Pathological knee laxity in elite women team handball players: a pilot study

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ABSTRACT: To identify the anterior cruciate ligament (ACL) laxity thresholds and to evaluate the utility of this measure in case of onset of knee injury for elite women handball players. Anterior laxity was measured by an arthrometer. Data on 29 elite women handball players and 20 sedentary women were collected. Among the handball group, 9 participants suffered from full-thickness ACL tears. The recorded variables were the anterior knee laxities at pressure load (PL) of 134 N (PL134N) and 250 N (PL250N) on the upper calf, which allowed assessment of the inter-leg comparison by calculating the differential laxity thresholds and the differential slope coefficients. Considering the healthy knee as a reference within the injured players, the laxity thresholds were identified, and the diagnostic value of the tests was assessed. The handball players without a full-thickness tear presented lower knee laxity than the sedentary women, and 75% were diagnosed with pathologic laxity in at least one of the knee joints, compared to 10% of sedentary women. The differential laxity threshold was identified between the handball players without a full-thickness tear and those with a full-thickness tear at 1.5 mm with PL134N and 2.2 mm with PL250N. The best diagnostic result was obtained using PL250N (area under the curve = 0.95). Handball practice is associated with specific laxities that are rarely seen in the general population. The ACL laxity thresholds may be useful measures to check the state of the ACL and to suggest full-thickness tears, as joint laxity appears to be a factor contributing to ACL tears in female handball players.

CITATION: L'Hermette M, Jeremy Coquart J, Antoine Senioris A et al. Pathological knee laxity in elite women team handball players: a pilot study. Biol Sport. 2018;35(2):159–164.

Received: 2017-10-24; Reviewed: 2017-12-05; Re-submitted: 2017-12-13; Accepted: 2017-12-17; Published: 2018-01-24.

Key words:
Injury
Team sports
Knee arthrometer
Anterior cruciate ligament
Laxity threshold

INTRODUCTION

Rupture of the anterior cruciate ligament (ACL) results in an increase in anterior tibial translation disturbing the knee's biomechanics [1-3]. The diagnosis of ACL lesions is clinically based: the Lachman test is the most reliable, followed by the anterior drawer test and the pivot shift test [1,4,5]. However, clinical assessment of tibial translation often shows low accuracy and reproducibility [1,4,6,7] because of the subjective nature of any clinical diagnosis. Therefore, stress radiography or mechanical arthrometers are used to quantify anterior knee laxity. Stress radiography is the reference standard for laxity measurement, usually obtained using the Telos device or following Lerat's method [1,6]. However, radiography exposes the individual to radiation and the system is expensive. The KT-1000 (MEDmetric, San Diego, USA) [8] is the most popular arthrometer and has been used in several studies, but it presents limitations in reliability and reproducibility [4,5,9]. In 2009, the GNRB system (Genourob, Laval, France) was developed to address the inconveniences of using the KT-1000 and X-ray [10]. The arthrometers allow one to record the relative displacement of the anterior tibial tubercle with respect to the femur. Considering the GNRB, the lower limb of the subject is placed in an adjustable shell, a linear pusher allows two preset levels of antero-posterior forces (134 N or 250 N) on the proximo-posterior part of the calf, and a displacement transducer records the translation of the anterior tibial tuberosity [5,11]. Subsequent studies showed its advantages in diagnosing ACL tears and demonstrated that the laxity measurements could be used to discriminate the type of lesion [4-6,10,12]. In the case of full-thickness tears, the differential laxity threshold obtained with the GNRB was: (i) 3 mm for Robert et al. using a pressure load (PL) of 134 N (sensitivity: Se = 70%, specificity: Sp = 99%) [10], (ii) 2.5 mm for Lefevre et al. using PL of 250 N (Se: 84%, Sp: 81%) [5], and (iii) 1.5 mm for Beldame et al. using PL of 250 N (Se: 62%, Sp: 76%) [6].

