Using a Mobile Application to Assess Knee Valgus in Healthy and Post-Anterior Cruciate Ligament Reconstruction Participants

Kai-Yu Ho, Brenda Benson Deaver, Tyrel Nelson, and Catherine Turner

Context: Popularity of using handheld devices in clinical settings has increased, especially the use of motion analysis applications (MAAs). Video-based measurement tools have been found reliable in measuring knee valgus in subjects without anterior cruciate ligament (ACL) injury. However, there is a need for validation of using a MAA to measure knee valgus in an injured population, given that they may exhibit higher degrees of knee valgus. **Objective:** To examine the reliability and validity of using a MAA to measure knee valgus during functional activities used to assess return to sport after ACL reconstruction (ACLR). **Design:** Reliability and validity study. **Setting:** University laboratory. **Participants:** Twelve participants with ACLR and 20 healthy individuals. **Interventions:** Each subject performed single-leg drop landing, single-leg hop, and 90° cut with simultaneous 3-dimensional (3D) motion capture and video recording on an iPad. **Main Outcome Measures:** Peak knee valgus during the landing phase was measured using a MAA and 3D analysis. To obtain reliability, peak knee valgus was measured on 2 separate days. Reliability was determined using intraclass correlation coefficients and standard errors of measurement. Validity was assessed using Pearson correlation coefficients by comparing peak knee valgus between the MAA and 3D analysis. The *t* tests were used to compare knee valgus obtained between raters, within raters, and between the MAA and 3D analysis. **Results:** Our data revealed excellent intrarater and interrater reliability with low standard errors of measurement of using a MAA for both groups. Significant, moderate to large associations were found in comparing peak knee valgus between the MAA and 3D analysis. However, knee valgus was significantly different between the MAA and 3D analysis across all tasks in both groups. **Conclusion:** Although a MAA is reliable for measuring peak knee valgus in individuals with ACLR and healthy controls, the actual values obtained by a MAA should be viewed with caution.

Keywords: reliability, validity, movement analysis application

Single-leg landing, single-leg hopping, and cutting tests have been widely used in evaluating knee function after anterior cruciate ligament reconstruction (ACLR).^{1,2} It has also been found that females with ACLR showed greater knee valgus,² thereby predisposing them to increased risk of ACL reinjuries. Due to the kinematic deviations following ACLR, it is critical to identify those deficits in clinical practice. Three-dimensional (3D) motion analysis is considered most accurate for evaluating kinematics during dynamic movements; however, it requires expensive equipment, designated space, and extensive training. Two-dimensional (2D) video analysis is more readily available, inexpensive, and is a reliable measure of dynamic knee valgus during various functional tasks.^{3–6} In addition, the existing literature reveals moderate to excellent agreement between the 3D and 2D methods.^{3–5,7–9} However, these comparisons have all been done in individuals without ACL injury/surgery. In addition, although the popularity of motion analysis application (MAA) has increased due to the cheaper cost and easy accessibility of handheld devices, only 1 study was tested with the use of a tablet device⁸ that typically has a lower camera sampling frequency than other computer-based 2D motion analysis.

As individuals with ACLR may exhibit more knee valgus² and there is limited data regarding the reliability/validity of using MAA to measure knee movement, it is necessary for validation of using a MAA to measure knee valgus in individuals with ACLR. Therefore, the purpose of this study was to examine the reliability and

validity of a MAA to measure knee valgus during 3 functional activities (ie, single-leg drop landing, single-leg hop, and 90° cut) in both healthy and ACLR populations.

Methods

Participants

Twelve participants with ACLR (2 males and 10 females; 24.5 [7.2] y, 164.2 [11.2] cm, 67.9 [8.2] kg) and 20 controls without ACLR (13 males and 7 females; 25.2 [2.8] y; 175.1 [7.5] cm, 72.9 [10.4] kg) participated in this study. All subjects in the ACLR group had a noncontact, unilateral ACL injury with a surgical repair within the past 1 to 5 years (average 2.4 [1.4] y).

Instrumentations

A 10-camera motion analysis system (Vicon; Oxford Metrics Ltd, Oxford, UK) was used to capture lower-extremity kinematic data at 250 Hz. For 2D analysis, video recordings of the 3 tests were captured on an iPad Air 2 tablet (Apple Inc., Cupertino, CA, USA) at 30 frames per second. The iPad was mounted on a tripod to capture frontal plane kinematics at a fixed distance of 359 cm from the landing zone and 35 cm from the floor.

Procedures

Prior to the study, subjects were given informed consent approved by the institutional review board of University of Nevada, Las Vegas. All subjects performed functional testing with simultaneous

The authors are with the Department of Physical Therapy, University of Nevada, Las Vegas, Las Vegas, NV, USA. Ho (kaiyu.ho@unlv.edu) is corresponding author.

