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Comparison of Two-dimensional Measurement Techniques for Predicting Knee Angle and Moment during a Drop Vertical Jump

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Abstract

Objective—To determine the association of two dimensional (2D) video-based techniques and three-dimensional (3D) motion analysis to assess potential knee injury risk factors during jump landing.

Design—Observational study

Setting—Research Laboratory

Participants—Thirty-six female athletes in cutting and pivoting sports.

Assessment—Athletes performed a drop vertical jump during which movement was recorded with a motion analysis system and a digital video camera positioned in the frontal plane.

Main Outcome Measures—The 2D variables were the frontal plane projection angle (FPPA), the angle formed between thigh and leg, and the knee:ankle separation ratio, the distance between knee joints divided by the distance between ankles. The 3D variables were knee abduction angle and external abduction moment. All variables were assessed at peak knee flexion. Linear regression assessed the relationship between the 2D and 3D variables. In addition, intraclass correlation coefficients determined rater reliability for the 2D variables and compared the 2D measurements made from digital video to the same measurements from the motion analysis.

Results—The knee:ankle separation ratio accounted for a higher variance of 3D knee abduction angle ($r^2=0.350$) and knee abduction moment ($r^2=0.394$) when compared to the FPPA ($r^2=0.145$, 0.254). The digital video measures had favorable rater reliability (ICC:0.89–0.94) and were comparable to the motion analysis system (ICC 0.92).

Conclusion—When compared to the FPPA, the knee:ankle separation ratio had better association with previously cited knee injury risk factors in female athletes. The 2D measures have adequate consistency and validity to merit further clinical consideration in jump landing assessments.

Key Terms

ACL injury prevention; assessment tools; female athletes

Introduction

Female athletes who participate in cutting, jumping and pivoting sports sustain anterior cruciate ligament (ACL) rupture at a rate 2–6 times higher than males participating in the same sports.^{1–4} One of the potential factors thought to predispose females to ACL injury is the presence of “dynamic knee valgus” during cutting and landing maneuvers.^{3, 5} Dynamic knee valgus is a movement pattern characterized by excessive knee abduction combined with femoral adduction and internal rotation and relative external tibial rotation.^{3, 5, 6} This movement pattern is prevalent in female athletes during a variety of functional tasks and is not as commonly observed in male athletes.^{7–9} Retrospective assessments and modeling of video taken at the time of ACL injury have found that a knee valgus posture was assumed by female athletes immediate to their injury.^{10–12} Further supporting this proposed mechanism of injury is that a higher knee abduction angle and external abduction moment during a jump-landing predicted female athletes who would later sustain an ACL injury.³ The growing body of evidence supporting knee valgus as a risk factor for ACL injury motivates the need to identify female athletes with this potentially dangerous movement pattern.

The current “gold standard” for identifying knee valgus is the measurement of knee abduction angle and external abduction moment using three-dimensional (3D) motion capture systems and force platforms. The most common testing task is a drop vertical jump. This testing protocol has been adopted from a single prospective study that identified large knee abduction angle and external knee abduction moment during a drop vertical jump as risk factors for future ACL injury.³ Most clinical and sport training settings can easily implement the drop vertical jump task, but they cannot afford expensive laboratory equipment and lack the technical knowledge to operate the equipment. In order to facilitate clinical screenings for the knee valgus movement pattern, it is necessary to develop cost-effective alternative measurements that do not require extensive training to complete.

Observational analysis is a low-cost method to screen for knee valgus that is not technically demanding. Two conceptual approaches have been used: 1) visually estimating the frontal plane knee angle^{10, 11, 13}; or 2) categorizing subjects based on whether knee valgus is demonstrated during dynamic movement.^{14, 15} The difference between evaluators in visually estimating frontal plane knee angle is reported to be 5–6°, which is reasonably good.¹⁰ However, when visual estimates of frontal plane knee position from video were compared to 3D values, confidence intervals for the mean error crossed zero and there was poor agreement whether the knee position was neutral, valgus, or varus (Kappa coefficient = 0.19).¹³ Agreement may be slightly better when knee valgus is categorized dichotomously (ie. present or not present) since Kappa coefficients for intra-rater agreement range from 0.75 to 0.85¹⁴ and inter-rater agreement range from 0.77 to 1.0.^{14–16} Despite better agreement, the rating categories do not delineate the amount of differences in 3D knee abduction angle.^{14–16} Thus, observational methods to screen for knee valgus may not produce consistent decision-making in regards to the need for intervention.

