COMBINATIONS OF CLINICAL TESTS PREDICT FRONTAL PLANE KNEE ANGLE AND MOMENT IN BILATERAL DROP JUMP

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This project investigates whether performance in clinical tests can predict frontal plane knee angle and moment during bilateral drop jumps. Fifty-one recreational male athletes were assessed during clinical tests [lunge, star excursion balance test (SEBT), lateral step down (LSD), hop tests, and knee and hip isometric strength] and biomechanical assessment (3D kinematics and kinetics of bilateral drop jump). Linear regression models determined the predictive capacity of clinical tests to predict biomechanical outcomes. SEBT, triple hop test, LSD and lunge predicted frontal plane knee angle and moment with predictive power from 26 to 45%. A combination of at least two clinical tests significantly improves prediction of frontal plane knee angle and moment during bilateral drop jump. LSD, triple hop test and SEBT provide prediction for frontal plane knee angle and moment.

KEYWORDS: anterior cruciate ligament injuries, knee, adult, sports medicine.

INTRODUCTION: Anterior cruciate ligament (ACL) tears are frequent in recreational and competitive sports activities. The early detection of risk factors is crucial to prevent this injury. From the potential ACL injury risk factors, the biomechanical risk factors are important because they are modifiable. The excessive frontal plane knee angle, poor trunk control, excessive quadriceps force, and neuromuscular leg asymmetries are associated with potential mechanisms for an ACL injury (Pappas et al., 2013). Evaluating these risk factors is expensive, time-consuming and requires complex laboratory tests, but clinical assessments are accessible to monitor athletes in the field (Webster & Hewett, 2019).
Clinical (field) and biomechanical (laboratory) outcomes are related (Logerstedt et al., 2010). However, it remains unclear which biomechanical parameters could be predicted by clinical tests applied in the sports environment to assess tasks related to ACL injury like the bilateral landing. Bilateral drop jump is the more frequent jump used during assessment of effectiveness of injury prevention protocols (Lopes et al., 2018) and is commonly used to predict ACL injury (Leppanen et al., 2017). Therefore, investigating bilateral drop jumps is crucial for identifying predictors of biomechanical deficits associated with ACL injury. Here we identify the capacity of clinical tests commonly employed in sports physiotherapy to predict frontal plane knee angle and moment in recreational male athletes performing bilateral drop jumps.

METHODS: Participants were a convenience sample of males between 18 and 30 years old, free of acute lower extremity injuries for at least the past six months, with no history of surgery or ligament/tendon ruptures in the lower extremity or any neurological or musculoskeletal condition that could impair jump performance. The local institutional ethics committee approved this study (protocol number: 96793518.3.0000.5323). All procedures complied with the declaration of Helsinki and were performed in one laboratory visit. The clinical and biomechanical assessments were performed in addition to the assessment of demographic data, leg preference to kick a ball, physical activity level (Tegner scale), knee function (Lysholm scale), and the Lower Extremity Functional Scale.
Clinical assessments included the Lunge test, the modified star excursion balance test (SEBT), lateral step down test (LSD), hop tests, knee and hip strength. The larger distance from the big toe to the wall was measured in Lunge test from at least three attempts (Bennell et al., 1998). Maximal reach distance from at least three attempts of anterior, posterolateral and posteromedial directions of SEBT and total score were measured (Stiffler et al., 2015). LSD consisted of a score obtained from assessing arm strategy, trunk and pelvic alignment, knee

position, and steady stance during stepping down five repetitive times (Jones et al., 2014). Single leg hop, triple leg hop, and crossover hop were assessed at least three times each one and maximal reach distance was considered for analysis (Peebles et al., 2019). Knee extensors and flexors (Hansen et al., 2015) and hip adductors and abductors' isometric strength were measured at least three times with a hand-held dynamometer, and the highest value was considered for analysis (Jackson et al., 2017). The order of SEBT directions, joint and leg to test strength were randomized. SEBT and hop test results were normalized to the participant's leg length, and asymmetry indexes (preferred leg/non-preferred leg*100) were determined. Strength values were normalized to the individual body mass. The outcomes of interest for strength were: flexors and extensors strength, flexors to extensors strength ratio, abductors and adductors strength, abductors to adductors strength ratio.

