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Original article

Influence of residual anterior laxity on functional outcomes after anterior cruciate ligament reconstruction

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ABSTRACT

Introduction: Residual laxity can persist after anterior cruciate ligament (ACL) reconstruction. This increased anterior translation can be measured with a knee arthrometer. Nevertheless, the measurement parameters and functional impact of this residual laxity are not well understood. The aims of this study were to (1) evaluate the effect of applying loads of 134 N, 200 N and 250 N on the measured residual laxity after ACL reconstruction and (2) evaluate the prognostic ability of the various measurement parameters on the functional outcomes.
Hypothesis: After ACL reconstruction, the functional outcomes will be correlated to the postoperative residual laxity.
Methods: We did a prospective study of 61 recreational athletes who underwent surgical reconstruction of their ACL with the Kenneth-Jones technique between 2016 and 2019. The mean age of these patients was 27 ± 7 years, and most were men (75%). The side-to-side difference in laxity was measured pre- and postoperatively using the GNRB® arthrometer at three load levels: 134 N, 200 N and 250 N. The functional outcomes were determined based on the return to sports and the KOOS, IKDC and ARPEGE scores. The mean follow-up was 30 ± 10 months.
Results: Half the patients had returned to sport at their pre-injury levels, while 25% had returned to a lower level and 25% had stopped doing any physical activity. At 134 N, a 1-mm increase in side-to-side difference was associated with a 2-fold higher risk of not returning to sports (OR 2; 95% CI 1.22–3.23; $p < 0.01$). At 200 N, a 1-mm increase in side-to-side difference was associated with a 50% higher probability of having a poor/fair ARPEGE score (OR 1.5; 95% CI 1.05–2.02; $p = 0.02$). At 200 N, a 4-mm side-to-side difference was the prognostic threshold for failure to return to sports with a positive predictive value of 86% and specificity of 98%.
Conclusions: This case series found a strong correlation between residual laxity and the functional outcomes after ACL reconstruction. A threshold of 4 mm residual laxity evaluated on the GNRB® at 200 N was predictive of adverse outcomes and failure to return to sports in our population of recreational athletes.
Level of evidence: IV, retrospective study.

1. ntroduction

The standard treatment of anterior cruciate ligament (ACL) tears is arthroscopic reconstruction [1]. The mean rate of return to sports at the pre-injury level varies between 40% and 92% [2,3]. While worse functional outcomes have been reported to be proportional to the amount of residual anterior laxity after conservative treatment [4], this relationship has not been demonstrated in patients undergoing surgical reconstruction.

Anterior knee laxity is typically evaluated by determining the side-to-side difference between the laxity in the injured knee and the healthy contralateral knee. Residual laxity corresponds to laxity of the operated knee and is evaluated by determining the difference between the pre- and postoperative laxity. Knee arthrometer devices such as the GNRB® [5–8] have been introduced, with demonstrated reliability in vivo [5,6] and in cadaver studies [7]. However, the measurement parameters and interpretation of the laxity results are still controversial. A 134-N translation force is

Abbreviations: ACL, Anterior cruciate ligament; N, Newtons; BMI, Body mass index; PPV, Positive predictive value.

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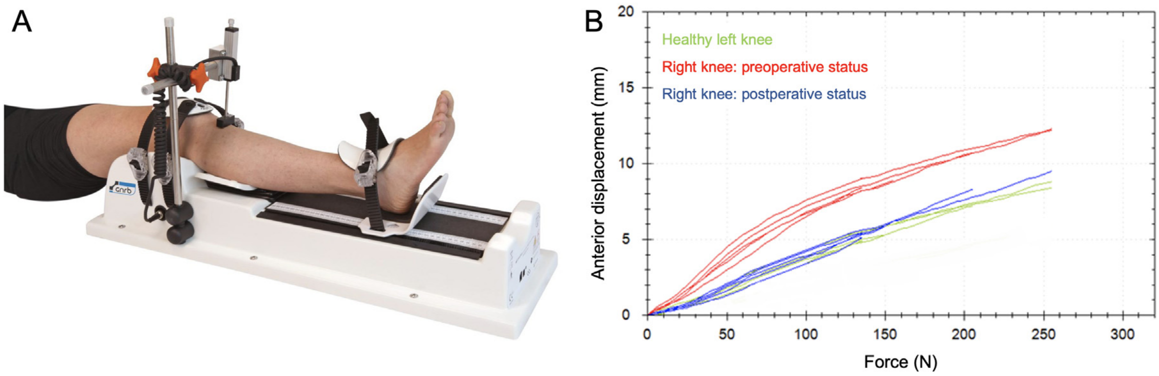

Fig. 1. GNRB® device used to measure knee laxity (A). Example of pre- and postoperative knee laxity in a right knee having an ACL tear and uninjured left knee (B).

