17 MRI-Based Laxity Measurement for Return to Play

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17.1 Introduction

Returning to sports participation after an anterior cruciate ligament (ACL) injury has been controversial in both scientific evidence and clinical practice. In this sense, the debate between time-based and criteria-based return to play (RTP) has been extensively scrutinized by the scientific community.

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The RTP should be a shared decision, including the healthcare professionals, the player, and the possibly other stakeholders involved (the coach, the manager, and, in some cases, the player's relatives). Still, the healthcare professional is responsible for providing objective advice on management options and possible clinical and functional outcomes, as well as the potential risks, such as reinjury and long-term health and performance deterioration [6, 19, 25, 52].

Within an average of 12 months, around 80% of elite athletes will return to their preinjury sports level, compared to 60% return to sports among nonelite athletes [45]. When focusing on football, 85% of football players return to their preinjury sports level, between 6 and 10 months [21, 37, 45, 89, 93]. Still, approximately one fourth of elite athletes may not return to sports at the same level [45], and reasons include mainly fear of reinjury [8, 44, 55] and lack of psychological readiness [7, 9].

Although having relatively high rate of RTP, the ACL graft may fail and re-rupture in around 5% of elite athletes [45]. Moreover, ACL reinjury rates may go as far as 15% (7% ipsilateral and 8% contralateral) or 23% for athletes younger than 25 years who return to sport [90]. In addition to an adequate rehabilitation process [87], objective criteria in the decision for allowing the return to high-level sports play a crucial role in decreasing the risk of ACL reinjuries [34, 85].

17.2 Residual Knee Deficits After ACL Reconstruction

Reestablishing the knee biological homeostasis (bone bruises, mechanoreceptors and sensory afferents, and graft maturation) and normal biomechanical function (mechanical stability, range of motion, neuromuscular control, quadriceps strength) plays a crucial role in RTP, as they may reduce the incidence of secondary ACL injuries [62]. These biomechanical deficits may persist for years after ACL reconstruction, or even after the player returned to competition [1, 17, 18, 31, 61, 63, 64, 71, 79, 81, 82, 92].

Residual knee laxity may be present 6–12 months after ACL reconstruction [61, 64, 69, 76]. Within this line, it has been previously shown that ACL-reconstructed knees display greater maximal anterior tibial translation during gait exercises, even after a 5-year follow-up period [79]. Furthermore, the peak ACL strain is correlated with anterior tibial translation and bipedal simulated landing, i.e., greater knee laxity produces higher levels of peak ACL strain during landing exercises. Therefore, higher peak ACL strain could place the individual at higher risk of sustaining an ACL injury [34, 48]. Additionally, increased dynamic tibial rotation that often persists after ACL-reconstruction and leads to abnormal knee motion during gait [29, 30] or running exercises [82]. These findings raise some concerns regarding RTP, particularly within those who RTP prematurely, adding further risk factors for reinjury. In addition, the increased rotatory knee laxity may, itself, decrease the player's self-efficacy and performance, as well as increase the risk of reinjury. Moreover, rotatory knee laxity deficits may contribute to associated meniscal or cartilage lesions and early development of long-term knee joint degeneration [20, 82, 88] and subsequently to a poorer associated quality of life [25, 26]. Thus, more strict criteria regarding rotatory knee laxity after ACL reconstruction should be employed in RTP battery tests.

17.3 Importance of Imaging and Laxity Measurement

Knee joint residual laxity is considered one of the major risk factors for further ACL and meniscus injury, as well as one of the reasons for ACL reconstruction failure [38, 40, 70, 73, 75, 83, 91].

Measurement of sagittal knee laxity has been extensively performed in the follow-up of ACL-reconstructed patients [2, 32, 39, 74, 86]. However, the reliability and diagnostic accuracy of KT-1000™ instrumented AP laxity testing has been questioned [27, 33]. In this regard, stress radiography, mainly through the Telos device [10, 72, 77], emerged as a potential noninvasive method to measure the tibial anterior translation.