For the biomechanical assessment participants were standing upright on a 40 cm high rigid box wearing their own personal athletic shoes with arms crossed over chest. They were instructed to drop off and land on double support with one leg on each force plate (OR6-2000, AMTI Inc., USA, sampling data at 3 kHz) embedded at the level of the laboratory floor. After landing, they immediately jumped as high as possible, performing a countermovement and landed again with one foot on each force plate. The second landing was analyzed. Fifteen cameras (Bonita B10, VICON Motion Systems, Oxford, UK) sampled kinematic data at 200 Hz. The same researcher always placed twenty-one reference markers on participant's body according to the Plug-in Gait Full-Body model adapted. At least three successful trials were recorded and mean values were considered for analysis. Kinematic and kinetic data were low pass filtered by a 4th order zero-lag Butterworth filter with a cut-off frequency of 8 Hz. External joint moments were calculated with inverse dynamics equations of motion by Vicon Plug-In Gait Model (Nexus software, version 1.8.5) and normalized to individual body mass. Biomechanical outcomes are frontal plane knee angle and moment at the initial contact (IC, threshold of 20 N) and maximal knee flexion (MF), and peak of frontal plane knee angle and moment (KAM) from landing phase data.

We assessed the capacity of clinical tests to predict the frontal plane knee biomechanics in bilateral jump landing with linear regression analyses considering data from the preferred and non-preferred legs in a two-step process. The first step was selecting clinical outcomes by Pearson or Spearman correlation tests (according to data normality, Shapiro-Wilk test). Clinical outcomes showing association with biomechanical outcome at $p \leq 0.20$ were inserted in the regression model. The second step was stepwise multiple linear regression analyses performed for each biomechanical outcome. Assumptions of linear regression analysis were confirmed: independence of observations; linear relationship; data homoscedasticity; multicollinearity; and normality of residuals distribution. Outliers were identified and excluded when the standard residual was higher than 3, Cook's distance was higher than 1, or Mahalanobis distance was higher than 11. We selected those models with $r^2>0.2$, that is, those explaining >20% of the variance and potentially providing meaningful tools for clinicians and researchers. All tests were performed in SPSS (17.0 IBM Corp., Armonk, USA) considering a significance level of 0.05. The power and global effect size (f^2) of the final model were also computed. Effect size (f^2) interpretation was: small to ≥0.02, medium to ≥0.15, and large to ≥0.35 (Cohen, 1988).

RESULTS: Fifty-one individuals took part in this study with a mean (standard deviation; min-max) age of 24 years old (3; 18-30), body mass of 81 kg (13; 52-109), height of 177 cm (6; 162-192), Tegner physical activity level of 5 (2; 1-9), knee function in the Lysholm scale of 92 (8; 72-100), and Lower Extremity Functional Scale of 77 (3; 63-80). The right leg was preferred for 41 participants.

Frontal plane knee angle at IC was predicted by SEBT total score and triple hop test asymmetry for preferred leg (medium effect size, Figure 1A). The frontal plane knee moment at MF was predicted by triple hop test, LSD and lunge for preferred leg and by SEBT total score asymmetry and LSD for non-preferred leg (large effect sizes, Figure 1 – B, C). We did not find prediction models that explained >20% of the variance for peak values of frontal plane knee angles and moments.

