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Association of Hip and Foot Factors With Patellar Tendinopathy (Jumper's Knee) in Athletes

Patellar tendinopathy is an overuse injury associated with jumping and landing activities[2] and thought to be caused by excessive or repetitive forces applied to the patellar tendon.[15] The prevalence of this condition in elite volleyball and basketball athletes has been reported to be about 40%,[23] and prevention and management strategies are often challenging.[9] Understanding the risk profile of this condition is necessary because patellar tendinopathy is associated with long-term pain and functional limitations that can not only affect sport participation but also end a sport career.[9]

BACKGROUND: Investigations on the causes of patellar tendinopathy should consider impairments at the hip and foot/ankle because they are known to influence movement patterns and affect patellar tendon loading.

OBJECTIVES: To investigate hip and foot/ankle impairments associated with patellar tendinopathy in volleyball and basketball athletes using classification and regression tree analysis.

METHODS: In this clinical measurement, cross-sectional study, 192 athletes were assessed for impairments of the hip and foot/ankle, including shank-forefoot alignment, dorsiflexion range of motion (ROM), iliotibial band flexibility, passive hip internal rotation ROM, and hip external rotator and hip abductor isometric strength. Athletes with tenderness and/or pain at the inferior pole of the patella were considered to have patellar tendinopathy. Athletes with scores higher than 95 points on the Victorian Institute of Sport Assessment-patella (VISA-P), no pain during the single-leg decline squat, and no history of patellar tendon pain were considered not to have patellar tendinopathy. Classification and regression tree analyses were performed to identify interacting factors associated with patellar tendinopathy.

RESULTS: Interactions among passive hip internal rotation ROM, shank-forefoot alignment, and hip external rotator and abductor strength identified athletes with and without patellar tendinopathy. The model achieved 71.2% sensitivity and 74.4% specificity. The area under the receiver operating characteristic curve was 0.77 (95% confidence interval: 0.70, 0.84; $P<.001$).

CONCLUSION: Impairments of the hip and foot/ankle are associated with the presence of patellar tendinopathy in volleyball and basketball athletes. Future studies should evaluate the role of these impairments in the etiology of patellar tendinopathy.
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The majority of studies evaluating factors related to patellar tendinopathy have focused on anthropometric,[8,14,43] biomechanical, and anatomical variables[35,37,41] that are frequently related to the knee joint (local factors).[14,17,28] A systematic review published by van der Worp et al[41] found weak associations between local, nonlocal, and demographic risk factors and patellar tendinopathy. Thus, it is possible that other factors, such as those related to impairments of the hip and foot/ankle, could play a role in patellar tendon overload and, consequently, contribute to patellar tendinopathy.

It has been suggested that impairments of the hip and foot/ankle may contribute to the development of pathological conditions of the knee by means of direct and indirect influences on movement patterns or anatomical alignment that could overload the knee structures.[1,7,12,13,18,26,29-31,36,37,39,41] For example, there is evidence that individuals with patellofemoral pain have increased hip adduction[12] and excessive femoral internal rotation (IR)[39] during functional activities. These altered hip motions may be caused by hip abductor and hip external rotator (ER) weakness.[44] In addition, studies investigating

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lower-limb kinematics in the sagittal plane reported that athletes with patellar tendinopathy exhibit altered hip and knee movement patterns during landing, when compared to those who are pain free.[25,35,38]

However, no investigation has included analysis of factors related to frontal and transverse planes of motion in individuals with patellar tendinopathy. It has been reported that altered hip joint range of motion (ROM) during landing tasks could overload the patellar tendon.[25] Moreover, deficits in ankle dorsiflexion (DF) ROM and increased varus foot alignment also have been found to lead to excessive foot pronation and increased lower-limb IR,[40] which are thought to overload the patellar tendon.[1,26,34] Thus, the presence of hip abductor and ER weakness, ROM impairments (restriction or excessive mobility), and anatomical alignment at the hip joint and foot-ankle complex may influence lower extremity movement patterns and, consequently, alter the force distribution on the knee joint structures (eg, patellar tendon).[5,11,12,19,26,37,41]

Because of the complexity related to injury occurrence, statistical methods that include linear and nonlinear associations and the identification of interaction effects should be used.[4,16,32] The classification and regression tree (CART) method allows the identification of factors and uncovers interactions related to a specific condition.[20] This method has been used in the medical literature to identify clinical decision rules that enable the classification of participants into clinically important categories.[20] In addition, this statistical method may reveal the complex relationships among factors related to impairments of the hip and foot/ankle that may contribute to patellar tendinopathy. Thus, the objective of this cross-sectional study was to investigate, by means of CART analysis, impairments of the hip and foot/ankle that are associated with patellar tendinopathy in volleyball and basketball athletes.