Another low-cost method to screen for knee valgus is assessing frontal plane knee position from digital video, producing a 2D measure that is more objective than visual observation. Two techniques are typically used: measuring frontal plane knee angle from the position of the thigh and leg segments,^{9, 17–19} which is also called the frontal plane projection angle (FPPA),¹⁷ or measuring the distance separating the knees with or without normalization by the distance separating the hips.^{20–22} An advantage of the FPPA technique is that it can be measured in one-legged or two-legged activities, while knee separation can only be measured in two-legged activities. However, digital video assessments that calculate the joint separation distance may be easier to compute than the FPPA because it requires less data points to determine the measure. Criterion validity of the FPPA technique, assessed by

comparing the FPPA to simultaneously captured 3D knee abduction angle, shows variation across activities with r^2 values ranging from 0.04 to 0.64 for a shuttle run, the side step, a side jump and vertical jumping.^{9, 18} Criterion validity of the knee separation technique, when the difference in knee separation at initial contact and peak knee flexion is calculated, shows a moderate correlation ($r = .40$) to peak knee abduction angle during a drop vertical jump.²² Convergent validity of the knee separation technique, calculated in the same manner during a drop jump, exhibits a high correlation ($r = .87$) between measurements made from video and 3D motion analysis software.²³ To the best of our knowledge intra-rater reliability has only been reported for the FPPA technique²⁴ and inter-rater reliability has not been reported for either technique.

Given the potential importance of clinical screenings for knee valgus and the small body of literature related to the efficacy of 2D video-based measurement techniques, the purpose of this study was to 1) determine the association of the FPPA and knee:ankle separation ratio with 3D knee abduction angle and external knee abduction moment, and 2) investigate the reliability of the FPPA and the knee:ankle separation ratio for one evaluator, and 3) compare the 2D measures made using digital video as opposed to the criterion standard of the motion analysis system. We chose to normalize the distance separating the knees by the distance separating the ankles because prior reports of the mechanism of injury for non-contact ACL tears is often when the foot is positioned lateral to the knee.¹⁰ We hypothesized that both 2D measurement techniques would be associated with 3D knee abduction angle and moment and that they would have acceptable reliability for a single evaluator. We further posited that the 2D assessments made with digital video would be closely related to the same measures taken from the motion analysis system. The results of this study will contribute to determining the efficacy of the FPPA and the knee:ankle separation ratio for assessing dynamic knee valgus and abduction moments.

Materials and Methods

Subjects

Thirty-six female Division I collegiate athletes participating in cutting and pivoting sports were recruited for this study during off-season team meetings. Potential subjects were excluded from participation if they had significant physical limitations, surgery in the lower extremities or back in the last six months and a history of significant lower extremity injury. The average age of the subjects was 19.6 ± 1.2 years, and the average BMI was 25 ± 2 kg/m². Subjects had an average of 10 ± 3 years of experience in their respective sports of soccer ($n=9$), basketball ($n=11$), tennis ($n=9$) and volleyball ($n=7$). Written informed consent was obtained from all subjects and the study was approved by the Institutional Review Board for Human Subjects Research at Eastern Washington University.

Testing Protocol

The drop vertical jump (DVJ) was performed by subjects as previously described.^{3, 25} Subjects stood with their feet shoulder width apart on a box (31 cm high), and were instructed to drop off the box, land with one foot on each force plate, immediately perform a maximum vertical jump by reaching their arms upward to simulate a basketball rebound, and land again with one foot on each force plate. Each subject was given three practice trials and then additional trials were performed until three successful trials, determined by adherence to the instructional set, were completed.

While subjects performed the DVJ, a seven camera motion analysis system (VICON 624c Datastation, Workstation Software 4.6, M2 cameras, Oxford Metrics, London, England) synchronized with two force plates (Kistler Instruments, Amherst, NY) collected three