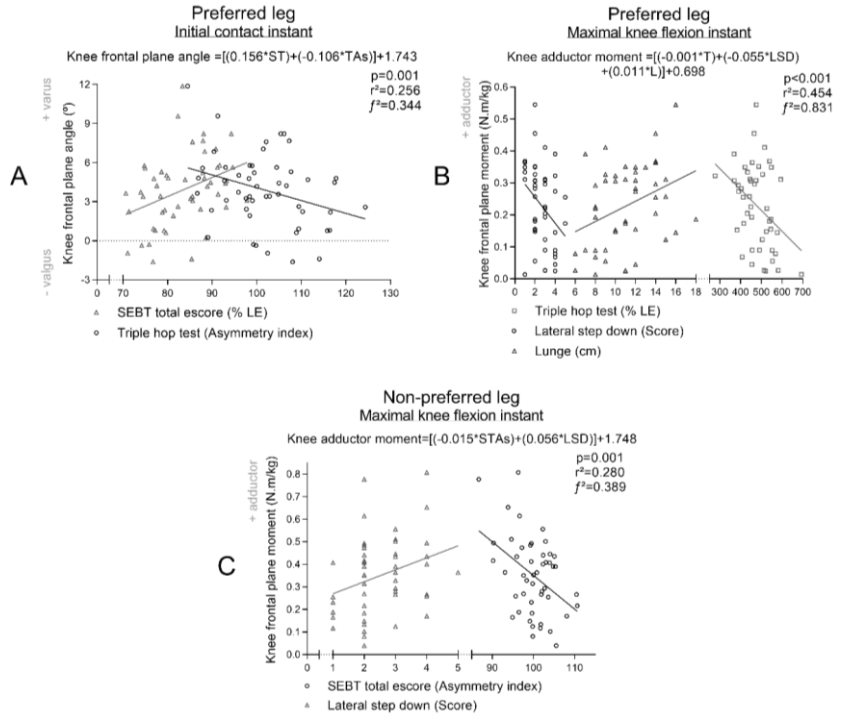

Figure 1: Frontal plane knee angles and moments predicted by clinical tests. ST: SEBT (star excursion balance test) total score; TAs: triple hop test asymmetry index; LE: Lower extremity; T: triple hop test; LSD: lateral step down; L: lunge; STAs: SEBT total score asymmetry index.

DISCUSSION: We found predictive models after combining at least two clinical tests explaining up to 45% of variance for frontal plane knee angles and moments. Clinical tests were not able to predict peak values of frontal plane knee angle and moment. Models need to be considered individually for each leg.

Frontal plane knee angle and moment are related to the ligament dominance theory, involving excessive loading at the knee ligaments, especially the ACL. The fact that SEBT, triple hop test, lunge and LSD predicted KAM is important due to the complexity of acquiring KAM data. The need for a good quality of movement involving multiarticular segments (trunk, thigh, leg, foot) may explain LSD predicting KAM. LSD was included in models for the preferred and non-preferred leg, most likely because it requires a complex control for the trunk, hip, and knee (Silva et al., 2019). LSD should be considered for estimation of knee biomechanics for both legs. A complete clinical evaluation would need to include the triple hop test and lunge for preferred leg, and SEBT for non-preferred leg.

Frontal plane knee angle is considered a high-risk factor for an ACL injury and an outcome to estimate ACL strain (Bates, Myer, et al., 2020). We found prediction only at IC and not for peak value. Frontal plane knee angle identified at IC can explain the mechanism of injury, which occurs within 50ms after IC (Bates, Schilaty, et al., 2020). Excessive frontal plane knee angle may originate from proximal or distal joints, which may explain the frontal plane knee angle being predicted by SEBT and triple hop test with moderate effect size. Triple hop test requires high hip abduction and hip extension torques and knee extension torques (Alvim et al., 2018). These biomechanical characteristics are associated with the injury mechanisms and help to explain the findings. Triple hop test and SEBT can estimate frontal plane knee angle at IC.

CONCLUSION: Clinical tests can predict frontal plane knee angle and moment at initial contact and maximal knee flexion during bilateral drop jump in recreational male athletes. A combination of at least two tests is needed to achieve good prediction models. Triple hop test, SEBT and LSD should be considered for screening assessments. Knee and hip strength seem not essential to predict frontal plane knee outcomes during bilateral landing. The choice of clinical tests should consider biomechanical outcomes of preferred or non-preferred leg separately and include a variety of landing tasks, including unilateral landings.

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