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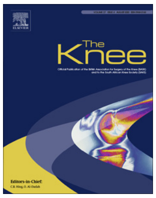

GNRB® laximeter with magnetic resonance imaging in clinical practice for complete and partial anterior cruciate ligament tears detection: A prospective diagnostic study with arthroscopic validation on 214 patients

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ABSTRACT

Background: Accurate diagnosis of anterior cruciate ligament (ACL) injury is not always obtained with magnetic resonance imaging (MRI). Other tools, such as the GNRB® arthrometer, help to accurately identify the type of ACL tear. The aim of this study was to show that the GNRB® could be a relevant complementary solution to MRI in ACL injuries detection.
Methods: A prospective study performed between 2016 and 2020 included 214 patients who had undergone knee surgery. The study compared sensitivity/specificity pairs of MRI and the GNRB® at 134 N to detect healthy ACL, partial and complete ACL tears. Arthroscopies were the 'gold standard'. Forty-six patients had a healthy ACL with associated knee lesions, 168 patients had ACL tears where 107 were complete tears and 61 were partial tears.
Results: For healthy ACL, MRI scored 100% for sensitivity (SE) and 95% for specificity (SP), and the GNRB® scored SE 95.65% and SP 97.5% at 134 N. For complete ACL tears, MRI scored 80.81% for sensitivity (SE) and 64.49% for specificity (SP), and the GNRB® scored SE 77.78% and SP 85.98% at 134 N. For partial tears, MRI scored SE 29.51% and SP 88.97%, and the GNRB® scored SE 73.77% and SP 85.52% at 134 N.
Conclusion: GNRB® sensitivity and specificity were equivalent to those of MRI for healthy ACL and complete ACL tear detection. However, MRI had some difficulty in detecting partial ACL tears compared with the GNRB® which showed better sensitivity.

1. Introduction

Rupture of the anterior cruciate ligament (ACL) is a common injury of the knee, especially in sport activities requiring pivot [1,2]. Yet the basic medical support for a suspected ACL tear is not standardized [3]. Usually, a good history and physical examination are key to detecting an ACL rupture. Combining multiple and good history elements with physical examination tests, such as the Lachman test, the pivot shift test and the anterior drawer test, is advocated to increase the validity

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of the diagnosis of partial and complete ACL tears [4]. But in cases of equivocal clinical diagnosis, supplementary diagnostic aids such as magnetic resonance imaging (MRI) or/and laximetry tests can help, although each comes with advantages and disadvantages.

Currently, MRI is the most common non-invasive screening tool for detecting an ACL tear. It has the advantages of good soft tissue contrast, high spatial and allows multi-parameter evaluation of morphological changes in an injured ACL. However, the accuracy of MRI diagnosis depends on the scanning technique and the experience of the musculoskeletal radiologist. Thus, sensitivity and specificity varies owing to the slightly oblique angle of the ACL crossing the knee joint and to the difficulty of displaying the full ACL in the true sagittal plane via a single MRI scan [5]. Many studies have shown good diagnostic performance on complete ACL tears, but few consider partial tears [6,7]. Nevertheless, MRI is increasingly prescribed and could be inappropriate for knee pain [8–10], despite the expense and long waiting time involved for patients. Moreover, it cannot directly assess knee laxity and is mainly used only to assess the associated tears.

Laximetry was therefore introduced to supplement patients' medical history and examination. It measures anterior tibial drawer relative to the femur and thus gives an objective measurement of the tibial translation, using an arthrometer. Today, laxity measurements are commonly obtained using the KT-1000 laximeter (MEDmetric®, San Diego, CA, USA) first introduced in the early 80 s by Daniel et al. [11], the Rolimeter$^{\mathrm{TM}}$ (Aircast, Summit, NJ, USA) developed by Roland Jacob [12] or stress radiography via the Telos$^{\mathrm{TM}}$ by Pässler et al. [13] (Gmbh, Hungen/Obbornhafen, Germany). However, an abundant literature documents these devices' inaccuracy [14–16] and low reproducibility [17–19] as leading to inaccurate, subjective, and poorly reproducible results.