METHODS

Participants

Male and female volleyball and male basketball athletes from professional clubs in Brazil participated in a preseason screening over an 8-month period. The inclusion criteria were regular sport participation of at least 12 hours per week during the immediate previous season, absence of Osgood-Schlatter disease and absence of anterior knee pain not related to the patellar tendon (both confirmed by a sport medicine physician or physical therapist), and no history of lower-limb surgery and/or patellar tendon steroid injection (as determined by self-report of the athlete or by the physical therapist). All participants read and signed the informed-consent form approved by the Universidade Federal de Minas Gerais Ethics in Research Committee (report number 0493.0.203.000-09).

Athletes with patellar tendinopathy were those with tenderness and/or pain at the inferior pole of the patella (confirmed by a sport medicine physician or physical therapist). The severity of symptoms was assessed using the Victorian Institute of Sport Assessment-patella (VISA-P) questionnaire. This tool is scored from 0 to 100, with a score of less than 80 points indicating severe patellar tendinopathy (n = 59).[11,42] A VISA-P score greater than 95 points, no pain during the single-leg decline squat, and no patellar tendon pain history indicated that an athlete did not have patellar tendinopathy (n = 133).[22,27,45] Those athletes with VISA-P scores between 80 and 94 points were excluded from the study.[42]

Clinical Assessment

Preseason assessments included shank-forefoot alignment (SFA), DF ROM, iliotibial band flexibility, passive hip IR ROM, and hip ER and hip abductor isometric strength. These tests were selected because the conditions they evaluate are thought to contribute to excessive femoral and tibial motions in frontal and transverse planes.[1,5,7,12,19,24,26,29,39,44] The clinical measurements were made sequentially, with the strength assessments performed last. Six pilot studies were conducted to determine each measurement's reliability by means of intraclass correlation coefficient (ICC). Two examiners with at least 5 years of experience in preseason assessments were trained in all tests to obtain acceptable ICC values (**TABLE 1**).

Both examiners participated in more than 300 assessments prior to the current study, which contributed to their excellent reliability coefficients and, consequently, small standard error of the measurement (SEM) and minimal detectable difference values for all variables. Different samples were used in each of the pilot studies.

TABLE 1 Pilot Study Sample Size, Intrarater and Interrater Reliability, SEM, and MDD of Each Variable Examined

Variable	Sample Size, n	Interval Between Measures, s	Intrarater Reliability*	Interrater Reliability*	SEM	MDD
SFA, deg	10	4	0.93	0.90	2.47	6.82
Hip ER torque, Nm	6	7	0.98	0.90	0.53	1.49
Hip abductor torque, Nm	6	7	0.94	0.90	1.10	3.05
Ankle DF ROM, deg	12	4	0.98	0.92	0.56	1.57
Passive hip IR ROM, deg	6	4	0.99	0.99	0.55	1.52
Iliotibial band flexibility, deg	6	4	0.99	0.94	0.31	0.85

Abbreviations: DF, dorsiflexion; ER, external rotator; IR, internal rotation; MDD, minimal detectable difference; ROM, range of motion; SEM, standard error of the measurement; SFA, shank-forefoot alignment.
**Values are intraclass correlation coefficient.*

Shank-forefoot alignment and ankle DF ROM required a larger sample due to low variability of the measurements previously identified in other studies. **TABLE 1** shows the sample size, interval between measures, intrarater and interrater reliability, SEM, and minimal detectable difference of each variable.

The SFA was measured according to the method described by De Michelis Mendonça et al,[10] with the participant lying prone on a treatment table. The shank was bisected by a line joining the midpoint of the tibial plateau and the midpoint between the medial and lateral malleoli. A metal rod was strapped over the metatarsophalangeal heads. The participant actively maintained neutral position of the ankle joint (90°), and the examiner took a picture of foot position with a digital camera (D5000; Nikon Corporation, Tokyo, Japan). The SFA was determined, using the Simi Motion Twinner software (Simi Reality Motion Systems GmbH, Unterschleissheim, Germany), as the angle between the shank bisection line and the orientation of the metal rod positioned on the forefoot (**FIGURE 1A**). Positive values indicated varus alignment.[10] The mean of the SFA, determined from 3 photos, was used for analysis.

