Journal of Sport Rehabilitation, 2018, e-pub only
https://doi.org/10.1123/jsr.2018-0002

Human Kinetics
TECHNICAL REPORT 49

Assessment of Knee Kinetic Symmetry Using Force Plate Technology

Aaron Nelson, Nathan Koslakiewicz, and Thomas Gus Almonroeder

Context: Athletes who have undergone an anterior cruciate ligament reconstruction often demonstrate more pronounced interlimb knee kinetic symmetry in comparison with uninjured athletes, even after they have completed rehabilitation. Part of the reason for the persistent asymmetry may be that sports medicine professionals are typically not able to assess knee joint kinetics within the clinic setting. Developing measures to assess knee joint kinetic symmetry could help to augment current rehabilitation practices. ***Objective:*** The purpose of this study was to explore the extent to which interlimb vertical ground reaction force (GRF) symmetry can predict knee kinetic symmetry during a drop landing task. ***Design:*** Cross-sectional study. ***Setting:*** Motion analysis laboratory. ***Participants:*** A total of 21 uninjured subjects (9 males and 12 females). ***Protocol:*** Three-dimensional kinematic data were collected using a multicamera system while subjects performed double-leg drop landings. GRF data were collected synchronously using 2 adjacent force plates. ***Main Outcome Measures:*** Knee joint moments and power were calculated for both limbs during the landing trials. An interlimb symmetry index (dominant/nondominant limb) was calculated for both the peak knee joint moment and power variables, as well as for the peak vertical GRFs. Linear regression analyses were performed to determine if the degree of symmetry in the peak vertical GRFs predicted the degree of symmetry for the kinetic variables. ***Results:*** The symmetry index for the vertical GRFs was a significant predictor of the symmetry indices for the knee joint moments ($r = .81$; $P < .001$) and power ($r = .88$; $P < .001$). ***Conclusion:*** Interlimb symmetry in the peak vertical GRFs can be used to predict knee joint kinetic symmetry during a double-leg drop landing task.

Keywords: biomechanics, rehabilitation, sports

Surgical reconstruction is recommended for athletes following an anterior cruciate ligament (ACL) injury.[1] Unfortunately, nearly 25% of young athletes who return to sports following an ACL reconstruction suffer a second ACL injury during their career.[2] Interestingly, in many instances, the second injury involves the previously uninjured knee. It appears that there is an urgent need to improve rehabilitation following ACL reconstruction.

Athletes who have undergone an ACL reconstruction often demonstrate greater interlimb knee joint kinetic (ie, joint moments and power) asymmetry during landing in comparison with uninjured athletes.[3,4] The typical pattern of asymmetry is for the uninjured knee to experience greater loading compared to the knee that underwent the ACL reconstruction. Persistent asymmetry in knee kinetics may place the athletes at risk for a second ACL injury. In fact, Paterno et al[5] found that athletes who sustain a second ACL injury demonstrated greater knee kinetic asymmetry during landing in comparison with athletes who were able to return to sport without injury. It appears that a key rehabilitation goal may be to limit interlimb knee kinetic asymmetry before an athlete is cleared to return to sport.

Sports medicine professionals are typically not able to analyze knee kinetics within the clinic setting. This presents a challenge, as it may be difficult to address residual deficits that cannot be readily assessed. The primary barrier is that 3-dimensional (3D) motion capture is limited as a clinical tool because of the time and expertise required for data collection or processing. The development of surrogate measures to assess knee kinetic symmetry may help to improve rehabilitation.

Nelson and Koslakiewicz are with the Department of Kinesiology, University of Wisconsin-Milwaukee, Milwaukee, WI, USA. Almonroeder is with Physical Therapy Program, Rinker-Ross School of Health Sciences, Trine University, Fort Wayne, IN, USA. Almonroeder (almonroedert@trine.edu) is corresponding author.