Recent studies compared a new laximeter, the GNRB®, to other measurement systems: KT1000 and Telos, however, no studies in the literature have been found regarding comparison between MRI and the GNRB® for ACL tears detection. The GNRB®, the first automated dynamic laximetry (ADL) system, was found to reliably offer greater accuracy and reproducibility [20–24] than other devices. While previous studies have compared the diagnostic performance of the MRI to arthroscopy in complete tears [25], our aim here was to compare the sensitivity (SE) and specificity (SP) of the GNRB® to MRI for detecting both partial and complete ACL tears.

The differentiation of partial tears and complete tears is important because it impacts the management of medical care [26–29]. But partial ACL tears are difficult to detect. Using arthrometers to measure knee laxity for partial ACL tears is not new, but their efficacy has been questioned. Furthermore, the use of imaging equipment, such as MRI, seems to be insufficient to describe the exact pattern of an ACL injury when used alone, mainly because of the many patterns of partial tears and the frequent similarity of partial tears to complete tears or even to mucoid degeneration of the ACL [27,30,31]. Our hypothesis was that the GNRB® would be a good complementary device to MRI, showing accuracy and precision in ACL tears detection with arthroscopic characteristics taken as reference standard. The clinical objective was to provide information useful in making therapeutic choices between physical therapy, ACL augmented repair or ACL reconstruction.

2. Materials and methods

2.1. Study design

The ethics committee of our institution approved our study protocol and amendments. All patients provided informed consent before participation. A total of 214 patients with knee injury for whom knee arthroscopy was scheduled were enrolled in this prospective, single-center and single-operator study. They were between 18 and 71 years old, with an average of 30 ± 12 years old. Sixty-three patients were women (30.5%) and 143 were men (69.5%). They all underwent MRI examinations before starting the study. All patients had GNRB® measurements. All operations were performed between June 2016 and June 2020 by a senior surgeon with considerable experience in knee surgery after GNRB® measurements.

Inclusion criteria were as follows: over 18 years old, consulted for an acute or chronic knee injury with a planned arthroscopy, and clear and detailed MRI conclusions from radiologists' reports. Exclusion criteria were: patients who have already undergone a ligamentoplasty, ACL re-rupture, lack of information in MRI reports and lack of patient consent. Patients were also excluded if ACL tears with serious associated lesions were reported in their MRI reports, such as a bucket-handle, ramp, root and complex tears for meniscus, or complete tears of the collateral ligaments. Other associated injuries were considered as minor, such as bone/cartilage contusions, partial collateral ligament injuries and longitudinal/radial tears for the meniscus. As long as no ACL injury was detected with associated lesions according to the preliminary examinations, surgery was planned for meniscus tears, and tears of the others ligaments such as the posterior cruciate ligament (PCL), the medial collateral ligament (MCL) and the lateral collateral ligament (LCL). If lesions were multiple and too serious, patients were also excluded. After getting all consents from patients who respected inclusion/exclusion criteria, all GNRB® tests were performed by medical residents before the surgery. The final evaluation was performed by arthroscopy, considered to be the 'gold standard', and all arthroscopic characteristics of ACL were assessed by the same surgeon. According to reports, all MRI films were carried out by experienced radiologists in musculoskeletal diseases who were blinded to the arthroscopic findings. The study was designed to compare the accuracy of the GNRB® side-to-side laxity assessment at 134 N with the accuracy of MRI reports in detecting, healthy ACL, complete and partial ACL tears, using arthroscopic reports as reference. Although the surgeon was not blinded to the preoperative GNRB® or MRI results, the type of surgery chosen (ACL augmentation or replacement) depended on knee testing under anesthesia and on the ACL characteristics during the surgical procedure.