dimensional video data and ground reaction forces, respectively. Reflective markers were first placed bilaterally over anatomical landmarks including the iliac crest, greater trochanter, medial and lateral femoral condyles, medial and lateral malleoli, the heads of the first and the fifth metatarsals. Two markers were placed on the heel counter of the shoe. In addition, rigid thermoplastic shells with four reflective markers at the corners were placed bilaterally on the lateral thighs and lateral shanks using elastic wraps (Superwrap; FabriFoam, Inc., Exton, PA). Another shell was affixed over the sacrum using Velcro sewn into elastic shorts worn by the athletes. A standing calibration was performed to determine the ankle and knee joint centers and define the ends of the body segments. The knee and ankle joint centers were determined by taking the bisection between the anatomical markers. The estimation of the position of the hip joint center was created as previously reported^{25–28}. First, a virtual marker was formed at the bisection of the greater trochanter markers. Then the hip joint was placed at the bisection of the newly-created virtual marker and the corresponding greater trochanter marker. During the drop vertical jump trials, only the markers on the thermoplastic shells and the shoes were left in place. In addition to the motion analysis system cameras, a digital video recorder (SonyR DVCam™) was placed on a tripod 3 m directly in front of the subjects at a height of 0.3 m.

Two Dimensional Data

Digital video recorded at 30 Hz was uploaded into WindowsR Movie Maker for conversion to still images, and the frame at the point of peak knee flexion during the initial landing phase was selected for analysis. Peak knee flexion was defined as the one frame before the point when the athlete started to increase knee extension to transition from their lowest body position during the landing phase to the vertical jump phase of the DVJ. Two dimensional measurements, the knee:ankle separation ratio and the FPPA, were made from the selected frame using ImageJ, a free, open access image processing program provided by the National Institute of Health (<http://rsb.info.nih.gov/ij/>). Measurements were made by 2 evaluators (JJT and RLM) on 2 occasions separated by 1 week.

The FPPA was computed only for the dominant leg, which was determined by asking subjects what foot they would use to kick a ball for distance. The right leg was the dominant leg for 35 of the 36 subjects. To measure the FPPA, the evaluator first created a femoral segment by placing a straight line that bisected the thigh outline, terminating at the evaluator's estimation of the bisection of the femoral epicondyles. The epicondyle estimation was made from available visual landmarks such as the outline of shadowing of the patella, muscular shape outline of the quadriceps, and the thickness of the leg's outline in the area of the knee joint. The shank segment began at the termination of the thigh segment and bisected the borders of the lower leg, terminating at the estimated position of the ankle malleoli. The ankle malleoli position was made from available visual landmarks such as shoe position, bony outlines or shadows of the bones of the leg, and the thickness of the leg outline in the area of the ankle joint. Both evaluators had prior experience and training in human anatomy, surface palpation of anatomical landmarks, and placing reflective markers for motion analysis data collections. At the time of the assessments, evaluator JJT was in professional graduate school and evaluator RLM had 9 years of post-graduate experience. No markers were used over bony landmarks to guide the measurements of the digital video. The angle formed by these two segments was then measured and used for analysis (Figure 1). A measurement of 0° represents a neutral position of the knee in the frontal plane; whereas negative values represent a valgus knee angle, and positive values represent a varus knee angle.

The knee:ankle separation ratio was determined by placing a horizontal line between the visual estimation of the knee joint centers and another horizontal line was drawn between the estimation of the ankle joint centers (Figure 2.) The length of each line in pixels was

measured and the ratio between the length of the knee line and the length of the ankle line was computed. A value of 1.0 represents alignment of the knees directly over the ankles. A value less than one occurred when the knee joint centers were more medially aligned than the ankle joint centers and thus represented dynamic knee valgus.

The knee:ankle separation ratio is a modification of the normalized knee and normalized ankle separation distances described by Noyes and colleagues.²⁰ In their calculation, the distances between the knee joint centers and ankle joint centers are divided by the distance between hip joints centers. Consequently, their normalized separation distances represents the alignment of the joints relative to the hip.²⁰ However, because the normalized knee separation distance does not account for the position of the feet, two people with the same hip and knee distances could have different amounts of dynamic knee valgus if one person has the feet closer together (knees over ankles) and the other person has the feet farther apart (ie. the knees are more medial to the ankles). The proposed normalization of knee separation to that of the foot/ankle position was theorized to be an improved approach to Noyes prior work.

Three Dimensional Data

Force plate data was sampled at 1500 Hz and three dimensional video data was sampled at 250 Hz. Marker trajectories were low pass filtered at 6 Hz and force plate data was low passed filtered at 50 Hz with a fourth order phase-corrected low pass Butterworth filters. Just as with the 2D digital video data, only the dominant leg was analyzed. Knee joint angles were calculated with Euler angles resolved in the first the sagittal and then frontal plane. Joint kinematics and kinetics were calculated with inverse dynamics using rigid body analysis with Visual 3D software (Visual 3D, Version 3.34, C-motion Inc., Rockville, MD). The peak knee flexion during landing was determined and used for analysis. The knee abduction moment was expressed in the local coordinate system of the thigh segment. The moment was normalized to bodyweight (BW).