A handheld dynamometer (microFET2; Hoggan Scientific, LLC, Salt Lake City, UT) was used to assess hip ER and abductor isometric strength.[26,44] Hip ER strength was measured with the participant positioned in prone, with the pelvis stabilized with a rigid strap. The handheld dynamometer was placed proximal to the medial malleolus,[44] and the participant performed 3 isometric contractions (**FIGURE 1B**). A 15-second interval was provided between trials. Force values were multiplied by the linear distance from the dynamometer placement to the hip axis of rotation and normalized by body mass (Newton meters per kilogram).

Hip abductor strength was assessed using the protocol described by Bittencourt et al,[5] with the participant positioned in sidelying and the pelvis stabilized with a rigid strap. The dynamometer was positioned proximal to the lateral femoral condyle. Participants performed 3 trials of maximal isometric hip abduction contractions with a 15-second interval between trials (**FIGURE 1C**). Hip abduction torque was calculated as the product between the mean of 3 force measures and the distance from the greater trochanter to the location of the dynamometer.

Ankle DF ROM was assessed using the protocol described by Bennell et al.[3] The participant was positioned facing a wall and was instructed to move the knee forward until it touched the wall. The participant maintained the foot on this line without lifting the heel off the floor (**FIGURE 2A**). An analogical inclinometer (Starrett, Athol, MA) was placed 15 cm from the tibial tuberosity to define maximum shank anterior inclination (ankle DF ROM). The average of 3 measurements was considered for analysis.[1]

To evaluate passive hip IR ROM, the examiner applied the protocol described by Carvalhais et al,[6] in which the participant was positioned prone on a treatment table with the knee flexed to 90°. The passive movement of hip IR, produced by the weight of the leg and foot, was allowed until tension in muscle and passive structures of the hip joint stopped this movement (**FIGURE 2B**). In other words, the end position was one in which the torque produced by the mass of the lower leg and foot was equal to the passive-resistance torque generated to prevent further hip IR. In contrast to typical passive ROM measurements, this test did not rely on the examiner's perception of the hip joint end feel. Prior to the test, the examiner moved the hip joint passively to produce the tissue's viscoelastic accommodation.[6] The passive hip IR ROM was measured with an analog inclinometer (Starrett) positioned 5 cm from the tibial tuberosity, and the mean of 3 measures (degrees) was used for analysis.[6] This particular method of passive hip IR ROM was selected because it is related to hip passive stiffness.[6] A previous study reported excellent ICC (0.99) and small SEM (1.5°) values for this measure.[5]

The modified Ober test protocol was used to assess iliotibial band flexibility, as described by Reese and Bandy.[33] The participant was positioned in sidelying, with the arms in front of the body. The examiner maintained the pelvis alignment with one hand (keeping the pelvis in neutral rotation relative to the treatment table) and performed passive hip joint motions of flexion, external rotation, abduction, and extension. The examiner then removed the support slowly until the lower limb moved to the position of maximal hip adduction. A second examiner measured the thigh's inclination to the horizontal (hip adduction angle)

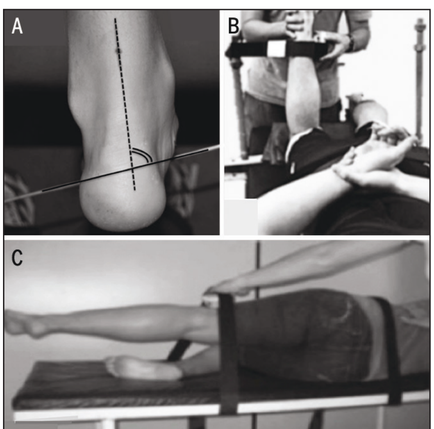

FIGURE 1. (A) Quantification of shank-forefoot alignment angle with 2-dimensional software, (B) position for hip external rotation, and (C) hip abductor isometric strength assessment.