Analysis of ground reaction force (GRF) symmetry using force plate technology could potentially be used to indirectly assess knee kinetic symmetry.[6] Force plate technology does not require the same degree of time or expertise compared with 3D motion capture. This would allow sports medicine professionals to objectively evaluate patient progress throughout rehabilitation. They could also provide athletes with feedback regarding their GRF symmetry as training. The purpose of this study was to explore whether GRF symmetry is a significant predictor of knee kinetic symmetry during landing.

Methods

A total of 21 uninjured subjects (9 males and 12 females) participated in this study. Subjects were required to be 18–35 years old and to indicate that they engage in regular physical activity (Tegner and Lysholm[7] score greater than 4/10). Individuals with a previous lower-extremity surgery or a lower-extremity injury in the past 6 months were excluded. Individuals without a history of injury were included in this preliminary analysis because it was intended to serve as a pilot study. An a priori sample size estimate indicated that 19 subjects would be sufficient to achieve statistical significance for a correlation coefficient of .6 using an $\alpha = .05$ and a $\beta = 0.20$. A correlation of this strength was anticipated based on results reported by Dai et al.[6] G*Power software (Version 3.1, University of Dusseldorf, Dusseldorf, Germany)[8] was used for sample size estimation. The study was approved by the institutional review board at University of Wisconsin–Milwaukee.

Subjects were given footwear to use during the warm-up/testing session (Saucony Jazz, Lexington, MA). The warm-up involved jogging on a treadmill at a self-selected pace for

5 minutes. Next, retroreflective calibration markers were placed bilaterally on the anterior–superior iliac spines, posterior–superior iliac spines, greater trochanters, medial/lateral femoral epicondyles, medial/lateral malleoli, and the first and fifth metatarsal heads. In addition, marker clusters (ie, 4 markers attached to a rigid shell) were applied bilaterally to the thigh and shank to track these segments during the movement trials. Marker clusters were also applied to the heel counter of each shoe to track the foot. A standing calibration trial was conducted with all markers in place. The 3D positions of the markers were recorded at 200 Hz with a 10-camera system (Motion Analysis Inc, Santa Rosa, CA). Calibration markers were removed following the standing trial with the exception of the markers on the anterior–superior and posterior–superior iliac spines, which tracked pelvis motion during the movement trials.

Following the standing calibration trial, subjects performed double-leg drop landings from a 31-cm high box onto 2 adjacent force plates (40 × 60 cm dimensions) that recorded GRFs at 1000 Hz (FP4060-NC; Bertec Corp, Columbus, OH). The top layer of the force plates was the same color as the surrounding platform to minimize visual targeting. The box was positioned 15.24 cm behind the front edge of the force plates. Each subject performed 6 drop landing trials (3 practice trials and 3 recorded trials). Subjects were not given instruction regarding where to position their feet during the landings.

The marker and force data were filtered using a fourth-order, zero-lag, recursive Butterworth filter with a cutoff frequency of 20 Hz. Right-handed Cartesian local coordinate systems defined the position and orientation of the thighs, legs, feet, and pelvis. The midpoint between the medial/lateral femoral epicondyles and the medial/lateral malleoli was used to estimate the knee and ankle joint centers, respectively. A previously described regression approach was used to estimate the hip joint center.[9] Net joint moments were calculated via inverse dynamics, which incorporates segment kinematics, GRF data, and body segment parameters.[10] Moments were resolved into the local coordinate system of the distal segment and expressed as "internal" moments. Knee joint power was calculated by multiplying the net joint moments and joint angular velocity. Negative power values indicate that the joint is absorbing energy eccentrically. For each limb, the initial 100 ms after foot contact was analyzed. Initial foot contact was defined as the time when the vertical GRF first exceeded 20 N. Visual3D software (C-Motion Inc, Rockville, MD) was used for data processing.