The International Handball Federation officially comprises 150 member federations representing approximately 800,000 teams and more than 19 million players. In Europe, team handball is one of the most popular team sports [13,14]. Cutting manoeuvres and rapid stopping and acceleration intended to avoid obstructions are typical of the game [15]. The ability to perform these actions in rapid succession is a major component of competitiveness, but the weight-bearing effects on the locomotive apparatus are cumulative [16,17]. Handball places heavy mechanical loads on the knee joint in what has been described as the most risky dynamic situation for the ligaments, especially the ACL [4,18-20]. Moreover, Ramesh et al. have established that the risk of an ACL tear was higher for subjects with high joint laxity [7]. Several studies have shown the incidence of handball-related ACL injuries in women players [2,3,13,21-23]. These authors agree that women handball players are particularly impacted by ACL tears due to intrinsic factors – including physiological laxity – despite the differences in protocols highlighted [20,24] such as heterogeneous study designs, injury definitions, observation periods and levels of play. The literature is divided about the relationship between joint laxity and ACL tears, partly because of the inconsistencies in assessing laxity [7]. ACL tears can be complete or partial and can rupture because of a contact or non-contact event, often ending a player's season or career, and usually requiring costly surgery and rehabilitation. Non-contact injury is more common and is characterized by an awkward, single-leg landing, abrupt stopping or rapid direction changes [13,25], whereas contact injury arises from a collision causing valgus-varus stress and pivoting [26].

To introduce laxity control procedures for competitive handball players, data are needed to clearly show any association between team handball practice and ACL laxity. The aims of this study were to identify the ACL laxity thresholds and to evaluate the utility of this measure in health follow-up for elite women handball players.

MATERIALS AND METHODS

Subjects

The experimental group was composed of 29 elite women handball players from two clubs in France's first division: 20 active players training and competing regularly and 9 non-active players who had complete ACL tears confirmed by magnetic resonance imaging (MRI). These 9 injured players presented a symptomatic rupture of the ACL. The examination using the arthrometer was performed between the MRI and the ACL reconstruction. The mean age was 24.0 ± 2.6 years, mean height was 1.75 ± 0.06 m, and mean body mass was 70.3 ± 7.3 kg. The subjects had played handball for 16.6 ± 2.4 years (5.4 ± 2.8 years at the top level). The total number of training hours per week ranged from 12 to 14 h.

The examination with the arthrometer was performed as part of routine monitoring in a physiotherapy centre. Twenty women were recruited to constitute the control group; all were professionally active, had sedentary lifestyles with little sports practice (total time less than 1.5 hours per week), and were free from lower limb injury at the time of testing. The control group was matched for age and body mass. Participants with trauma to the lower limb were excluded from the study. All signed an informed consent form before testing began. The protocol was fully approved by the local scientific committee and the study was performed in conformity with the ethical standards of the 1964 Declaration of Helsinki.

Protocol

The GNRB system (Figure 1) was used to measure the translation of the anterior tibial tuberosity.

A physical examiner, using the system for more than 6 months on many different subjects, rigorously installed the participant and manipulated the device. Indeed, the patellar clamp has to be positioned accurately to measure the tibial translation, the pressure on each patella is controlled by a pressure sensor, and the position of each lower limb is controlled by a length scale. The tibial tuberosity was located by palpation to position the displacement sensor.

When a participant had an ACL tear confirmed by MRI, the healthy knee was assessed first. In line with recommendations from Robert et al. [10,12], the subject lay in the decubitus dorsal position on a standard examination table with the knee at ~20° flexion. The lower limb was placed in a single thermoformed shell adaptable to any leg length, with the hip in a free position; the arms were along the body. The knee was locked in the shell with a patellar support placed against the inferior patella margin. The ankle was fixed in a moveable boot leaving the foot free to rotate without a predefined position. The linear pusher allowed two preset levels of PL, 134 N or 250 N [5,11], on the proximo-posterior part of the calf. These forces were only applied in the sagittal plane. A displacement sensor (the accuracy given by the manufacturer is 0.1 mm; TR50 NOVOTECHNIK, FGP Instrumentation, Garches, France) recorded the translation of the anterior tibial tuberosity from its initial position. The recorded data determined the displacement curves for each PL. The recording conditions were collected for each limb (clamping pressure to the patella, stress push). The obtained results were the displacement-load curve, the side-to-side difference in mm and the slope in $mm \cdot N^{-1}$ [10,11].