More recently, the objective measure of rotational knee laxity has gained increasing interest from the scientific community. This has been traditionally accomplished through pivot-shift manual test. Reports concerning the lack of standardization and objective grading [3, 13, 28, 58, 59, 78] led to the development of new mechanical testing devices to assess the knee rotational laxity including arthrometers [12, 48–51, 57, 60, 65, 84], electromagnetic sensor systems [4, 35, 36, 42, 43, 54], inertial sensors [11, 41, 46, 47, 53], and stress laxity assessment within magnetic resonance imaging (MRI) evaluation [22, 23, 67, 68].

The MRI is an accurate noninvasive tool widely used in the evaluation of intra-articular knee injuries [56]. The use of MRI in the postoperative follow-up enables the clinician to assess knee effusion, graft preservation, tunnel preservation, cartilage damage, and meniscal injuries [73]. The visualization of non-healed bone bruises may also be followed by MRI and has a crucial role during the rehabilitation phases and RTP decision [15]. Moreover, graft biological integrity ("ligamentization") is an important process in the RTP decision, which MRI plays a fundamental role in the evaluation [14, 24].

The examination of partial ACL tears with MRI is important as physical examination may be unclear when assessing isolated bundle ruptures [94], and partial tears can heal on their own, which can be carefully followed using MRI [5].

Despite the MRI accuracy in evaluating and following ACL injuries, it has been highlighted that both instrumented laxity and MRI examination are needed in combination with clinical evaluation in order to obtain the greatest accuracy [16]. Thus, the ideal tool to measure the ACL laxity should be able to assess both "anatomy" and "function" on the same examination [23].

17.4 Porto-Knee Testing Device

The Porto-Knee Testing Device (PKTD) is an MRI-compatible knee laxity testing device that is capable of measuring multiplanar knee laxity, i.e., the sagittal tibiofemoral translations and tibial internal and external rotation (Fig. 17.1). The assessment of knee laxity in combination with MRI allows the correlation of both the ligament "anatomy" and "functionality" within the same exam [66].

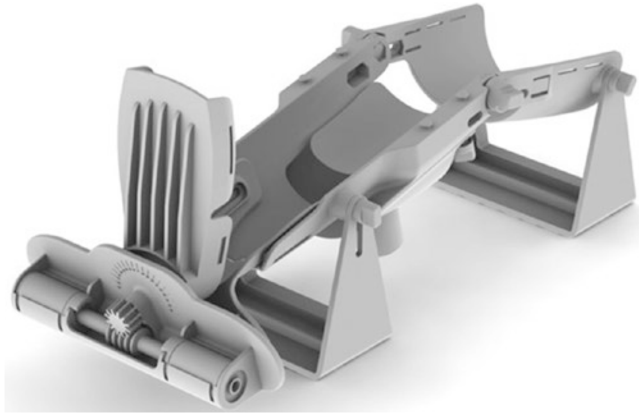

Fig. 17.1 Porto-Knee Testing Device (PKTD), developed at the Clínica do Dragão, Espregueira-Mendes Sports Centre - FIFA Medical Centre of Excellence

Fig. 17.2 Demonstration of PKTD sequences: without pressure (**a**), with PA pressure (**b**), and with external rotation pressure (**c**). *Arrow* indicates the tibial PA translation induced by the pressure applied in the posterior proximal calf region through the plunger pressurizing (part **b**)

The PKTD is made of polyurethane composite material, which allows to be used within the MRI and computerized tomography examination. The PKTD is capable to stress the knee at different degrees of knee flexion (from−10° to 50°) and combined with different degrees of internal/external rotation (0–90°). The tibial posteroanterior (PA) translation may be assessed alone or in combination with tibial rotation. In order to stress the ACL, a standardized pressure of 4 bar is applied to the proximal posterior calf (Fig. 17.2).

The PKTD measurements are determined through two sets of 1 mm spacing MRI slices. The first examination is made without any pressure, and a second examination is made with the application of pressure. On the obtained images, measurements (in mm) are then calculated by drawing a perpendicular line to the tibial slope, crossing the most posterior point of the tibial plateau, and a parallel line, crossing the most posterior point of the femoral condyle. This procedure is repeated for the medial and lateral tibial plateaus [80].