For each trial, the peak vertical GRFs (maximum value), peak knee extension moments (maximum value), and peak knee sagittal plane power (minimum value) were identified for each limb. A symmetry index was calculated for each trial by dividing the values of the dominant limb by the nondominant limb. The dominant limb was considered the leg that subjects reported they would use to kick a ball. A symmetry index greater than 1.0 indicated greater loading for the dominant limb and a symmetry index less than 1.0 indicated greater loading for the nondominant limb. The subject's 3 trial mean was calculated for each of the symmetry index values. Linear regression analyses were performed, where the outcome variables were the knee moment symmetry index and the knee power symmetry index and the predictor variable was the vertical GRF symmetry index. An alpha of .05 was used to test statistical significance. The strength of the relationship between the predictor and outcome variables was assessed based on the correlation coefficient (r) using the following criteria: $r = .10$ to .29, weak relationship; $r = .30$ to .49, moderate relationship; and $r > .50$, strong relationship. SPSS software (version 22.0; IBM Corp, Armonk, NY) was used for statistical analysis.

Results

The mean (SD) of age, height, and mass of the subjects were 22.7 (3.8) years, 1.7 (0.1) m, and 69.2 (13.1) kg, respectively. The vertical GRF symmetry index was a significant predictor of the knee moment symmetry index ($r = .81$; $P < .001$; Figure 1) and the knee power symmetry index ($r = .88$; $P < .001$; Figure 1). The coefficient of determination (R^2) indicated that 65.6% of the variance in the knee moment symmetry index and 77.4% of the variance in the knee power symmetry index was explained by the vertical GRF symmetry index.

Discussion

Our findings indicate that interlimb GRF symmetry is a significant/strong predictor of knee kinetic symmetry during landing. As a result, we believe that force plate technology could potentially serve as a useful surrogate measure to assess knee kinetic symmetry during rehabilitation.

Dai et al[6] also reported that GRF symmetry predicted knee extension moment symmetry during a land-and-jump task. Their study included individuals who had previously undergone an ACL reconstruction and the subjects were required to sprint forward before performing the land-and-jump task. This type of sprint

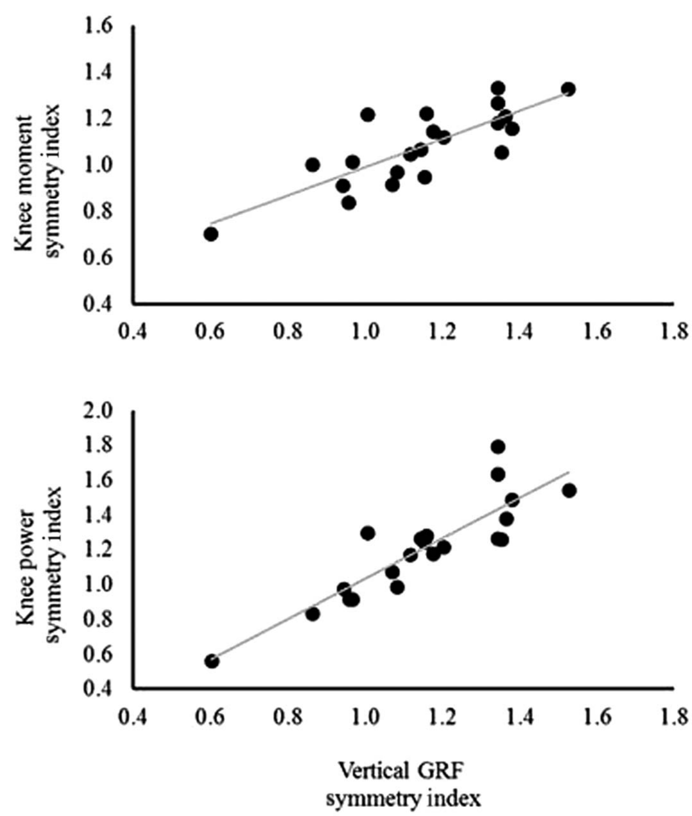

Figure 1 — Scatterplots for the peak vertical GRF symmetry index and the peak knee extension moment symmetry index (top panel) and the peak knee power symmetry index (bottom panel). GRF indicates ground reaction force.