The 3D data were also used to calculate the FPPA and the knee:ankle separation ratio at the point of peak knee flexion for comparison as a criterion standard for the measures taken from the digital video data. The FPPA was calculated using the vertical and horizontal position of the proximal (hip joint) and distal (knee joint) centers of the thigh segment and the center of the distal segment of the shank segment (ankle) take from the global, or laboratory's, coordinate system. The knee:ankle separation ratio was also calculated from the motion analysis by dividing the horizontal separation distances using the global coordinate system.

Statistical Analysis

Data were analyzed using SPSS for Windows, version 17.0 (SPSS Inc., Chicago, IL). One successful trial was randomly chosen for each athlete and the data from the digital video and motion analysis system for that same trial were used for analysis. Descriptive statistics were calculated for the FPPA and the knee:ankle separation ratio as taken from the still frames from the digital camera and the FPPA, the knee:ankle separation ratio, the frontal plane knee abduction angle and frontal plane knee abduction moment take from the motion analysis system. Linear regression analysis was performed with 2D variables entered as independent variables and 3D variables entered as dependent variables. Intra-rater and inter-rater reliability for knee-to-ankle separation ratio and FPPA measurements were computed with intraclass correlation coefficients (Models $_{3,1}$ and $_{2,1}$ respectively). The FPPA and the knee:ankle separation ratio measurements made from 2D and 3D systems were compared using ICC $_{(2,1)}$. The mean absolute errors between the 3D measure and the corresponding data from the 2D video-based measure were also calculated. Differences in the FPPA and

the knee:ankle separation ratio were assessed using an ANOVA with an F statistic. The alpha level for all statistical analyses was set at $p < 0.05$.

Results

Average values for 2D and 3D variables are shown in Table 1. The average FPPA was -7.6° and the average knee:ankle separation ratio was 0.76. Both 2D measures are in the direction of dynamic knee abduction. The average values of the FPPA and the knee:ankle separation ratio taken from the 3D motion analysis system are also reported in Table 1.

Significant associations were found between the 2D calculation of the FPPA and the knee:ankle separation ratio and the 3D variables of knee abduction and external knee abduction moment. The r^2 values were higher for the knee:ankle separation ratio than for the FPPA, and both digital video variables showed closer association with knee abduction moment than knee abduction angle (Table 2). The correlation coefficients for the digital video FPPA to motion analysis knee abduction were negative, indicating that a more valgus in the FPPA (negative values indicate valgus) was associated with a higher knee abduction angle and moment. Similarly, the correlation coefficients for the digital video knee:ankle separation ratio were negative, indicating that a smaller ratio was associated with a larger knee abduction angle and external knee abduction moment from the 3D system.

The FPPA as determined from the digital video or the motion analysis system were not statistically different ($F=1.458$, $p=0.237$). The consistency between the measures taken from the different systems was excellent with an ICC value of 0.918. The mean absolute error comparing the digital video to the motion analysis measures of FPPA was 3.3 ± 3.9 degrees.

The knee:ankle separation ratio was significantly different when taken from the digital video as compared to the motion analysis system ($F=9.005$, $p=0.005$), but the effect size of the difference was small (0.20). The ICC for the knee:ankle separation ratio when comparing the two systems was 0.939. The mean absolute error between the digital video and the motion analysis measures of the knee:ankle separation ratio was 0.045 ± 0.041 .

The ICC values for intra- and inter-rater reliability of the FPPA from the digital video were 0.95 and 0.89. The ICC values for intra- and inter-rater reliability of the knee:ankle separation ratio from digital video were 0.97 and 0.92, respectively. The ICC values between the three test trials for the motion analysis system have been reported previously²⁵ with 0.94 for knee abduction angle and 0.90 for external knee abduction moment. When using motion analysis to calculate a FPPA and a knee:ankle separation ratios, the ICC values were 0.84 and 0.85 respectively.

Discussion

The current study was undertaken to increase knowledge about video-based techniques for measuring dynamic knee valgus for potential use in clinical screenings. We studied the FPPA, which is a technique that has previously been reported in the literature^{9, 17–19}, and the knee:ankle separation ratio, which is our modification of a previously reported technique^{20, 22}. The criterion validity of these techniques, determined by univariate association with 3D knee abduction angle and external abduction moment, ranged from poor to moderate with the knee:ankle separation ratio showing higher association than the FPPA. Both techniques have acceptable clinical consistency within and between evaluators as well as in comparison to 3D measurements of the same variables. Our findings suggest that the knee:ankle separation ratio may be a more promising video analysis technique to develop for screening athletes for knee injury risk based on their drop jump landing performance.