Table 1
Patient characteristics.

Characteristics	Overall (n = 61)
Age (years)	27 ± 7
Follow-up (months)	29 ± 10
Sex, males (n, %)	46 (75)
BMI (kg/m^2)	24 ± 3
Pivot sport (n, %)	44 (72)
Medial meniscal repair (n, %)	21 (34)
Lateral meniscal repair (n, %)	20 (33)
Dual meniscal repair (n, %)	7 (11)
Outpatient procedure (n, %)	17 (28)
Rehabilitation center (n, %)	20 (33)

generally used for diagnostic purposes, with a 70% sensitivity and 99% specificity and pathological threshold of 3 mm [9]. While applying a force of more than 200 N appears to increase the diagnostic sensitivity and specificity [8], no recommendations exist for following a patient's recovery during the postoperative period, since the thresholds were only validated for diagnostic purposes.

The primary aim of this study was to determine how the residual postoperative laxity measured by the GNRB affects the functional outcomes. The secondary objective was to evaluate the prognostic ability of various measurement parameters on the functional outcomes. We hypothesized that there was a correlation between functional outcomes and the residual laxity after ACL reconstruction.

2. Materials and methods

2.1. Patients

This was a retrospective study of patients who underwent surgical reconstruction of their ACL with the Kenneth-Jones technique between 2016 and 2019 in our surgery ward. Among the 334 patients operated on during this period, we excluded those who underwent another type of ACL reconstruction, who had multiple ligament injuries, who could not undergo knee laxity measurements or who refused to participate in the study. After the study was approved by our institutional review board (IRB-MTP_2020_09_202000579), each patient was enrolled after signing an informed consent form. Finally, 61 patients were included in the study (Table 1) with a mean follow-up of 29 ± 10 months (12–50 months). A large portion of the patient group was male (46/61, 75%) with the mean age at the time of surgery of 27 ± 7 years [16–42 years] and a mean BMI of 24 ± 3 kg/m^2 [18–35 kg/m^2].

2.2. Knee laxity measurements

During the final in-person follow-up visit, knee laxity was measured with a GNRB® arthrometer by applying different loads

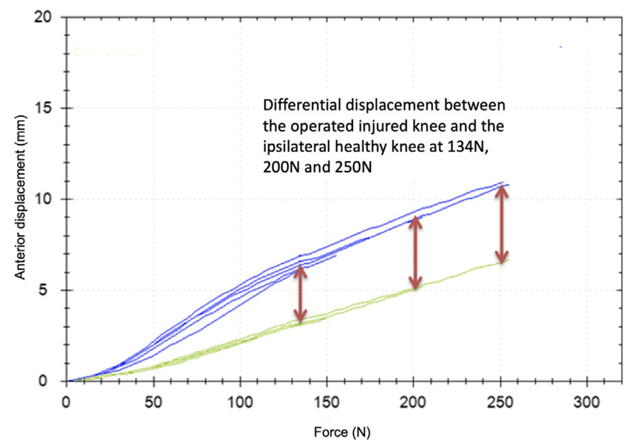

Fig. 2. Example of post-ligament reconstruction knee laxity in a right knee in a patient who had residual anterior laxity.

successively (134 N, 200 N and 250 N) and calculating the side-to-side laxity difference (Figs. 1 and 2). All the knee laxity measurements were made by the same operator and with the same device. The test was stopped if the patient could not tolerate it. To evaluate the performance of each testing parameter, the sensitivity and specificity were measured using ROC (receiver operating characteristics) curves and the area under the curve (AUC) [10]. The prognostic criteria were the return to sports at any level, return to sports at the pre-injury level and the ARPEGE score classified as poor/fair versus good/excellent. This analysis was done for each threshold of side-to-side difference and for each applied load to determine which knee laxity measurement parameters yielded the best sensitivity and specificity.