The laxity measurement is made by calculating the distance between the two lines, in each of the two sets of MRI slices, i.e., without and with pressure, obtaining the anterior displacement of the medial and lateral tibial plateau (Fig. 17.3). Comparison with the healthy contralateral knee can be made.

The PKTD is a reliable tool for assessment of the PA translation with a moderate-to-strong correlation with side-to-side KT-1000 measures for medial (correlation coefficient = 0.73; $p < 0.05$) and lateral (correlation coefficient = 0.5; $p < 0.05$) tibial plateaus displacement. The assessment of the rotatory knee laxity has a strong positive correlation with the pivot-shift test under anesthesia (correlation coefficient = 0.8; $p < 0.05$) and with side-to-side differences (correlation coefficient = 0.83; $p < 0.05$) [23]. More recently, two additional PKTD mea-

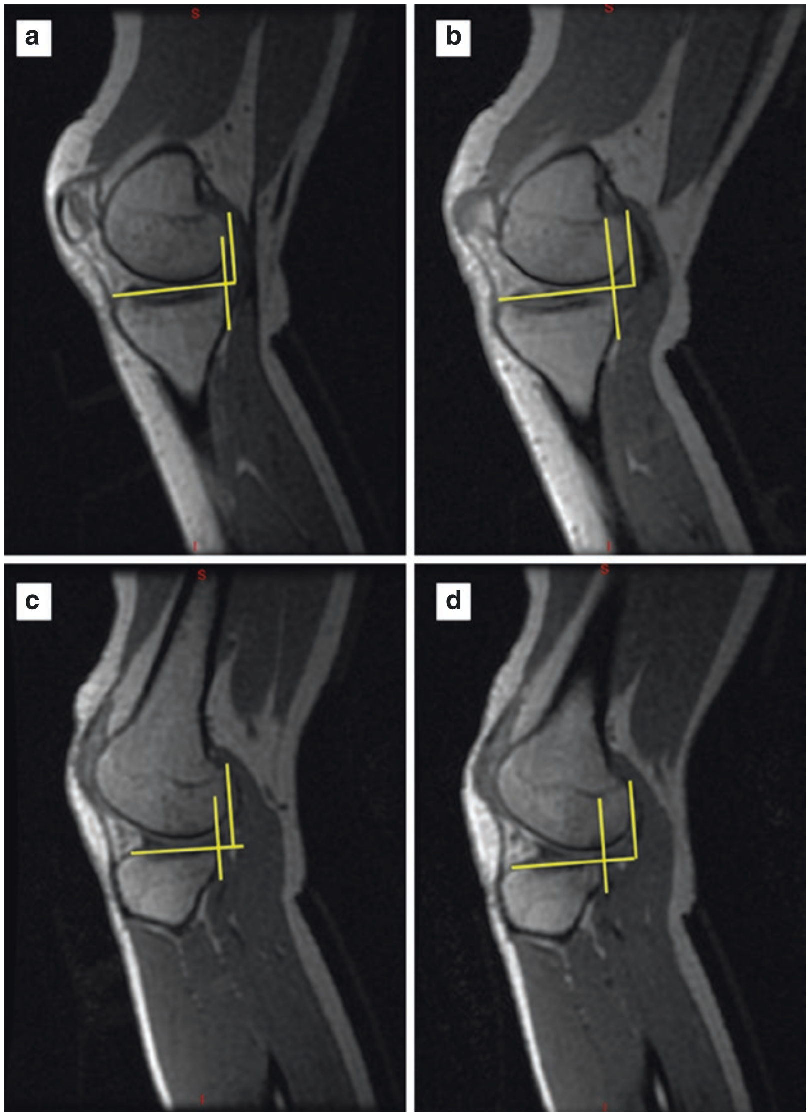

Fig. 17.3 Representation of the measurements of medial knee compartment tibial positioning without (**a**) and with pressure (**b**) and of the lateral knee compartment tibial positioning without (**c**) and with pressure (**d**), obtained from MRI slices using the PKTD

sures were investigated—the anterior global translation and the global rotation. These measurements showed high sensitivity and specificity in identifying complete ACL ruptures. The anterior global translation (PA translation of both medial and lateral tibial plateaus) has high specificity (94%), with a cutoff point of 11.1 mm. The global rotation (internal rotation at the lateral tibial plateau plus external rotation at the medial tibial plateau) is highly sensitive (93%) with a cutoff point of 15.1 mm [56].