2.2. GNRB® and MRI protocols

The GNRB®, presented in Figure 1, is an automated device for laxity measurement of anteroposterior tibial translation at 20° knee flexion, thus reproducing the Lachman test position. The patient is lying on an examination table in a supine position. First, the healthy knee is investigated for comparison with the injured one. The lower limb under examination is placed in a rigid adjustable leg support with the knee at 0° rotation. The knee must be tightly held under the patellar support to avoid anterior displacements of the femur. The tight value under the patellar support is displayed on the GNRB® software for operator guidance. In order to obtain the most accurate comparison between knees, tight values must be similar for each knee (difference should not exceed ±10 N according to the standard protocol). A linear jack can exert gradually increasing thrust forces up to 250 N on the upper section of the calf. Although the highest limit was chosen by the examiner, it was not always possible to reach 250 N because of great laxity or knee pain. A displacement transducer records the relative displacement of the anterior tibial tubercle with respect to the femur. A displacement/force curve (ACL laxity in mm) is plotted for each test per knee. According to the standard protocol of the manufacturer, the laxity difference at 134 N between the injured and the healthy knee (side-to-side laxity) is directly computed by the GNRB. Moreover, as thresholds are established also at 134 N to detect partial and complete ACL tears in literature, displacements at other forces were not recorded [32]. All results were recorded on several dates before the surgery and were listed in a laxity database. If several data were available for a same knee, the closest test to the date of MRI, and data with symmetric tightening at 134 N between the legs were chosen in order to obtain reproducible conditions for this study. To accurately define complete and partial tears, thresholds values for side-to-side difference were calculated following the procedure described in 2009 by Robert et al. [32].

All MRIs were performed by different experienced radiologists in musculoskeletal diseases from different centers using a 1.5-T MRI scanner (Siemens or Philips) according to a standard protocol for the knee: sagittal fat-suppressed (FS) T2-weighted, sagittal proton density (PD)-weighted, axial FS PD-weighted, coronal T2 and PD-weighted images. No sagittal or coronal oblique planes were performed in this series.

2.3. Outcome evaluation

Baseline characteristics of the patients – sex, age at time of accident, side, date of injury, MRI date, laximetry date, date of surgery, ACL tear classification at time of surgery – were recorded and tabulated in a common file. Side-to-side laxity data at 134 N was directly retrieved from the GNRB® database. ACL characteristics were assessed by visual inspection, probing, and tensioning of ACL remnants. MRIs were performed between 1 and 6 months post-injury. MRI and GNRB® testing took place on average over a period of 2 ± 7 months. The GNRB® and MRI results were then compared with the arthroscopic descriptions, considered as the current gold standard.

MRI images assessments were performed by experienced radiologists in musculoskeletal diseases, who were blinded to the arthroscopic findings. These qualitative data from MRI reports were screened to select information about ACL tears, meniscus, cartilage, bone, or other ligaments. Data were always taken from the conclusions, which generally mentioned a partial (partial discontinuity) or complete ACL tear (failure to visualize the ACL), and were recorded in the common file of the study.

Tears from arthroscopic reports were divided into different categories according to the surgeon and the description used by Panisset et al. and Dejour et al. [33,34]. Figure 2 provides a flow chart of the whole cohort of 214 patients who satisfied the eligibility criteria, specifying group criteria and how different knee injuries mentioned in arthroscopic reports classified ACL as healthy, or with a partial or complete tear.

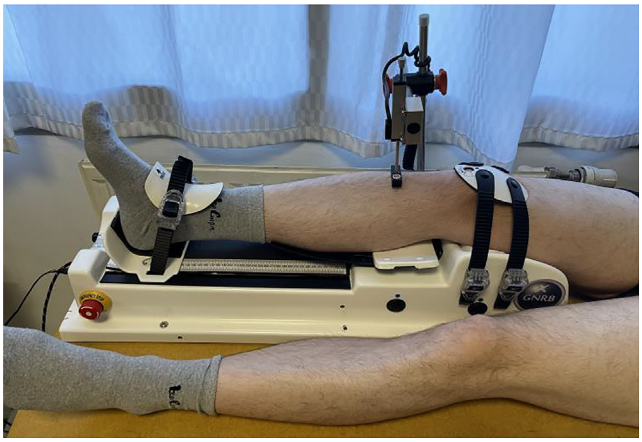

Figure 1. Placement view of a patient's leg on the GNRB® arthrometer.