2.3. Functional analysis

At the final follow-up visit, the assessment consisted of a clinical examination, knee laxity measurement, and functional outcomes based on the KOOS (Knee injury and Osteoarthritis Outcome Score) [11], IKDC (International Knee Documentation Committee) [12] and ARPEGE (Association pour la Recherche et la Promotion de l'Étude du Genou) scores [13].

2.4. Statistical analysis

The data were summarized by their mean and SD for continuous variables and by the counts and percentages for discrete variables. The comparisons between groups were made using the Chi-square test for qualitative variables or the Fischer test when the conditions for the Chi-square test were not met. Student's t test was used to compare the quantitative variables. The significance threshold was annotated as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ and **** $p < 0.0001$. The statistical analysis was carried out using R software (version 3.6.3) by our facility's clinical research and epidemiology department.

3. Results

3.1. Knee laxity

At 134 N, the mean preoperative laxity in the injured knee was 4.9 ± 1.8 mm while the laxity in the contralateral healthy knee was 1.5 mm ± 2.5 mm. Consequently, the mean preoperative side-to-side difference was 3.4 ± 1.8 mm (0.6–7.3 mm). Postoperatively, the mean side-to-side difference was 1.4 ± 1.6 mm (−2–6.6 mm). Less than 3 mm postoperative side-to-side difference was found in 54 patients (88.5%), while 3 mm or more was found in 7 patients (11.5%).

At 200 N, the mean preoperative laxity in the injured knee was 7.1 ± 2.2 mm while the laxity in the contralateral healthy knee was 3.0 mm ± 2.9 mm. Consequently, the mean preoperative side-to-side difference was 4.1 ± 2.2 mm (0.8–8.6 mm). Postoperatively, the mean side-to-side difference was 1.6 ± 1.9 mm (−2.9–7.1 mm). Less than 3 mm postoperative side-to-side difference was found in 47 patients (77%), while 3 mm or more was found in 14 patients (23%).

At 250 N, the mean preoperative laxity in the injured knee was 8.4 ± 2.4 mm while the laxity in the contralateral healthy knee was 3.9 mm ± 3.1 mm. Consequently, the mean preoperative side-to-side difference was 4.5 ± 2.2 mm (1.2–9.9 mm). Postoperatively, the mean side-to-side difference was 1.7 ± 2.2 mm (−4.2–6.7 mm). Less than 3 mm postoperative side-to-side difference was found in 43 patients (74%) while 3 mm or more was found in 16 patients (26%).

At 200 N and 250 N, the mean difference in knee laxity between the 134 N and 200 N loads was 2.0 ± 0.6 mm in the patients who had less than 3 mm side-to-side difference and was 2.6 ± 0.7 mm in the others.

3.2. Functional outcomes

Forty-five patients (74%) returned to their sport, with 30 patients (49%) returning to their pre-injury level. The KOOS was 88 points ± 15 (28–100) for symptoms, 90 points ± 14 (41–100) for pain, 95 points ± 10 (42–100) for function in daily living, 79 points ± 26 (0–100) for function in sport and recreation and 66 points ± 28 (0–100) for knee-related quality of life. The mean value of the subjective IKDC was 86 points ± 17 (37–100) while it was 7.4 points ± 2.1 (1–10) for the IKDC objective. The mean values of the ARPEGE score were 8.1 ± 1.8 (1–9) for stability, 7.5 ± 1.8 (2–9) for pain/strength, and 8.8 ± 0.6 (6–9) for mobility/function.

3.3. Effect of laxity measurement parameters

After the reconstruction, there was a significant improvement in the side-to-side difference at 134, 200 and 250 N ($p < 0.0001$). The patients who still had laxity (defined as residual side-to-side difference of 3 mm at 200 N and 250 N) had a greater variation in knee laxity (defined as the increase in anterior translation achieved when the device load was increased from 134 N to 200 N) than the other patients (at 200 N: +2.6 mm vs +2.0 mm; $p = 0.0038$ and at 250 N: +2.6 mm vs +2.0 mm; $p = 0.0008$).

A side-to-side difference threshold of 3 mm was associated with worse results on the ARPEGE stability scale and the KOOS knee-related quality of life subscale at 134 N (Table 2), 200 N (Table 3) and 250 N (Table 4). At 200 N, patients who had a side-to-side difference of ≥ 3 mm had worse ARPEGE stability results than the other patients (6.7 versus 8.5, $p = 0.046$).