3D motion capture and video recording on an iPad. Reflective markers were applied by the same investigator to the lower-extremity landmarks of the participants to obtain the lower-extremity kinematics using the definition described by Stearns and Pollard.² Each subject performed 3 functional tests in the order: single-leg drop landing, single-leg hop, and a 90° cut bilaterally. During the single-leg drop landing task, participants stood on the contralateral leg, stepped forward off a 30-cm box with the test leg, and then landed at least 30 cm from the box. Single-leg hop was performed with the subject being instructed to hop as far as possible. During the 90° cut, participants approached the marked cutting point at the maximum speed they could confidently perform the task, beginning at 7 m behind the cutting point.

Data Processing

The peak knee valgus during the landing phase was obtained for each task using the 3D motion analysis and a MAA. The landing phase began at initial contact of the landing leg and ended at maximal knee flexion. If knee valgus was not observed, the minimum varus angle was obtained.

For 3D motion analysis, the reflective markers were labeled and digitized using Vicon Nexus software (Oxford Metrics Ltd), and peak knee valgus was analyzed using Visual 3D software (C-Motion, Rockville, MD).² For 2D analysis, recorded videos were uploaded to Simi Move MAA (Simi Reality Motion Systems, Unterschleißheim, Germany) without further video filtering. Knee valgus was determined using the frontal plane projection angle formed by a line along the midline of the thigh to the center of the patella and a line from the center of the patella to a point bisecting the malleoli (Figure 1).^{4,7,8} The investigator visually determined the time point of peak knee valgus for measurements.

To establish intrarater reliability, one investigator analyzed the videos on 2 separate days with at least 7 days apart. Interrater reliability was determined by comparing the measurement of the investigator to that of the other investigator.

Statistical Analysis

Values from both legs were combined for each task during analysis. Interrater and intrarater reliability were analyzed using intraclass correlation coefficients ($ICC_{3,k}$) and standard error of measurement (SEM). ICC values were classified according to the following criteria⁵: poor (<.4), fair (.4–.7), good (.7–.9), and excellent (>.9). The validity was determined by comparing 2D and 3D measurements of knee valgus using a Pearson correlation coefficient. Correlation was defined as small (.1–.3), moderate (.3–.5), large (.5–.7), very large (.7–.9), and extremely large (>.9).¹⁰ In addition, independent *t* tests were used to compare knee valgus measured between 2D and 3D methods and between the 2 raters. Paired *t* tests were used to compare the knee valgus obtained by the same rater between days. A significance level was set at .05.

Results

Our data demonstrated excellent intrarater reliability with low SEM when using a MAA to measure knee valgus in all tasks in both groups (Table 1). The interrater reliability was also excellent in all tasks for both groups (Table 1). For validity, Pearson correlation coefficients were moderate to largely correlated and significant across all tasks for healthy controls ($r = .46$ –.57; $P \leq .003$) (Figures 2A–2C) and individuals with ACLR ($r = .52$ –.66;

Figure 1 — Measurement of peak knee valgus angle during the landing phase using Simi Move motion analysis application during (A) single-leg drop landing, (B) single-leg hop, and (C) 90° cut.

$P \leq .004$) (Figures 2D–2F). In addition, peak knee valgus obtained by the MAA was significantly greater than that obtained by 3D analysis across all tasks in both groups ($P < .001$; Table 1). No differences were found between raters and within the rater for using a MAA to quantify knee valgus ($P > .05$).

Discussion

Our data demonstrated excellent interrater and intrarater reliability for measuring knee valgus during functional activities using a MAA. However, the agreement between a 3D motion analysis system and a MAA was moderate to large and there were differences in knee valgus between the 2 methods. This indicated that the actual values obtained by a MAA may not be accurate.

The excellent intrarater and interrater reliability found in this study was similar to that reported in other studies using healthy populations.^{4,5,9} The interrater reliability of the existing literature ranged from moderate to excellent, with King and Belyea⁸ reported .45 to .99 during a drop jump task, whereas Herrington and Munro⁷ reported .97 to 1.0 in a single-leg landing and Mizner et al⁹ reported .89 during a drop vertical jump. In terms of intrarater reliability, Herrington and Munro⁷ reported .58 to .96 in a single-leg landing, whereas Mizner et al⁹ reported .95 during drop vertical jump and Maykut et al⁴ reported .96 to .98 during running. Based on the

Table 1 Repeatability (Interrater and Intrarater Reliability) of Knee Valgus Angles Measured on a MAA and the Comparisons of Knee Valgus Angle Obtained Between/Within Raters and Between MAA and 3D Methods for the Control and ACLR Groups

