 ± 6.2** Dif(ADMC) = 7.3 ± 4.8 Dif(ADLC) = 7.9 ± 5.8	5 mm	84	90	*P < 0.05 **P < 0.05
Our series (112 patients)	144 normal 70 ruptured	Passive drawer	Telos® at 250 N	ADMC = 0.53 ± 3.37* ADLC = 2.40 ± 5.23** MAD = 1.64 ± 3.49***	ADMC = 4.68 ± 6.14* ADLC = 7.46 ± 6.79** MAD = 6.30 ± 6.06***	4 mm 4 mm	52 72	83.8 55.5	*P < 0.05 **P < 0.05 ***P < 0.05
	32 normal 70 ruptured			Dif(ADMC) = 2.17 ± 1.28* Dif(ADLC) = 2.88 ± 2.09** Dif(MAD) = 2.08 ± 1.46***	Dif(ADMC) = 5.90 ± 5.25* Dif(ADLC) = 6.69 ± 5.66** Dif(MAD) = 5.90 ± 5.20***	4 mm 4 mm 4 mm	59.4 60.8 55	90.6 81.2 93.7	*P < 0.05 **P < 0.05 ***P < 0.05
	144 normal 70 ruptured	Active drawer	Franklin 7 kg at ankle	ADMC = −0.22 ± 6.01* ADLC = 0.22 ± −7.80** MAD = 0.25 ± 3.33***	ADMC = 2.77 ± 5.76* ADLC = 2.94 ± 7.01** MAD = 2.77 ± 4.64***				*P < 0.05 **P < 0.05 ***P < 0.05
	32 normal 70 ruptured			Dif(ADMC) = 3.98 ± 4.22* Dif(ADLC) = 6.90 ± 5.48** Dif(MAD) = 2.66 ± 1.79***	Dif(ADMC) = 5.09 ± 3.95* Dif(ADLC) = 5.60 ± 4.26** Dif(MAD) = 3.84 ± 3.45***				*,**,***, NS

[a] The population of healthy knees was made up of the contralateral knees (assumed to be healthy) of this population.

Staubli et al. [15] used the Telos® at 200 N but only reported absolute drawer values (more than twice as high as ours), without treating the differentials or the diagnostic values.

For the active dynamic X-rays, Franklin et al. [10] did no more than prove the diagnostic value of their method on a population of 60 ruptured ACLs; to our knowledge, their study is the only one using this method. The only study found on the diagnostic value of active X-rays with weight on the leg segment is Lerat et al.'s [25], (using 9 kg on a series of 1050 patients), with necessarily different drawer values.

As for the diagnostic value of dynamic X-rays found in the literature compared to the present study (Table 8), comparison is also very difficult. The cutoff value criteria vary from 2 mm [24], 4 mm [6], 5 mm [13,20] to 6 mm [25] of differential depending on the authors. The sensitivity of dynamic radiographs varies from 67 to 96%, for a specificity oscillating between 87 and 100%. With a cutoff value at 4 mm of differential on the ADMC (with the Telos® images), our series is located in the lower range in terms of sensitivity (59.4%) and in the mean for specificity (90.6%).

Within our study, partial ruptures made up a particular group whose laxity was intermediate between the two extreme groups. For the Telos® absolute measurements, this group differed from total ruptures but not from healthy ACLs. For the differential measurements on a smaller group, they made up a group that did not differ from the two extreme groups. For this lesional entity, dynamic radiographic studies are rare. Robert et al. [30] are the only ones to have defined a cutoff value on the GNRB® at 134 N (1.5 mm, with Se 80% and Sp 87%). In 67 cases, Panisset et al. [21] measured laxity at 4.97 ± 3.1 mm on the Telos® X-rays at 150 N. This result is compatible with our study whose differential on the ADMC was 3.07 ± 1.89 mm on the Telos® device at 250 N.

All in all, the diagnostic value of the dynamic images (Telos® Se = 59%, Sp = 90%) seems low. In our study, it is inferior to the clinical examination by an expert (Se = 85% and Sp = 94% for the Lachman test according to the meta-analysis conducted by Benjamin et al. [31] in 2006) or the study by Garces et al. [19] (clinical: Se = 70%, Sp = 98.5%; Telos®: Se = 67% and Sp = 100%). This diagnostic value is also inferior to modern MRI whose Se and Sp are greater than 90% (Oei et al. meta-analysis [32] in 2003). However, this is the sole technique that studies the mechanical value of the ACL without the soft tissues (in contrast to clinical laximetric examinations).

In current practice, the clinical exam remains the key to lesional diagnosis of ACL and MRI the first-line complementary examination. The Telos® radiographs are only used for diagnosis in cases when the clinical examination remains doubtful or difficult, or in cases of discordance with the MRI: radiologically demonstrating a differential drawer greater than 4 mm is a strong argument for an ACL lesion. On the other hand, the true role to be played by Telos® X-rays is prognostic or therapeutic, allowing the surgeon to quantify preoperative laxity and follow its progression postoperatively.

Conclusion

This study has compared the diagnostic value of two types of dynamic radiographs based on two different principles.

It shows that anterior drawer measurements on dynamic radiographs (both active and passive) are reliable and reproducible, particularly when using the medial compartment (easier to visualize) and the differential measurements that alleviate measurement errors and individual physiological laxity (ICC = 0.96).

Our study shows the superiority of the passive Telos® images compared to the active Franklin images, in terms of both their technical realization and the diagnostic value of the tests. When taking the images, the active X-rays are more painful and difficult for the patient and their quality is lower than passive X-rays.

The absolute anterior drawer value on the Franklin and Telos® X-rays is significantly different between the healthy ACL group and the ruptured ACL group. However, for the differential values (with a smaller series), only the Telos® radiographs have a diagnostic value: at 250 N and for a differential cutoff value of 4 mm, their sensitivity is 59% and their specificity 90%.

The diagnostic value of the dynamic X-rays in our study is low compared to other ACL exploration methods (clinical exam and MRI). However, their value in cases in which the clinical exam is difficult or there are contradictory exam results can be major, like their prognostic and therapeutic value.

Conflict of interest statement

None.

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