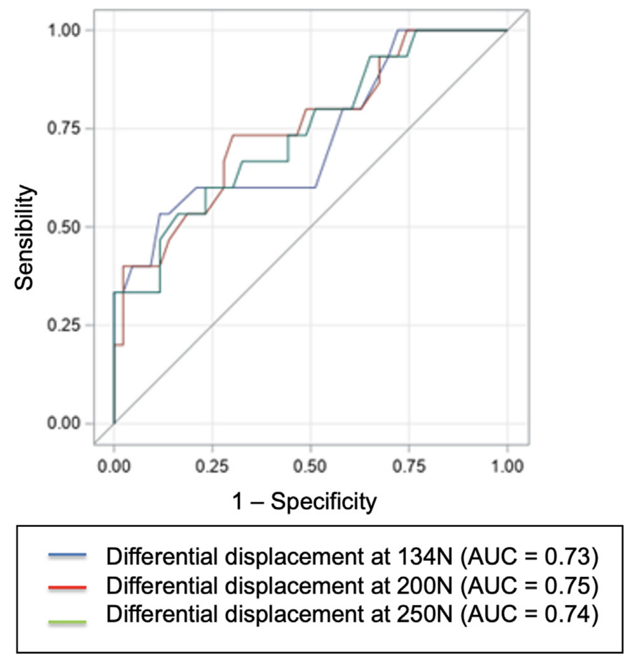

Fig. 3. ROC curve used to analyze the sensitivity and specificity of the GNRB® for predicting failure to return to sports at any level.

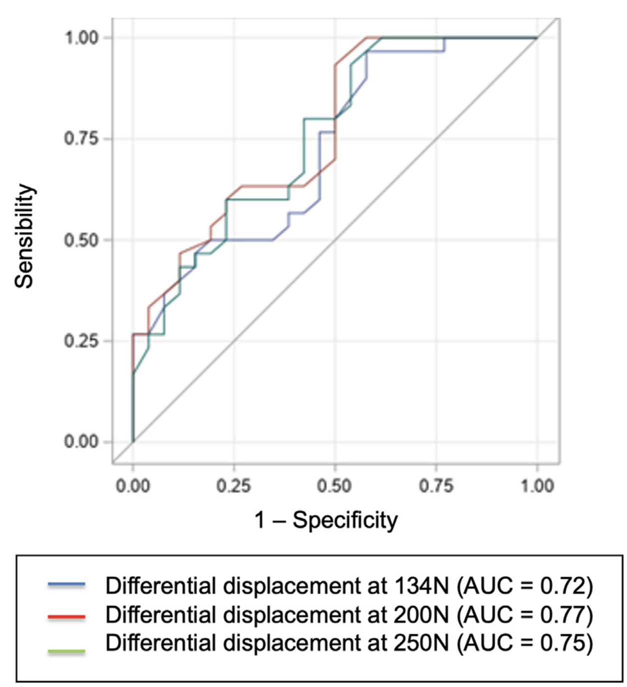

Fig. 4. ROC curve used to analyze the sensitivity and specificity of the GNRB® for predicting failure to return to sports at the preinjury level.

A postoperative side-to-side difference of 3 mm was also a factor for failure to return to sports and to return to pre-injury level of sport, no matter which load was used for the laxity testing (Table 5). Nevertheless, better prognostic performance of 200 N to predict failure to return to sports (AUC of 0.75 [0.6–0.9]) (Fig. 3) and failure to return to pre-injury levels (AUC of 0.77 [0.6–0.9]) (Fig. 4) was found based on the ROC curves. A side-to-side difference threshold of 4 mm at 200 N was also predictive of failed return to sports with a positive predictive value (PPV) of 86% and specificity of 98%.

At 134 N, a 1-mm increase in side-to-side difference was associated with a 2-fold higher risk of not returning to sports (OR 2; 95%

Table 2
Functional outcome scores relative to side-to-side difference when 134 N load is applied.

	Subjective IKDC	ARPEGE stability	ARPEGE pain	ARPEGE mobility function	KOOS symptoms	KOOS pain	KOOS ADL	KOOS function	KOOS QOL
Side-to-side difference < 3 mm	87 ± 17	8.5 ± 1.3	7.6 ± 1.8	8.8 ± 0.6	88 ± 16	90 ± 14	95 ± 11	79 ± 27	69 ± 26
Side-to-side difference ≥ 3 mm	78 ± 15	5.5 ± 3.5	7 ± 17	8.8 ± 0.4	89 ± 9	91 ± 11	97 ± 7	75 ± 21	37 ± 26
p-value	0.2	0.09	0.45	0.96	0.8	0.84	0.59	0.65	0.03

Table 3
Functional outcome scores relative to side-to-side difference when 200 N load is applied.