2.4. Statistical analysis

Statistical analyses were performed using XLSTAT (Addinsoft, Paris, France), a software suite for data analysis and statistics in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Receiving operator characteristic (ROC) curves were plotted for each group using a multi-class analysis. Predicted SE and SP were obtained by varying the thresholds of complete and partial ACL tears. These predictions represented all points on the ROC curves. Note that it was not possible to obtain more than one pair of values for MRI. The best possible prediction method considers the point closest to the upper left corner on the graph, which represents the best prediction result for the associated threshold. Positive and negative predictive values were also computed.

From these ROC curves, it was possible to compute area under the curve (AUC). The diagnostic value was considered null if AUC = 0.5, poorly informative if $0.5 < AUC \leq 0.7$, fairly informative if $0.7 < AUC \leq 0.9$ and highly informative if $0.9 < AUC \leq 1$, according to Lefevre et al. [24].

Parametric z-tests were performed to compare GNRB® and MRI results, individually and combined, and to assess whether the differences between two paired samples were significant, using sensitivity, specificity, positive and negative predictive values as indicators for proportions.

3. Results

Figure 3 shows ROC curves for healthy ACL (green), ACL with partial (yellow) and complete (red) tears with AUC in parentheses in the legend for MRI and GNRB®. For the GNRB, each point represents a pair SE/SP by varying the side-to-side laxity thresholds for partial and complete ACL tears detection. The multiclass analysis showed that SE and SP results for GNRB® were better with a threshold of 3 mm side-to-side laxity for the diagnosis of complete tears and a threshold of 1.3 mm for partial tears. The AUC for healthy ACL group designates the MRI and GNRB® ROC curves as highly informative. For complete ACL tears group, the AUC designates the MRI and GNRB® ROC curves as fairly informative. However, there is a difference for the partial ACL tears group: the AUC designates the ROC curves as fairly informative for MRI, and highly informative for GNRB®. Table 1 compares SE and SP of MRI and GNRB® for optimal threshold levels found with ROC curves at 134 N.

All these values confirm that individually, the GNRB® was at least as effective as MRI at true positive detection among patients with a healthy ACL with a difference of 4.45% (95% confidence interval (CI) (−1.6%; 10.3%), $P = 0.153$). It is also the case for tears detection (true negatives), whatever its nature with a difference of 2.5% (95% CI (−1.7%;6.7%), $P = 0.248$). Both differences are not significant. Positive and negative predictive values for healthy ACL detection are almost the same between GNRB® and MRI, with a difference of 6.48% (95% CI (−0.19;0.06), $P = 0.306$) and 1.27% with GNRB® (95% CI (−0.01;0.03), $P = 0.156$), respectively. Both differences are not significant.

The GNRB® detects patients who do not have a partial ACL tear as well as the MRI patients (true negatives), with a difference of 3.45% (95% CI (−4.1%;11%)) which is not significant. The same is true for detecting patients who do have a