FIGURE 2. Participant's position to assess (A) ankle dorsiflexion range of motion, (B) passive hip internal rotation range of motion, and (C) iliotibial band flexibility.

with an analog inclinometer (Starrett) positioned distal to the lateral femoral condyle (**FIGURE 2C**). Before the test, the examiner simulated the test 3 times to allow the tissue's viscoelastic accommodation. Measures were taken 3 times, and the mean (degrees) was used for analysis. Positive values were considered as hip abduction (less flexible iliotibial band).[26]

Participants were assessed bilaterally, and all examiners who performed the preseason screening tests were blinded to the participant's group assignment. Data from the injured or most symptomatic lower limb for the athletes with patellar tendinopathy, and from the dominant lower limb in athletes without patellar tendinopathy, were considered for analysis.[5] Limb dominance was identified by asking the participants which leg they would choose to kick a ball.

Statistical Analysis

Descriptive statistics of VISA-P questionnaire score, age, height, weight, sex, iliotibial band flexibility, hip abductor torque, hip ER torque, passive hip IR ROM, ankle DF ROM, and SFA were used to characterize the sample. A CART analysis was used to determine which factors and interactions were associated with the presence or absence of patellar tendinopathy.[20] The CART is a multivariate and nonparametric classification model that, throughout binary recursive divisions of the initial set of data, selects the predictors and their respective cutoff points that best classify the individuals in each of the outcome categories,[20] in this case, presence or absence of patellar tendinopathy. The predictors are selected based on the strength of association with the outcome variable (patellar tendinopathy occurrence), and the divisions reveal interactions among predictors. The CART model starts with all data (n = 192) in the first node. Then, the variable that is most associated with the outcome is selected, and the data are divided into 2 groups, according to specific cutoff values. For all nodes, the CART model searches for the best cutoff value for partitioning the selected variable to get the maximum separation of the sample in terms of patellar tendinopathy occurrence (presence or absence of patellar tendinopathy). This process produces a classification similar to a tree.

The following criteria were used to produce the partitions and, consequently, tree growth: a minimum of 8 participants in each node to make a division, a minimum of 4 participants to generate a node, and a Gini index of 0.0001 to maximize the node's homogeneity. A maximum depth of 3 levels was established, and a pruning procedure was applied to avoid overfitting partitions.[5] The classification cost was considered symmetric between categories, and patellar tendinopathy occurrence probability was established as equal between groups.[23]

After CART model development, a receiver operating characteristic (ROC) curve was created to verify the accuracy of the model.[5] A probability of type I error of .05 was used to verify whether the area under the ROC curve was different from 0.5, which indicates that the model was accurate to predict the outcome categories. Finally, prevalence ratios were calculated for each terminal node of the CART model to investigate the strength of associations.

RESULTS

Descriptive Data

Initially, 311 athletes participated in the preseason screening. Of those, 41 were excluded due to the presence

TABLE 2 Descriptive Demographic and Independent Variable Data of the Entire Sample, Separated by Those With and Without Patellar Tendinopathy *

Variable	Range	Total Sample (n = 192)	With Patellar Tendinopathy (n = 59)	Without Patellar Tendinopathy (n = 133)	Excluded (n = 80)
Age, y	15-37	17.85 ± 4.72	18.25 ± 0.69	17.68 ± 0.38	16.71 ± 2.99
Time in practice, y	1-20	5.12 ± 4.64	5.71 ± 0.62	4.86 ± 0.39	5.20 ± 3.57
Height, m	1.53-2.13	1.86 ± 0.10	1.85 ± 0.01	1.86 ± 0.09	1.84 ± 0.11
Body mass, kg	51.40-125	76.47 ± 13.58	75.32 ± 1.88	76.56 ± 1.26	75.25 ± 14.66
BMI, kg/m^2	16.18-30.37	21.73 ± 2.48	21.70 ± 0.29	21.79 ± 0.24	22.02 ± 2.83
VISA-P score	39-100	90.32 ± 14.83	68.73 ± 1.14	99.70 ± 0.08	90.75 ± 7.78
Ankle DF ROM, deg	23.66-54.33	39.52 ± 6.26	39.48 ± 0.79	39.89 ± 0.58	38.87 ± 6.43
Passive hip IR ROM, deg	10.97-59.71	32.92 ± 10.6	34.49 ± 10.04	32.25 ± 10.90	34.04 ± 11.03
Iliotibial band flexibility, deg	−16.2-14.98	3.91 ± 4.80	4.27 ± 4.48	3.74 ± 4.94	4.89 ± 3.91
Hip ER torque, Nm/kg	0.09-0.81	0.33 ± 0.13	0.30 ± 0.01	0.35 ± 0.01	0.35 ± 0.15
Hip abductor torque, Nm/kg	0.58-2.65	1.51 ± 0.36	1.49 ± 0.05	1.50 ± 0.03	1.49 ± 0.35
SFA, deg	−3.68-46.64	22.31 ± 9.22	23.38 ± 1.16	21.93 ± 0.87	18.46 ± 10.90