The main purpose of the PKTD is distinguishing functional from nonfunctional ACLs or ACL grafts. Partial ACL ruptures may also be identified. By combining the sagittal and rotational laxity measurements, the PKTD is able to correlate the ligament anatomy with the functional competence of the remnant bundle

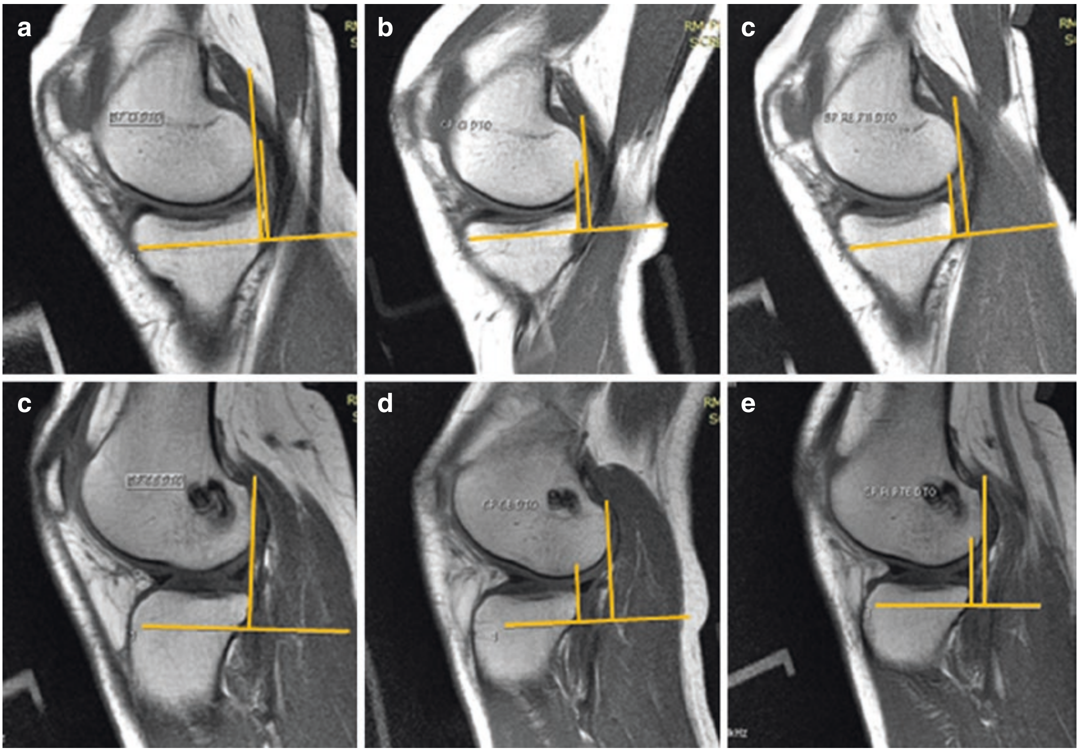

Fig. 17.4 Follow-up of PKTD-MRI; a case of an ACL-reconstructed knee with significant residual laxity in his right knee precluding return to sports. (**a**) Medial tibial plateau, no stress (−1 mm); (**b**) medial tibial plateau, posteroanterior stress (3 mm); (**c**) medial tibial plateau, external rotation stress (5 mm); (**d**) lateral tibial plateau, no stress (0 mm); (**e**) lateral tibial plateau, posteroanterior stress (13 mm); (**f**) lateral tibial plateau, internal rotation stress (4 mm)

[55]. This may play an important role in the follow-up of ACL-reconstructed patients as partial ACL graft ruptures or reconstruction failure may occur in case of surgical errors and complications, inadequate rehabilitation or anticipated RTP.