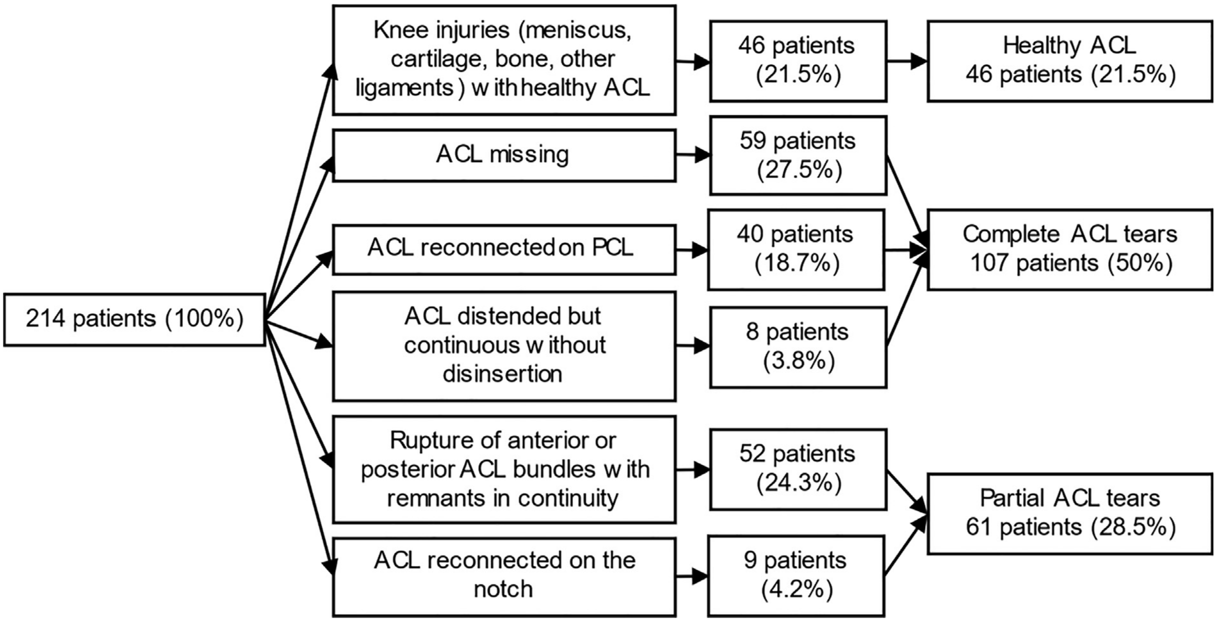

Figure 2. Flowchart showing group criteria for patients, according to arthroscopic reports to classify anterior cruciate ligament (ACL) as healthy, with a partial tear or a complete tear. The number of patients per group is detailed with the percentage in parentheses.

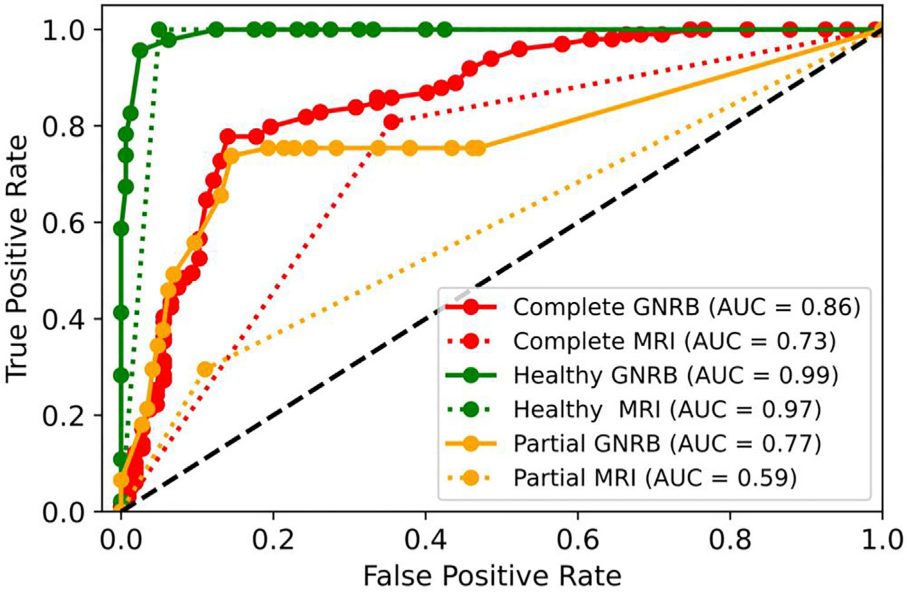

Figure 3. Receiving operator characteristic curves for sensitivity and specificity of magnetic resonance imaging (MRI) and the GNRB® arthrometer in diagnosis of healthy anterior cruciate ligament (ACL) (green), partial ACL rupture (yellow) and complete ACL rupture (red). Area under the curve (AUC) for each curve is computed in parentheses in the legend. Optimal sensitivity/specificity results for GNRB® are obtained with a threshold of 3 mm side-to-side laxity for complete tears detection and a threshold of 1.3 mm side-to-side laxity for partial tears detection.