Abbreviations: BMI, body mass index; DF, dorsiflexion; ER, external rotator; IR, internal rotation; ROM, range of motion; SFA, shank-forefoot alignment; VISA-P, Victorian Institute of Sport Assessment-patella.
**Values are mean ± SD unless otherwise indicated.*

of Osgood-Schlatter disease, history of surgery, or steroid injection. Using the criteria described above, 59 athletes were included in the patellar tendinopathy group (22 women and 37 men) and 133 in the non–patellar tendinopathy group (25 women and 108 men). Participants with a VISA-P score between 80 and 94 points (n = 78) were excluded from this study. **TABLE 2** shows descriptive statistics for demographic characteristics and predictors for the study sample. Statistical difference of descriptive variables between athletes with and without patellar tendinopathy was found only for the VISA-P questionnaire score (P<.001), which was expected given the inclusion criteria.

CART Model and Prevalence Ratios

The classification tree identified passive hip IR ROM, SFA, hip ER torque, and hip abductor torque as predictors for patellar tendinopathy (**FIGURE 3**). Passive hip IR ROM was the first predictor selected by the CART model, with a cutoff of 40.76°. In individuals with lower values of passive hip IR ROM, SFA was the second predictor, with a cutoff point of 16.95°, and hip ER torque was selected as the third predictor, with a cutoff point of 0.31 Nm/kg. For individuals with passive hip IR ROM values above the cutoff point, the model selected another passive hip IR ROM cutoff point (44.46°) on the second level, and hip abductor torque with a cutoff point of 1.57 Nm/kg on the third level.

The model indicated that the interaction of lower values of passive hip IR ROM with lower values of SFA was best at predicting the absence of patellar tendinopathy (terminal node 3). The absence of patellar tendinopathy also was observed in individuals with lower values of passive hip IR ROM and greater values of forefoot varus alignment, but with greater values of hip ER torque (terminal node 8). On the other hand, patellar tendinopathy occurrence was best predicted by passive hip IR ROM between 40.76° and 44.46° (terminal node 5) and by the interaction of lower passive hip IR ROM, greater SFA, and lower hip ER torque (terminal node 7). The interactions representing the patellar tendinopathy presence/absence profiles are illustrated in **FIGURE 4**.

TABLE 3 provides the prevalence ratios for each terminal node and the strength of the associations of predictors with outcome. The results indicated that the interactions among predictors of nodes 3, 5, 7, and 8 were statistically associated with the absence or presence of patellar tendinopathy.

The CART model correctly predicted 42 of the 59 athletes with patellar tendinopathy (71.2% sensitivity) and 99 of the 133 athletes without patellar tendinopathy (74.4% specificity). The total prediction of the model was 73.4%, and the area under the ROC curve was 0.77