	Subjective IKDC	ARPEGE stability	ARPEGE pain	ARPEGE mobility function	KOOS symptoms	KOOS pain	KOOS ADL	KOOS function	KOOS QOL
Side-to-side difference < 3 mm	87 ± 17	8.5 ± 1.3	7.6 ± 1.8	8.9 ± 1.5	87 ± 16	89 ± 14	95 ± 11	79 ± 27	70 ± 26
Side-to-side difference ≥ 3 mm	82 ± 18	6.8 ± 2	7.3 ± 1.7	8.8 ± 0.6	93 ± 8	92 ± 12	96 ± 10	80 ± 25	49 ± 29
p-value	0.44	0.046	0.53	0.56	0.11	0.58	0.91	0.92	0.036

Table 4
Functional outcome scores relative to side-to-side difference when 250 N load is applied.

	Subjective IKDC	ARPEGE stability	ARPEGE pain	ARPEGE mobility function	KOOS symptoms	KOOS pain	KOOS ADL	KOOS function	KOOS QOL
Side-to-side difference < 3 mm	86 ± 17	8.5 ± 1.3	7.5 ± 1.9	8.9 ± 0.6	87 ± 17	88 ± 15	95 ± 11	77 ± 27	69 ± 26
Side-to-side difference ≥ 3 mm	87 ± 17	7.6 ± 1.9	7.7 ± 1.5	8.8 ± 0.6	93 ± 7	94 ± 12	96 ± 9	84 ± 24	63 ± 29
p-value	0.85	0.1	0.72	0.71	0.07	0.17	0.64	0.38	0.5

Table 5
Return to sports rates relative to side-to-side laxity difference and testing parameters.

	n at 134 N	Return to sports at 134 N	Return to preinjury level at 134 N	*n* at 200 N	Return to sports at 200 N	Return to preinjury level at 200 N	*n* at 250 N	Return to sports at 250 N	Return to preinjury level at 250 N
Side-to-side difference < 3 mm	54	43 (80%)	27 (50%)	47	38 (81%)	25 (53%)	43	37 (86%)	23 (53%)
Side-to-side difference ≥ 3 mm	7	1 (14%)	0 (0%)	14	6 (43%)	2 (14%)	16	7 (44%)	3 (19%)
p		0.001	0.01		0.01	0.01		0.006	0.02

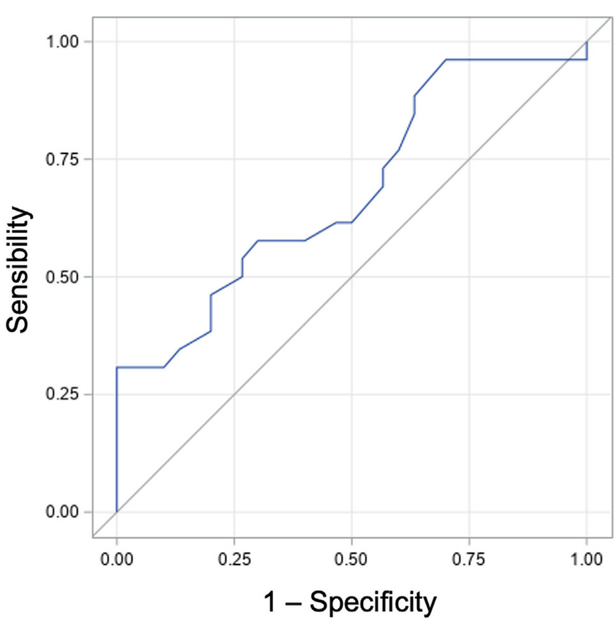

Fig. 5. ROC curve used to analyze the sensitivity and specificity of the GNRB® for predicting a poor/fair ARPEGE score.

CI 1.2–3.3; $p < 0.01$). Thus, the PPV for failure to return to sports for thresholds of 4, 3, 2 and 1 mm was 100%, 75%, 50% and 30%, respectively. At 200 N, a 1-mm increase in side-to-side difference was associated with a 50% higher probability of having a poor/fair ARPEGE score (OR 1.5; 95% CI 1.1–2.1; $p = 0.02$) (Fig. 5).