A unique aspect of our study is that we investigated the association of the 2D knee valgus measurement techniques with both the 3D knee abduction angle and the knee abduction moment which have both identified as predictors of ACL injury status.³ In contrast, previous investigations of the FPPA^{9, 18} or the change in knee separation during a drop vertical jump²³ have been focused solely on the association with knee abduction angle. We were surprised to find that both the FPPA and the knee:ankle separation ratio had higher magnitudes of association with the motion analysis variable of knee abduction moment as opposed to the knee abduction angle. It is logical to assume that 2D knee valgus measures would have better association with the knee abduction angle than the moment because ground reaction forces, used to calculate moment, are not obtained in video analysis. It should be noted that the digital camera does collect data at a much slower rate than the motion analysis system. Perhaps the difference in the frame rates between the techniques has a more powerful effect on the kinematic results as compared to the kinetics.

The FPPA accounted for 35% of the variability of the knee abduction moment while the knee:ankle separation ratio accounted for 39.4%. These associations can be considered moderate to good²⁹. However, a large amount of variance was not explained by these variables, which agrees with recent findings that knee valgus motion along with knee flexion range of motion, body mass, tibia length and quadriceps to hamstrings strength ratio predicted knee abduction moment status.²³ Thus, 2D measures of knee valgus have the potential to be one of multiple independent predictors of 3D knee abduction moment. It is important to note that predicting a high knee abduction moment is not the same as directly predicting ACL injury risk.

The current study is part of a growing body of evidence to explore the association between video-based techniques for measuring knee valgus and 3D knee abduction angle. McLean and colleagues found that FPPA had the lowest association with the shuttle run ($r^2 = 0.04$) and the highest association with the side jump, ($r^2 = 0.64$)⁹, and Nagano et al found a moderate association between FPPA and knee abduction angle during a 5-repetition vertical jumping task ($r^2 = 0.34$).¹⁸ We studied the commonly utilized drop vertical jump task and obtained r^2 values of 0.145 for the FPPA and 0.254 for the knee:ankle separation ratio. The association between the FPPA and the knee abduction angle in our study ($r^2 = 0.145$) is on the low end of values reported by McLean et al⁹ and Nagano et al¹⁸, although neither study included the drop vertical jump task. Also, what appears to be knee valgus with the FPPA can be explained by a combination of transverse and frontal plane motions of the hip and knee.^{3, 5, 6, 15, 17} This phenomenon may explain while the knee:ankle separation ratio had a better association with knee abduction angle than the FPPA. It appears that both the functional task and specific 2D measurement technique used can influence the strength of the association observed with the 3D measure of knee abduction angle. Thus, the knee:ankle separation ratio may have different strength of association with other functional tasks (e.g. squat) besides the drop vertical jump.

It should be noted that other studies have measured FPPA without markers or tape. Despite the lack of skin markers to aid visualization in this study, ICC values for intra- and inter-rater reliability ranged from 0.89 to 0.97 for both 2D knee valgus measurement techniques. This level of reliability is adequate for use in clinical screenings.²⁹ Stensrud et al²⁴ reported an identical ICC value of 0.95 for intra-rater reliability of the FPPA technique, also measured from a drop vertical jump task, but with sports tape adhered to the anterior superior iliac spine and tibial tuberosity. Nagano and colleagues had skin markers and reported test-retest ICC of 0.73 for their 2D valgus measure.¹⁸ Boden et al³⁰ reported that the ICCs for intra-rater reliability of 4 different angle measurements made from digital video without markers-- including the FPPA--ranged from 0.32 to 0.99, but the ICC for the FPPA was not specified. From our perspective, the reliability results obtained without markers or

tape are encouraging since these visualization aids would add to the time burden in clinical settings and large-scale screenings.

There is much less literature with which to compare our consistency results for the knee:ankle separation ratio. The within-test trial reliability of 0.85 was slightly less than the within-test trial reliability for hip, knee, and ankle separation distances reported by Noyes et al (0.90) who used skin markers. Therefore, this study contributes novel results on intra- and inter-rater reliability for the knee:ankle separation ratio.