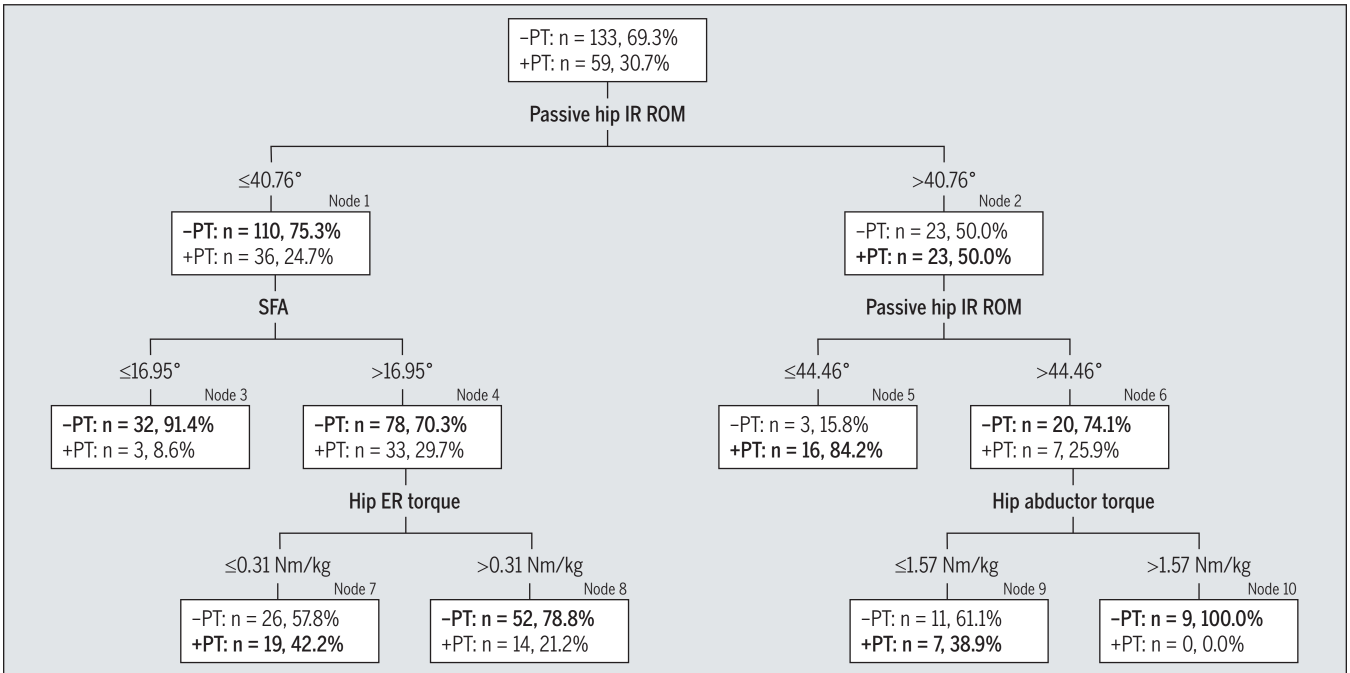

FIGURE 3. Classification and regression tree model for PT. The bold text in each node (+PT or –PT) corresponds to the predicted category. The classification profile for the presence of PT in terminal node 5 was passive hip IR ROM between 40.76° and 44.46°; in terminal node 7 was passive hip IR ROM under 40.76°, SFA above 16.95°, and hip ER torque under 0.31 Nm/kg; and in terminal node 9 was passive hip IR ROM above 44.46° and hip abductor torque under 1.57 Nm/kg. The classification profile for the absence of PT in terminal node 3 was passive hip IR ROM under 40.76° and SFA under 16.95°; in terminal node 8 was passive hip IR ROM under 40.76°, SFA above 16.95°, and hip ER torque above 0.31 Nm/kg; and in terminal node 10 was passive hip IR ROM above 44.46° and hip abductor torque above 1.57 Nm/kg. Abbreviations: ER, external rotation; IR, internal rotation; PT, patellar tendinopathy; ROM, range of motion; SFA, shank-forefoot alignment.

(95% confidence interval: 0.70, 0.84; standard error, 0.03; $P<.001$), indicating that the model's classification was not due to chance.

DISCUSSION

By means of CART analysis, the authors examined the interactions among clinical measurements associated with patellar tendinopathy.[4] The CART model revealed that interactions among variables related to the hip joint and foot-ankle complex were associated with the presence or absence of patellar tendinopathy. Specifically, different interactions among passive hip IR ROM, SFA, hip ER torque, and hip abductor torque were associated with patellar tendinopathy occurrence. Overall, the model accurately identified 71.2% of athletes with patellar tendinopathy and 74.4% of athletes without patellar tendinopathy. Thus, interactions among other variables not investigated in this study, including biomechanical, behavioral, and physiological factors, also may contribute to the occurrence of patellar tendinopathy and should be explored in future studies.