	Control					ACLR				
	Intrarater		Interrater			Intrarater		Interrater		
<i>Single-leg drop landing</i>	<i>ICC</i>	<i>SEM, deg</i>	<i>ICC</i>	<i>SEM, deg</i>		<i>ICC</i>	<i>SEM, deg</i>	<i>ICC</i>	<i>SEM, deg</i>	
Reliability	.98	1.09	.94	2		.99	0.6	.98	0.85	
	Day 1	Day 2	Rater 1	Rater 2	3D	Day 1	Day 2	Rater 1	Rater 2	3D
Knee valgus, deg	5.5 (8.4)	5.2 (7.3)	5.2 (7.3)	6.3 (8.3)	-0.1 (2.9)*	5.3 (6.3)	6.0 (6.5)	5.2 (6.0)	7.1 (6.4)	1.2 (3.5)*
<i>Single-leg hop</i>	<i>ICC</i>	<i>SEM, deg</i>	<i>ICC</i>	<i>SEM, deg</i>		<i>ICC</i>	<i>SEM, deg</i>	<i>ICC</i>	<i>SEM, deg</i>	
Reliability	.98	1.26	.97	1.64		.98	1.26	.97	1.64	
	Day 1	Day 2	Rater 1	Rater 2	3D	Day 1	Day 2	Rater 1	Rater 2	3D
Knee valgus, deg	7.9 (8.8)	6.8 (9.1)	7.3 (8.8)	8.5 (9.0)	0.1 (4.1)*	7.4 (7.4)	8.1 (7.6)	7.4 (7.2)	8.2 (7.5)	2.0 (4.0)*
<i>90° cut</i>	<i>ICC</i>	<i>SEM, deg</i>	<i>ICC</i>	<i>SEM, deg</i>		<i>ICC</i>	<i>SEM, deg</i>	<i>ICC</i>	<i>SEM, deg</i>	
Reliability	.97	2.44	.97	2.25		.97	2.44	.97	2.25	
	Day 1	Day 2	Rater 1	Rater 2	3D	Day 1	Day 2	Rater 1	Rater 2	3D
Knee valgus, deg	12.6 (14.1)	13.0 (13.8)	12.8 (13.9)	15.4 (13.8)	7.6 (4.8)*	17.4 (10.8)	18.1 (10.5)	17.3 (10.5)	19.7 (11.5)	8.0 (5.2)*

Abbreviations: 3D, 3-dimensional motion analysis; ACLR, anterior cruciate ligament reconstruction; ICC, intraclass correlation coefficients; MAA, motion analysis application; SEM, standard error of measurement.

*A statistically significant difference from the knee valgus angle obtained by the MAA using a *t* test ($P < .001$); no statistically significant differences were found in knee valgus angle obtained between raters and within the rater using a *t* test ($P > .05$).

Figure 2 — The correlations between peak knee valgus angles measured by a MAA and those measured by 3D motion analysis of healthy controls during (A) single-leg drop landing, (B) single-leg hop, (C) 90° cut and individuals with ACLR during (D) single-leg drop landing, (E) single-leg hop, and (F) 90° cut. 3D indicates 3-dimensional; MAA, motion analysis application.

excellent reliability of this study and its similarity to other studies that employed health controls, it can be concluded that peak knee valgus during dynamic activities can be measured reliably using a MAA for both healthy and ACLR populations.

Our study revealed a moderate to large correlation between the measurement obtained by a MAA and 3D motion analysis across single-leg drop landing, single-leg hop, and 90° cut. The correlation values in our study (.46–.66) are deemed comparable to or slightly lower than those in the existing literature. Maykut et al⁴ found a correlation of .54 for knee valgus when comparing 2D to 3D motion analyses during running, whereas other researchers reported a correlation in single-leg landing and squatting tasks ranging from .72 to .79.^{3,6,7} As knee valgus obtained from a MAA is simply a projection angle of the result of hip adduction, hip and knee rotation, knee flexion, and knee abduction, it is thought that the differences in knee valgus measured between 2D and 3D measurements are due to the inability to account for hip/knee joint rotation and knee flexion with 2D analysis.⁴ In addition, our sampling rate is limited to 30 Hz due to hardware restriction, whereas Gwynne and Curran³ used a sampling rate of 40 Hz and Sorenson et al⁶ used a sampling rate of 240 Hz. Another contributing factor leading to variability in validity data was the presence or absence of markers for bony landmark identification. Particularly, Gwynne and Curran³ and Munro et al⁵ used markers for identifying corresponding bony landmarks when making 2D measurements, which could effectively improve reliability and validity. Nevertheless, our study provides evidence regarding the validity of 2D motion analysis without the usage of additional markers, which is a common approach in clinical settings.

In conclusion, a MAA is reliable for measuring peak knee valgus in individuals with ACLR and healthy controls. However, given that the agreement between the MAA and 3D analysis was just moderate to large and there were differences in knee valgus between the 2 methods, the actual values obtained by a MAA should be viewed with caution.

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