4. Discussion

This study's main finding was the correlation between residual postoperative laxity measured with the GNRB® and the functional outcomes. For each millimeter of additional side-to-side laxity difference observed at 134 N, the risk of not returning to sports was two-fold higher.

The knee laxity and functional results in our case series are comparable to other published studies. At 134 N, the mean side-to-side difference in our case series was 1.4 ± 1.6 mm, comparable to other knee laxity studies of ACL reconstruction done with the patellar tendon [14]. The return to sports rate in our series of recreational athletes (74%) and return to the pre-injury levels (49%) was similar to the study by Gupta et al. who reported rates of 79% and 40% [2], while much higher rates were found in studies of professional athletes [15].

The current literature does not suggest that residual laxity has an effect on postoperative functional outcomes after ACL reconstruction [16–19]. Some authors have found worse functional outcomes proportional to the degree of residual laxity in patients who were treated conservatively [4]. Similarly, we found a negative impact of residual laxity on the postoperative functional outcomes, with an increased risk of not returning to sport (two-fold) for each millimeter of additional side-to-side difference measured at 134 N. We found a correlation between residual laxity and the functional ARPEGE score. At 200 N, each 1-mm increase in side-to-side difference increased by 1.45 times the risk of having a poor/fair ARPEGE score ($p = 0.02$). There was also a relationship between subjective stability and objective knee laxity (stability item on the ARPEGE at 6.7 in patients with laxity versus 8.5 in the others, $p = 0.046$; at 200 N and 3 mm for the prognostic threshold).

The testing parameters substantially affect the knee laxity results [20]. In our study, tests with a 200-N load appear to be more effective with an AUC of 0.75 [0.6–0.9]. But defining sensitivity as the probability of having a given side-to-side difference in patients who did not return to sports likely underestimates the AUC.

The prognostic threshold for laxity measurements by a knee arthrometer is also controversial. Some authors use a prognostic threshold of 3 mm [20–22] while other use 5 mm [16,18,23], with the latter corresponding to a mean side-to-side difference found when the ACL is torn [24]. Thus, failed surgery is typically based on criteria defined by diagnostic data [9,24], postoperative side-to-side difference ≥ 5 mm [16,18,23] or ≥ 3 mm [20–22], although these thresholds were not validated in the context of postoperative follow-up. For prognostic purposes, we propose using a side-to-side difference threshold of 4 mm at 200 N, which can predict failed return to sports with a PPV of 86% and specificity of 98%.

Various knee arthrometer devices are currently available commercially: Telos® [25], KT1000® [26], Rolimeter® [27], GNRB® [5]. The results of these various devices are not consistent with each other [28]. At different load levels, Klasan et al. found two times more significant side-to-side differences with the KT-1000® than the GNRB® [29]. Thus, our results cannot be extrapolated to the other knee arthrometer devices.

Several studies have confirmed the GNRB's better reliability relative to other knee arthrometer devices [5,28]. The main drawback of the GNRB® is that it uses a patella clamping device whose applied pressure could alter the knee laxity results [6], while there is no consensus on the load to be applied to the patella [5]. Our tests were done by applying a patellar compressive force between 50 N and 60 N to minimize this variability.

This study has several limitations. The number of patients who had their knee laxity measured was small (61 patients). One-third of patients evaluated had less than 2 years' follow-up; however, it has been shown that knee laxity stabilizes after 1 year [26]. Our analysis of functional outcomes and knee laxity did not factor in potential associated meniscus tears, but we did not find an effect of meniscus tears on the functional outcomes and knee laxity. Our findings are limited to the analysis of non-professional athletes by the GNRB® without testing the rotational stability [30]. These results cannot be extrapolated to the other knee arthrometer devices.

5. Conclusion

We found a direct relationship between residual knee laxity measured on the GNRB and the functional outcomes after ACL reconstruction. For each millimeter of additional side-to-side difference observed at 134 N, the risk of not returning to sports was two-fold higher. A 4-mm threshold at 200 N is predictive of adverse outcomes in our population of recreational athletes, with a PPV of 86% and specificity of 98% for failure to return to sports.

Ethics

Study approved by the institutional review board (IRB-MTP_2020_09_202000579).

Disclosure of interest

The authors declare that they have no competing interest.

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Author contributions

All authors confirm that they contributed to (1) the study's design, data acquisition or data analysis, (2) writing and correction of the manuscript and (3) approval of the final manuscript.

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