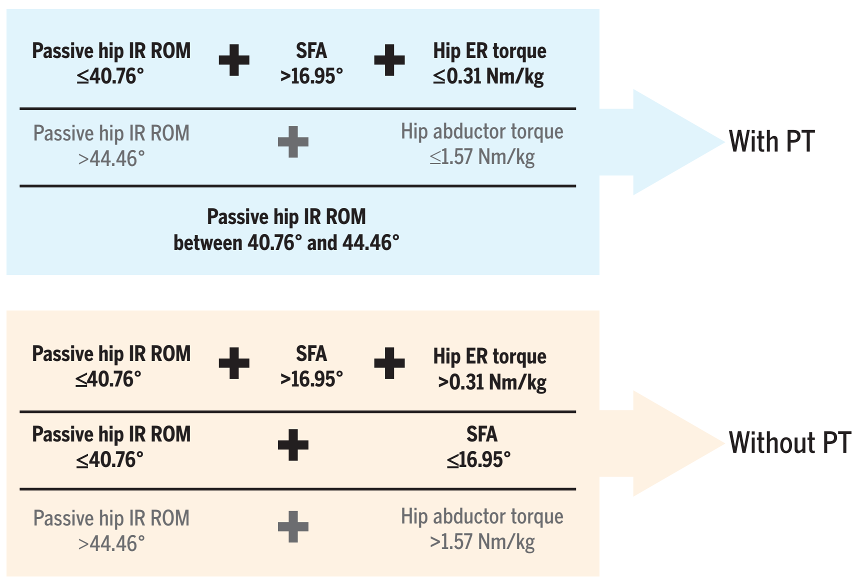

FIGURE 4. Interactions (profiles) revealed by the classification and regression tree model. Interactions in bold were statistically significant (see **TABLE 3**). Abbreviations: ER, external rotation; IR, internal rotation; PT, patellar tendinopathy; ROM, range of motion; SFA, shank-forefoot alignment.

TABLE 3 — Prevalence Ratio of Each Terminal Node of the CART Model

Terminal Node	Prevalence Ratio*
3	0.24 (0.07, 0.72)†
5	3.38 (2.45, 4.68)†
7	1.55 (1.01, 2.39)†
8	0.59 (0.35, 0.99)†
9	1.30 (0.69, 2.42)
10‡	...

Abbreviation: CART, classification and regression tree.
**Values in parentheses are 95% confidence interval.*
†Statistically significant.
‡In terminal node 10, it was not possible to calculate the prevalence ratio because all athletes (100%) were classified as not having patellar tendinopathy.

The first predictor selected by the CART model was passive hip IR ROM, with a cutoff point of 40.76°. Interestingly, hip IR ROM was associated with patellar tendinopathy occurrence or absence according to its cutoff points and the presence of other predictors (SFA and hip abductor and ER torques). Specifically, athletes with lower values of passive hip IR ROM (less than or equal to 40.76°, intermediary node 1), while having lower values of foot varus alignment (SFA less than or equal to 16.95°, terminal node 3), had 0.24 times the likelihood of having patellar tendinopathy (prevalence ratio of 0.24). In other words, they had a 76% less likelihood of having patellar tendinopathy. This finding is consistent with studies that have shown that athletes with adequate passive hip IR ROM (not too high or too low) and proper foot alignment have a decreased probability of exhibiting excessive lower-limb IR (and thus less patellar tendon loading) during weight-bearing tasks.[5,40]

Interestingly, athletes with lower passive hip IR ROM (less than or equal to 40.76°, intermediary node 1) but larger varus values of SFA (greater than 16.95°, intermediary node 4) had a 41% less likelihood of having patellar tendinopathy when they had greater values of hip ER torque (prevalence ratio of 0.59, terminal node 8). Although greater varus foot alignment may contribute to excessive pronation and excessive tibia IR,[40] the presence of adequate hip ER strength may help in controlling lower-limb IR, thereby mitigating the possible deleterious effects of this motion on the patellar tendon.[21,44]

The contribution of hip torque to the absence of patellar tendinopathy also was observed in terminal node 10. All athletes with greater values of passive hip IR ROM (greater than 44.46°, intermediary node 6), which is associated with low hip stiffness,[6] but greater values of hip abductor torque (greater than 1.57 Nm/kg, terminal node 10) were classified as not having patellar tendinopathy (n = 9; 100% did not have patellar tendinopathy). The authors speculate that the presence of adequate hip abductor strength could decrease patellar tendinopathy occurrence in athletes with high passive hip IR ROM.