FIG. 1. Assessment of anterior tibial translation at ~20° knee flexion.

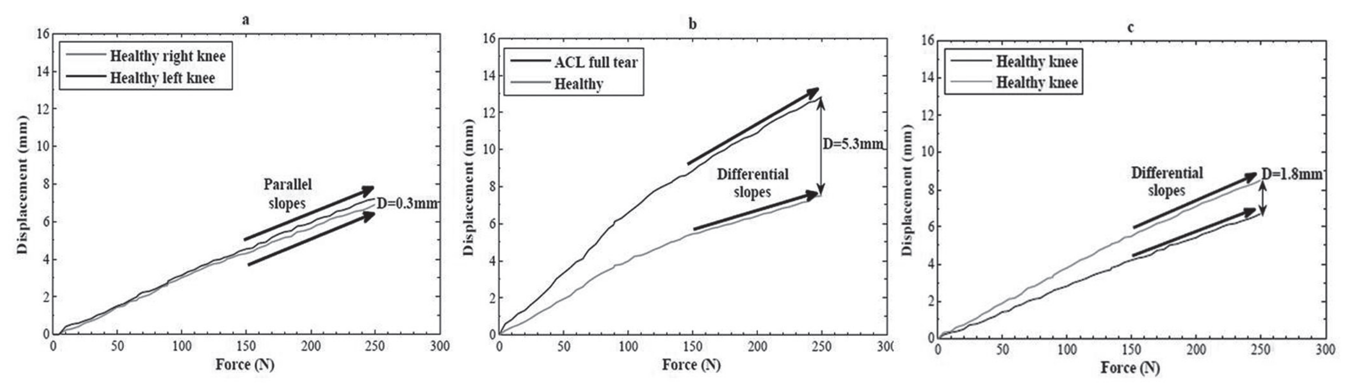

FIG. 2. Laxity thresholds classification of the handball players.

Three automatic measurements were obtained for each PL and the mean was recorded [5]. The curves obtained for both knees (anterior displacement in mm/force in N) provided an automatic calculation of the differential laxity values and the differential of the slope of the curves [10,11]. For the healthy handball players, the laxity threshold was the difference of the right and left translations in an absolute value; for the injured handball players, the laxity threshold was calculated using the healthy knee as a reference value. Specifically, the curves were used to distinguish three categories of participants within the handball group: active handball players with a healthy laxity threshold (Fig. 2.a), full-thickness tear handball players (Fig. 2.b), and active handball players with an asymptomatic knee but abnormal laxity (Fig. 2.c). The handball players with a healthy laxity threshold (Fig. 2.a) and those with an asymptomatic knee (Fig. 2.c) constituted the 4th category: handball players without a full-thickness tear.

Statistical analysis

Data are expressed as means ± standard deviation for continuous variables. For categorical data, the frequencies are presented. Parametric statistics were performed as normal distribution (Shapiro-Wilk test) and homogeneity of variance (Levene test) were confirmed. Analysis of variance (ANOVA) was used for quantitative variables and the chi-square test (χ^2, correction of Yates) compared the incidence of knees with asymptomatic laxity [7]. The fixed factors were group and dominant leg, and the dependent variables were anterior tibial translation for PL134N and PL250N, slope of the curve, and differential thresholds for PL and slope. The optimal laxity cut-off values were determined with the receiver operating characteristic (ROC) curves for the PL and slopes. The value was chosen to obtain the highest sensitivity and specificity. The diagnostic value of the tests was evaluated by the area under the curve (AUC) of ROC, determining five classification levels: null (AUC < 0.5), poorly informative ($0.5 \leq$ AUC < 0.7), fairly informative ($0.7 \leq$ AUC < 0.9), highly informative ($0.9 \leq$ AUC < 1), and complete (AUC $= 1$) [27]. Statistical tests were performed using SPSS software (version 17, SPSS Inc., Chicago, IL, USA). For all statistical analyses, significance was accepted at $p < 0.05$.