Table 1
Sensitivities (SE), specificities (SP), positive and negative predictive values (PPV and NPV) of magnetic resonance imaging (MRI), the GNRB®, and the combination of both devices in the detection of healthy anterior cruciate ligament (ACL), partial and complete ACL tears.

		MRI	**GNRB®**	**MRI + GNRB®**
Healthy ACL	SE	100%	95.65%	**100%**
	SP	95%	97.5%	**98.75%**
	PPV	85.19%	91.67%	**96%**
	NPV	100%	98.73%	**100%**
Partial ACL tears	SE	29.51%	73.77%	**74.2%**
	SP	**88.97%**	85.52%	86.9%
	PPV	52.94%	68.18%	**70.31%**
	NPV	75%	88.57%	**88.73%**
Complete ACL tears	SE	**80.81%**	77.78%	78.79%
	SP	64.49%	**85.98%**	85.05%
	PPV	67.8%	**83.7%**	82.98%
	NPV	78.41%	80.7%	**81.25%**

GNRB® results correspond to optimal threshold levels at 134 N obtained using receiving operator characteristic curves (3 mm for complete tears and 1.3 mm for partial tears). Better results appear in bold.

complete ACL tear (true positives) with a difference of 3.03% (95% CI (−7.7%;13.7%)). However, GNRB® offered higher SE for partial tears detection with a significant difference of 44.26% (95% CI (26.8%;61.7%)), which means it detected true positives among patients with a partial ACL tear more frequently than MRI. It also detected true negatives better among patients with no complete ACL tears with a significant difference of 21.49% (95% CI (11.1%;31.9%)). Differences between positive and negative predictive values for partial ACL tear detection are significant for GNRB and MRI, which are, respectively, equal to 15.24% (95% CI (−0.36;0.05), $P < 0.001$) and 13.57% (95% CI (−0.22;0.05), $P < 0.001$). For complete ACL tear detection, negative predictive values are almost equal between both devices with a non-significant difference of 2.29% (95% CI (−0.14;0.09), $P = 0.691$). However, the difference becomes significant and reaches 15.9% for positive predictive values (95% CI (−0.27; −0.04), $P = 0.006$). This means there was a higher proportion of positive patients who truly had a partial and a complete ACL tear with the GNRB® (respectively, negative patients with no partial and complete ACL tear).

Among the 214 exams performed by both devices, in total the GNRB® and MRI disagreed for 69 diagnostics (33.5%). According to arthroscopic reports, GNRB® had 46 correct diagnostics of the 69 disagreements (66.6%), versus 23 for MRI (33.3%). Thus, the results of both devices were combined in order to improve different diagnostics. When they provided different results, the GNRB® was used to give a final diagnosis. This slightly increases results in healthy ACL with no significant differences with MRI or GNRB® alone ($P > 0.356$) except for the positive predictive value for MRI only ($P < 0.001$). Results were homogenized for partial and complete ACL tears with no significant differences with GNRB® (respectively, $P > 0.892$ and $P > 0.9$), but still significantly superior of MRI alone ($P < 0.001$).

4. Discussion

The most important findings of the present study were first, that GNRB® performances were individually equivalent to MRI performances in detecting healthy ACL and complete ACL tears with no significant difference and better results for partial tears detection with a significant difference, using sensitivity as an indicator for proportions. Second, combining the two devices increased the accuracy of the diagnosis, and kept the strengths of both GNRB® and MRI for differentiating healthy ACL, partial and complete ACL tears with precious qualitative and quantitative data. Some disparities can be observed when the results of this study are compared with the literature. Table 2 shows in the first part of the array SE/SP results found in the literature for MRI studies. The second part of the array presents SE/SP results for GNRB® studies.