The mean values for the FPPA and the knee:ankle separation ratio in this investigation are comparable to results obtained in other studies. Stensrud et al²⁴ reported an average FPPA of 9° and 7° valgus for the right and left legs, respectively, in female athletes performing a drop vertical jump, and we obtained a value of 7.6° valgus. Hughes et al⁸ measured inter-knee and inter-ankle distance during landing from a volleyball spike using 3D coordinates. Although the investigators did not report a knee:ankle separation ratio, the values reported for their knee and ankle separation distances would create a ratio of 0.76, which is identical to the 0.76 ratio obtained in our study. The values for knee and ankle separation of female athletes in the study by Noyes et al would create a knee:ankle separation ratio of 0.66, which is lower than our ratio, but is not surprising given the age difference and potential difference in ability level between the subjects in our two studies (Noyes 14.1 ± 1.7 years, current study = 19.6 ± 1.2 years).²⁰ As more reports emerge using these types of measures, it will be possible to determine normative values to aid in future clinical interpretation of test results.

It was encouraging to see the close approximation of the FPPA and the knee:ankle separation ratio using the digital video in relation to the more sophisticated motion analysis system. The digital video technique for the FPPA used in the current study had a mean absolute difference of 3.3° compared to the FPPA using the motion capture data. Whereas, the error for observation analysis has been reported to be considerably worse (i.e. inter-rater error of 5–6°).¹⁰ We acknowledge that making video-based measurements does require the extra time and resources to record and process the digital video data that is not necessary when using simple observational analysis. However, current observational analysis methods have not shown a comparable ability to distinguish subjects with high knee abduction angle as recorded from 3D analysis.

The current study does have limitations, which need to be considered when interpreting the findings. The primary limitation of this study is that it is descriptive, and the results cannot directly be used in determining ACL injury risk. For example, this study does not confirm that these measurements are able to identify female athletes with high risk of ACL injury nor provide threshold values. Large, prospective studies that apply video analysis techniques and track ACL injuries are needed to fill this knowledge gap.³¹ Also, the reliability results in this study are for a single evaluator. It is unknown if similar reliability results would be obtained by different raters. Another limitation of this study is that the associations between 2D and 3D variables are univariate. It is unknown if the associations would be maintained in a multivariate regression model. Finally, we only made the FPPA measurements for the dominant leg. While this was appropriate for the objectives of this study, we recommend that future research assess both legs because an asymmetry in knee abduction angle between sides was found to be a predictor of ACL injury status.³ Despite these limitations, this study helps fill knowledge gaps related to the FPPA in the current literature and reports a new 2D assessment technique of the knee:ankle separation ratio for estimating an athlete's dynamic knee valgus.

In conclusion, the two video-based techniques for assessing dynamic knee valgus in this study have potential to be used as an acceptable proxy for expensive multi-camera motion

analysis systems. Both techniques showed an association to known ACL injury risk factors and had acceptable levels of reliability, which merit their inclusion in future research. We specifically recommend that these measures be included in prospective epidemiological research because it is the only study design that will reveal variables associated with ACL injury risk.

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Comparison of Two-dimensional Measurement Techniques for Predicting Knee Angle and Moment during a Drop Vertical Jump Landing

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Figure 1.
Measurement of the frontal plane projection angle (FPPA) from the 2D digital video file.

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Figure 2.
Measurement of the knee-to-ankle ratio from the 2D digital video file. .

Table 1

Descriptive data for 2D and 3D variables.

	2D Measures		3D Measures	
	Mean	SD	Mean	SD
Frontal Plane Projection Angle (°)*	-7.6	11.5	-6.5	14.0
Knee-to-Ankle Ratio	0.76	0.15	0.73	0.12
Knee Abduction Angle in Reference to the Thigh (°)*			3.6	6.1
External Abduction Knee Moment (N*m/kg of BW)			0.31	0.30

SD = standard deviation.

BW = body weight

N = Newtons

m = meters

Table 2

The association between the primary 2D and 3D variables during the drop vertical jump.

		2D Frontal Plane Projection Angle	2D Knee-to-Ankle Ratio
Knee Abduction Angle	r	−0.381 ($p < 0.022$)	−0.504 $p < 0.002$
	r ²	0.145	0.254
Knee Abduction Moment *	r	−0.591 ($p < 0.001$)	−0.628 ($p < 0.001$)
	r ²	0.350	0.394

* External moment taken in the local coordinate system using the motion analysis system