RESULTS

In handball players, 9 women had a full-thickness tear (displacement > 2.7 mm), 5 participants had a healthy laxity threshold (displacement < 1.5 mm), whereas 15 players presented an asymptomatic knee but abnormal laxity (displacement between 1.5 and 2.7 mm). For the handball players without a full-thickness tear (i.e., those with a healthy laxity threshold or with an asymptomatic knee; n = 20) and the sedentary women (n = 20), the ANOVA showed a significant group effect for the laxities at PL134N and PL250N, for the slope, and for the slope differential (Table 1), whereas there was no effect of leg dominance. The handball players presented general laxity and slope values lower than those of the sedentary women. Only the differential threshold of the slope was higher in the handball players without a full-thickness tear. Regarding the slope differential, a high incidence of asymptomatic laxity was noted in the handball players without a full-thickness tear: 75% (n = 15) were diagnosed with abnormal differential laxity thresholds compared with 10% (n = 2) in the sedentary women. This difference was significant ($\chi^2 = 17.38$) for the cut-off value of 2.7 mm$\cdot$N^{-1}, which corresponds to the pathological threshold [5]. Among the 9 players with a full-thickness tear, only 2 (22.2%) reported that the injury was caused by a collision with another person. The 7 other players with a full-thickness tear reported that the ACL tear happened as a result of a non-contact mechanism.

The differential laxity threshold values obtained with the ROC for the diagnosis of full-thickness tears was 1.5 mm (Se: 88.9%, Sp: 95.0%, correctly classified participants: 93.2%) with PL134N, and 2.2 mm (Se: 88.9%, Sp: 100%, correctly classified participants: 96.6%) with PL250N. The optimal results (the best Se for the best Sp) were obtained with PL250N. The threshold value for the slope differential was 5.6 $mm \cdot N^{-1}$ (Se: 66.7%, Sp: 70.0%, correctly classified participants: 75.9%). AUC analysis showed that the tests were fairly or highly informative, depending on the variable: the AUC of PL134N, PL250N and the slope curves were, respectively, 0.92 [95% CI, 0.61-0.88], 0.95 [95% CI, 0.60-0.88], and 0.76 [95% CI, 0.53-0.77].

DISCUSSION

Physiological joint laxity has been highlighted as an intrinsic factor contributing to ACL tears, although the precise relationship between ligament injury and ligament laxity is still unresolved [11,24,28]. The results of this study indicated an association between women's elite handball practice and disorders of anterior tibial translation. Handball players without a full-thickness tear had significantly lower anterior laxity than sedentary women. This difference underlines the biological adaptations of the knee joint to the accumulation of mechanical loads [2,20]. For the differential thresholds, the slope was significantly higher in handball players without a full-thickness tear compared to sedentary women. According to the literature, the slope differential threshold determines the ligamentous elasticity related to the quality of the ACL [10,12]. This observation associated with our results supports the concept that elite handball practice contributes to the accumulation of ACL micro-lesions, which in turn contributes to ACL functional degradation [19]. Indeed, using the arthrometer to analyze knee laxity in elite women handball players revealed a third class of participants presenting an asymptomatic knee with an abnormal differential laxity threshold. The incidence of knees with an abnormal laxity threshold was higher in the handball players without a full-thickness tear (75%) than in the sedentary women (10%). Moreover, if we take slope as the indication of ligamentous elasticity [10,12], the value of the slope differential threshold was often more than 2.7 $mm \cdot N^{-1}$, reflecting an accumulation of micro-traumatic lesions [5]. These outcomes suggest that preventive procedures should be used in female handball players, including a combination of technique/agility, balance/coordination, and strength/plyometric exercises, as presented in the literature [21,23,24]. Knee injuries commonly occur in jumping and cutting sports, limiting field and practice time and performance level. Although the injury etiology is primarily related to a sport-specific activity, women are at higher risk of knee injury than men in handball [21-23]. Our study clearly places intensive handball playing among other high-risk activities for ACL tears, such as soccer, basketball, football and skiing [19,21]. The gender, type of sport, length of time it has been practised, and playing level have all been suggested to contribute to ACL tears [14,18-20,24]. The exact mechanism of these tears is still debated in the literature, with as many as 70% of the injuries being caused by a non-contact event [7]. An ACL rupture that occurs this way has been characterized by no collision but an awkward, single-leg landing or stopping or cutting manoeuvres. The present study confirms this finding, with only 2 (among 9) cases of ACL tears caused by contact with another player. The rapid changes in the rhythm of the game causes the block of the lower limbs due to the multiple cutting manoeuvers and induce high mechanical constraints on the locomotive apparatus, especially the knee joint. However, in a collision injury, there is a tendency to valgus-varus stress and pivoting [17].