First, looking at detection of a healthy ACL, or detection of any ACL tear, MRI and the GNRB® detected almost all healthy ACL and all ACL tears in this study. These good results for MRI are similar to those of Li et al., Klass, and the meta-analyses of Smith et al. [5,35,36]. A high SE was found for complete ACL tears, as in Laoruengthan et al., Judet et al., Smith et al. [36–38], but SP score was low compared with their findings. For partial tears, the reverse applies: SE score was very low compared with the other studies and SP score was satisfactory. Our MRI scores were significantly different from those of other studies: for complete ACL rupture, SE $\in$ [62%;94.4%]/SP $\in$ [64.49%;95.3%], and for partial ACL tears, SE $\in$ [29.51%;84%]/SP $\in$ [52.4%;92%]. Umans et al. and Hoogeslag et al. concluded that MRI yielded poor to fair prediction of specific ACL rupture characteristics [26,39]. This suggests that 1.5-T MRI performed with a standard protocol by experienced radiologists in musculoskeletal diseases is not a reliable diagnostic tool to accurately classify ACL rupture characteristics. According to Li et al., using different magnetic field intensities and different techniques can change SE and SP [5]. Van Dyck et al. in two different studies showed and reaffirmed that it is difficult to differentiate partial and complete ACL tears, even for 3 T scanners where the difference is not significant from 1.5 T scanners [40,41]. Adding oblique planes to the protocol could improve results. According to Kwon et al., orthogonal, coronal and sagittal MRI images showed equivalence SE to the combination with additional oblique images in ACL injury detection, but it increases SP [42]. In practice, MRI is mainly performed to search for associated injuries, such as meniscal or chondral tears. Moreover, partial ACL tears are notoriously difficult to detect with MRI [27,30,31], and frequently the diagnosis is confirmed by arthroscopy. This can complicate medical care, because the diagnosis of partial tears impacts their management [26,28,29].

Regarding the GNRB®, our findings, in line with those of the literature, are very encouraging: for complete ACL tears, SE $\in$ [59.4%;92.2%] and SP $\in$ [85.98%;99%], and for partial ACL tears, SE $\in$ [72%;84%] and SP $\in$ [81%;87%]. However, as demonstrated in the present study, SE and SP are very sensitive to threshold values. Indeed, according to Robert et al., the optimal cut-off values are 1.5 mm for partial tears and 3 mm for complete tears [32]. This complete ACL rupture threshold was con-

Table 2

Literature sensitivity and specificity results obtained by different authors compared with this study for complete, partial, and non-specific anterior cruciate ligament (ACL) rupture detection.

MRI results in different studies for ACL tear detection			
	Healthy ACL (SE/SP)	**Partial tears (SE/SP)**	**Complete tears (SE/SP)**
Phelan et al., 2016	88% / 89%	–	–
Li et al., 2017	90% / 87%	–	–
Klass et al., 2007	95–100% / 90–95%	–	–
Laoruengthana et al., 2012	–	80% / 52.4%	90.9% / 84.6%
Judet et al., 2016	–	–	62% / 82%
Umans et al., 1995	–	40–75% / 62–89%	–
Di Iorio et al., 2014	–	84% / 92%	–
Smith et al., 2011	–	–	94.4% / 95.3%
Current study	**100% / 95%**	**29.51% / 88.97%**	**80.81% / 64.49%**
GNRB® results in different studies for ACL tear detection			
	Healthy ACL (SE/SP)	**Partial tears (SE/SP)**	**Complete tears (SE/SP)**
Robert et al., 2009	–	80% / 87%	70% / 99%
Klouche et al., 2015	–	–	92.2% / 96.3%
Beldame et al., 2012	–	–	59.4% / 93.1%
Lefevre et al., 2014	–	84% / 81%	–
Di Iorio et al., 2014	–	72% / NA	–
Current study	**95.65% / 97.5%**	**73.77% / 85.52%**	**77.78% / 85.98%**

MRI, magnetic resonance imaging; SE, sensitivity; SP, specificity.

firmed here, and the threshold for partial ACL rupture came very close to confirmation: applying the partial tear threshold of 1.5 mm did not make much difference to the SE/SP pair, with SE remaining the same and SP only decreasing by 1%.