Demonstrating the nonlinear and complex nature of factors associated with patellar tendinopathy, interactions among passive hip IR ROM, SFA, and hip torques also were associated with patellar tendinopathy presence, depending on their cutoff values. Athletes with lower passive hip IR ROM (less than or equal to 40.76°, intermediary node 1), larger varus SFA values (greater than 16.95°, intermediary node 4), and lower hip ER torque (less than or equal to 0.31 Nm/kg, terminal node 7) had a 55% increase in likelihood of having patellar tendinopathy (prevalence ratio of 1.55, terminal node 7). Lower levels of hip abductor torque (less than or equal to 1.57 Nm/kg, terminal node 9), in the presence of greater passive hip IR ROM (greater than 44.46°, intermediary node 6), also were related to patellar tendinopathy occurrence (prevalence ratio of 1.30, terminal node 9). This classification, however, did not achieve statistical significance with respect to prevalence ratio, and the interpretation that the interaction between low passive hip stiffness and hip abductor weakness may contribute to patellar tendinopathy occurrence should be made with caution.

The CART results indicated that individuals with passive hip IR ROM between 40.76° and 44.46° had a 238% increase in likelihood of developing patellar tendinopathy (prevalence ratio of 3.38, terminal node 5). As values of hip IR ROM over 40° may indicate low hip stiffness,[6] this result suggests that hip IR ROM values in this range may be enough to contribute to the occurrence of patellar tendinopathy, in the absence of other relevant risk or protective factors investigated in this study. However, it is important to note that, as a classification method, CART analysis may sometimes produce overly complex trees that do not generalize well from the analyzed sample (overfitting) and produce results that are difficult to interpret.[20] In addition, as the individuals in terminal node 5 had an important increase in the likelihood of having patellar tendinopathy, other factors not investigated in the present study may have contributed to the observed result. Although this result should be taken with caution, the contribution of low hip IR stiffness to patellar tendinopathy occurrence cannot be ignored.

These results should be interpreted with caution, as causal relationships cannot be established by the methods used (cross-sectional study). It is important to note that the prediction of this model be validated by an independent sample to verify the specificity and sensitivity of the model. That said, methodological issues should be considered when interpreting these results: (1) the cutoff points indicated are sample dependent, meaning that they may vary between populations and samples; and (2) prospective investigations need to be conducted to determine whether the physical impairments identified could be considered as a risk profile for patellar tendinopathy occurrence. In addition, it is necessary to investigate the contribution of movement impairments, apart from physical impairments, to patellar tendinopathy occurrence. A limitation of this study is that some of the participants were undergoing physical therapy at the time of testing, which might have affected the results. Moreover, factors such as trunk, quadriceps, and hamstrings strength and flexibility,[36,37,41] years of sport practice, and hours played,[2,17,43] although not the focus of the present study, should be investigated in the future.

The results of this study revealed nonlinear and complex interactions between predictors and the outcome variable and identified profiles related to patellar tendinopathy occurrence or absence. The contribution of one variable to the outcome (eg, passive hip IR ROM) depended on the presence of other variables (eg, SFA and hip torques). These results may help guide clinical practice, as clinicians might select interventions based on the individual profile established by the final CART nodes. For example, athletes with passive hip IR ROM under 40.76°, SFA above 16.95°, and hip ER torque under 0.31 Nm/kg have a greater chance of having patellar tendinopathy and, therefore, should undergo interventions focused on modifying these factors (eg, use of foot orthotics and hip ER strengthening). In addition, preventive programs could be planned based on achieving proper hip IR ROM (above 40.76°), adequate SFA alignment (under 16.95°), and high hip ER torque (above 0.31 Nm/kg), as athletes with this profile had increased likelihood of not having patellar tendinopathy.

CONCLUSION

FACTORS RELATED TO THE HIP JOINT and foot-ankle complex were associated with the presence or absence of patellar tendinopathy in volleyball and basketball athletes. The CART analysis produced a model that revealed interactions between passive hip IR ROM, SFA, hip ER torque, and hip abductor torque that should be considered when managing patellar tendinopathy–associated factors in athletes. ◉

KEY POINTS

FINDINGS: Impairments of the hip and foot/ankle were associated with the presence of patellar tendinopathy in volleyball and basketball athletes. Classification and regression tree analysis revealed that these factors interact to create a profile associated with patellar tendinopathy occurrence.

IMPLICATIONS: Clinicians may apply interventions or preventive programs based on the risk profile derived by the findings of this study. The interactions among factors are complex, and additional research is needed before the full implications of these results for clinical practice can be established.

CAUTION: The data of the present study were only collected during preseason evaluation in active athletes, some of whom were undergoing physical therapy, which might have affected these results. The results of this study are preliminary, and the classification and regression tree (CART) model should be independently validated in a larger sample.

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