Fact Box 1
The PKTD has several clinical and preventive applications within sports, including:

- Assessment of partial or total ACL ruptures
- Follow-up of ACL-reconstructed knees
- Additional objective criteria for RTP
- Planning of secondary prevention programs

The PKTD may be used in the RTP decision by examining the functional competence of the ACL graft (Figs. 17.4 and 17.5). Residual knee laxity may indicate the need for further rehabilitation or, in case of failure, evaluate the need for new surgical intervention before allowing the player to return to competition.

Fact Box 2
Suggested additional return-to-play objective criteria based on PKTD-MRI measurements:

- Anterior global translation after PA stress <11.0 mm
- Global rotation combined measure <15.0 mm

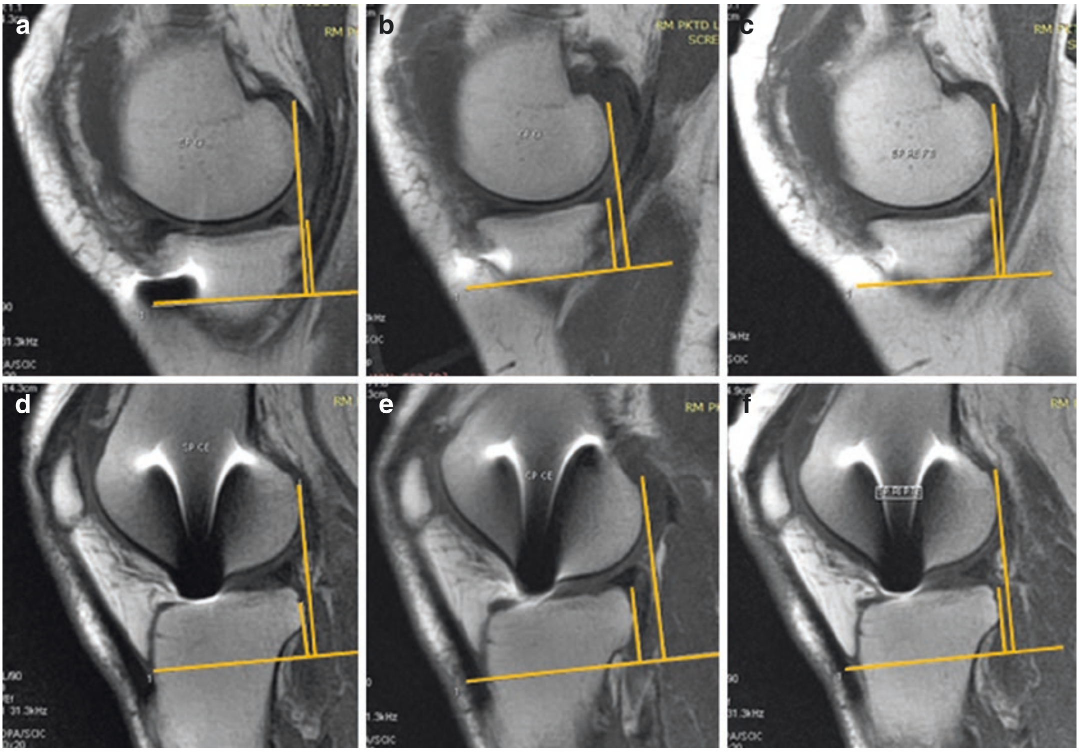

Fig. 17.5 Follow-up of PKTD-MRI; a case of an ACL-reconstructed knee with a stable joint that in presence of other achieved return-to-play criteria indicates that the player is ready to return to competition. (**a**) Medial tibial plateau, no stress (1 mm); (**b**) medial tibial plateau, posteroanterior stress (4 mm); (**c**) medial tibial plateau, external rotation stress (2 mm); (**d**) lateral tibial plateau, no stress (2 mm); (**e**) lateral tibial plateau, posteroanterior stress (6 mm); (**f**) lateral tibial plateau, internal rotation stress (3 mm)

Take Home Message

Instrumented assessment of knee laxity in combination with MRI enables the correlation of the ligament's "anatomy" and "function." In our hands, the PKTD is a helpful tool in the follow-up of football players with ACL-reconstructed knees, RTP decision-making, and planning of secondary prevention programs.

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