The ROC curves were used to assess Se and Sp depending on the cut-off value used. The cut-offs were defined in order to determine the optimal differential laxity thresholds for diagnosing full-thickness ACL tears in the elite handball players. Thus, the cut-off values identified were 1.5 mm with PL134N and 2.2 mm with PL250N. The threshold of 2.2 mm showed the best results by correctly classifying 96.6% of the participants with an Se of 88.9% and an Sp of 100%. The cut-off values for the handball players of the current study are lower than those reported by other authors: (i) 2 mm with PL134N and 2.5 mm with PL250N for Lefevre et al. [5], (ii) 3 mm with PL134N for Robert et al. [10], and (iii) 4.2 mm with PL250N for Beldame et al. [6]. The differential threshold of the slope (i.e., 5.6 $mm \cdot N^{-1}$) reflects the deterioration threshold of the ACL in the women handball players. This could be interpreted as a loss of stiffness in one knee, which can predispose to an ACL tear. The literature remains divided regarding the association between joint lax-

TABLE 1. Values of laxity, slope and differential thresholds (Δ) of the GNRB®.

Participants	Laxity 134N (mm)	Laxity 250N (mm)	Slope ($mm \cdot N^{-1}$)	Δ laxity 134N (mm)	Δ laxity 250N (mm)	Δ slope ($mm \cdot N^{-1}$)
Handball players without full-thickness tear (n = 20)	4.8 ± 1.4	8.2 ± 2.0	29.3 ± 5.8	0.7 ± 0.4	1.0 ± 0.6	4.5 ± 2.4
Sedentary participants (n = 20)	6.6 ± 2.1	10.0 ± 3.1	32.7 ± 5.1	0.7 ± 0.3	1.7 ± 1.8	1.6 ± 1.7
p value	0.0001	0.002	0.008	0.91	0.12	0.0001

ity and ACL injury, partly because of the inconsistencies in assessing the anterior tibial translation [1,4-7,10]. Further studies using the same standardized protocol must be conducted to confirm the association between joint laxity and ACL injury.

This study had certain strengths. It was a prospective study of 29 elite players. We used a device which has been shown to be valid and reliable compared with reference systems [4-6]. The manoeuvres are easy to perform, and the method is reproducible [4] and can be used repeatedly for diagnostic and monitoring purposes [1]. Furthermore, the subject is not exposed to radiation [4-6,10,12]. Nevertheless, we recognize that our pilot study has limitations: it would be interesting to perform a prospective study with young women players to follow the course of joint laxity over time, and the number of handball players should be increased to strengthen the power of the results. Moreover, the GNRB should be upgraded as the arthrometer was sometimes uncomfortable for the subject, and was sensitive to changes in positioning [11]. The positioning of the displacement sensor is sensitive to soft tissue movement, such as the tibial rotation which occurs during the test. It might be useful to control the repositioning of the subject in order to decrease the measurement error.

CONCLUSIONS

This study shows that the ACL laxity thresholds may be useful measures to check the state of the ACL and to suggest full-thickness ACL tears. There is sufficient evidence to warrant the implementation of further control measures, including the development of preventive measures for young elite women handball players, as the repetitive nature of the specific manoeuvres can lead to uncommon alterations.

Conflict of interest

The authors have no conflict of interest to declare. None of the authors have any link with any person involved in the GNRB® device. The GNRB® device used in the present study was acquired regularly by the University of Rouen and there has been no contact between the authors of the present study and the company, before, during or after the experiment.

Acknowledgements: We thank technical staff of Orthopedic Surgery and Traumatology Department in the Rouen Teaching Medical Center for his help concerning the implementation of the experimentation.

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