and cut task could not be performed until the late stages of rehabilitation, as athletes transition back to sports. Hence, we intended to supplement these earlier findings by utilizing a task (double-leg drop landing) that could be performed earlier during rehabilitation, potentially allowing sports medicine professionals additional time to intervene. We also chose to analyze a drop landing task because it may be ideally suited for clinical assessment and feedback training, as it requires limited space and is relatively easy to replicate (compared with a maneuver incorporating a sprint approach). We also wanted to supplement the work conducted by Dai et al[6] by exploring the relationship between GRF symmetry and knee power symmetry, as analysis of joint power provides insight into energy absorption during landing.[4]

A significant limitation of this study is that subjects did not have a history of ACL reconstruction, which limits our ability to generalize to this population. In addition, a relatively small sample was included. Our analysis was intended to serve as a pilot study to support future work; however, we believe these preliminary findings merit attention. Finally, future studies should be conducted to establish the typical degree of symmetry in uninjured athletes.

Acknowledgments

The authors of this paper do not have any conflicts of interest to report. This project was not supported by grant funding. Each of the authors listed has met the criteria for authorship.

References

1. Carey JL, Shea KG. AAOS clinical practice guideline: management of anterior cruciate ligament injuries: evidence-based guideline. *J Am Acad Orthop Surg*. 2015;23(5):e6–e8. PubMed ID: 25795770 doi:10.5435/JAAOS-D-15-00095
2. Wiggins AJ, Grandhi RK, Schneider DK, Stanfield D, Webster KE, Myer GD. Risk of secondary injury in younger athletes after anterior cruciate ligament reconstruction: a systematic review and meta-analysis. *Am J Sports Med*. 2016;44(7):1861–1876. PubMed ID: 26772611 doi:10.1177/0363546515621554
3. Gokeler A, Hof AL, Arnold MP, Dijkstra PU, Postema K, Otten E. Abnormal landing strategies after ACL reconstruction. *Scand J Med Sci Sports*. 2010;20(1):e12–e19. PubMed ID: 19210671 doi:10.1111/j.1600-0838.2008.00873.x
4. Orishimo KF, Kremenic IJ, Mullaney MJ, McHugh MP, Nicholas SJ. Adaptations in single-leg hop biomechanics following anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2010;18(11):1587–1593. PubMed ID: 20549185 doi:10.1007/s00167-010-1185-2
5. Paterno MV, Schmitt LC, Ford KR, et al. Biomechanical measures during landing and postural stability predict second anterior cruciate ligament injury after anterior cruciate ligament reconstruction and return to sport. *Am J Sports Med*. 2010;38(10):1968–1978. PubMed ID: 20702858 doi:10.1177/0363546510376053
6. Dai B, Butler RJ, Garrett WE, Queen RM. Using ground reaction force to predict knee kinetic asymmetry following anterior cruciate ligament reconstruction. *Scand J Med Sci Sports*. 2014;24(6):974–981. PubMed ID: 24118495 doi:10.1111/sms.12118
7. Tegner Y, Lysholm J. Rating systems in the evaluation of knee ligament injuries. *Clin Orthop Relat Res*. 1985;(198):43–49. PubMed ID: 4028566
8. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods*. 2009;41(4):1149–1160. PubMed ID: 19897823 doi:10.3758/BRM.41.4.1149
9. Bell AL, Pedersen DR, Brand RA. Prediction of hip joint center location from external landmarks. *Hum Mov Sci*. 1989;8:3–16. doi:10.1016/0167-9457(89)90020-1
10. Dempster WT. *Space Requirements of the Seated Operator: Geometrical, Kinematic, and Mechanical Aspects of the Body with Special Reference to the Limbs*. WADC Technical Report. 1955:55–159.