This study did not intend to show that the GNRB® is better than MRI, because it is clear that MRI cannot be replaced and is essential in clinical practice with really good results. The GNRB® alone does not bring enough information to help in surgical decisions, because results are only quantitative about a functional approach of the ACL. In contrast, MRI brings only qualitative data with a visual approach. Moreover, according to few studies, MRI prescriptions are inappropriate in some cases for knee injuries and should be reviewed to improve the clinical practice to avoid economic and technical issues. Solivetti et al. found that 21% of prescriptions were totally inappropriate and 18.8% uncertain in a study with 400 patients [43]. Refahi et al. found that 45.2% were inappropriate and 1.7% were uncertain in 115 patients [10]. Ebrahimipour et al. found 30.1% of inappropriate prescriptions and 19% uncertain [8] in 63 patients. Finally, Gómez-García et al. assessed 45% of prescriptions as inappropriate [9] in 300 patients. They all addressed the importance of performing a first good clinical and physical examination in the first instance, which directly impacts the decision for an MRI prescription. Lehnert et al., suggested a need for tools to help primary care physicians to improve the quality of their imaging decision requests [44]. This is in the specific context that GNRB® could be a good complementary solution to MRI in ACL tear detection in order to increase diagnosis accuracy.

Some limitations to this study should be noted. First, we used the conclusions from MRI reports, which vary according to type of hospital, university affiliation and radiologist's level of experience, explaining the differences between reports. Second, while the system of classification of types of ACL tears has received validation, it remains subject to interpretation, which may vary even with experienced surgeons. Third, our cohort did include patients with no ACL tears, but it cannot be considered as a control group. As the gold standard was the arthroscopy, patients were required to have knee injuries with a planned operation, which could have an impact for MRI assessment and side-to-side laximetry tests. Thus, sensitivity and specificity in our study reflect the two devices' capacity to detect healthy ACL, complete or partial tears among a population all of whom were injured and already operated on. Fourth, only 1.5 T MRI scanners were used with a classic protocol for knee injuries without using oblique planes. Performing an oblique scan in the sagittal and coronal planes might facilitate visualization of the ACL and provide more information on ACL characteristics [45]. Finally, we considered only minor associated ACL injuries, because serious associated injuries could significantly increase the anterior tibial laxity, which would not have been appropriate for GNRB® [46,47]. However, the main strengths of the present study are the large number of patients (214) assessed and the knee surgeon's experience in arthroscopic classification.

5. Conclusion

This prospective study on 214 patients demonstrated the good performances of combining both GNRB® and MRI exams, which offered good predictive results, with high SE and SP values. It was at least as effective as MRI in complete ACL tear and healthy ACL detection, and showed an indication for use of the GNRB® as a supplement for detecting partial ACL tears. The GNRB®, and in general ADL measures, should not be considered alone but in the whole clinical practice as an additional tool. First, a good clinical diagnosis performed by a physician in the first instance is enough to detect ACL injuries. If the injury is considered as a minor sprain, functional treatments with recovery, without surgery, are sufficient for recovery. If the pain persists with instabilities, or if it is a severe sprain, ADL measurements with GNRB® can be prescribed in order to assess precisely the anterior tibial drawer with an MRI. Following the results in the case where a partial ACL tear is detected, both devices are able to give enough information for surgeons to perform an operation or not, which would not necessarily be the case with MRI alone according to our study. GNRB® measurements were performed after MRI exams in this study. It is also possible to perform the tests before, and could in very specific cases avoid MRI prescriptions, such as the situation where only a partial ACL tear is suspected with unsatisfactory clinical and physical examinations. Thus, combining GNRB® as complementary examination with MRI in clinical practice could significantly improve the diagnosis of ACL tears and help surgeons in their decisions on surgery (selective or total ACL reconstruction) with precious pre-operative information. GNRB® brings a dynamic vision of the biomechanical behavior of the ligament compared to MRI, which brings a static anatomical vision. This study provides also good results which confirm thresholds already found in literature for GNRB® in complete and partial ACL tears detection.

Level of evidence: Prospective diagnostic study, level of evidence III.

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Author Agreement: TC: data analysis and interpretation, writing of the manuscript; LC, CB, HR: revision of the manuscript. All authors approved the final version of the manuscript.

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Consents: Informed consent to participate and to publish was obtained from all participants.

Data and Materials: All authors declare that all data and materials as well as software application or custom code support their published claims and comply with field standards.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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