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Comparison of six different marker sets to analyze knee kinematics and kinetics during landings

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Abstract: In motion analysis marker sets or protocols are mostly developed for gait analysis and it has been shown that the marker set used affects the results of gait analysis. These marker sets are also used for the analysis of high dynamic sports movements. Single-leg landings are a common tool to investigate functional knee stability and further to predict injury risks where frontal plane motion and loading seem to play an important role. Until now, it is unknown how the marker sets affect the motion analysis results of such high dynamic movements. Therefore, the aim of the study was to compare six different marker sets. Three-dimensional motion and force data of single-leg landings in 12 healthy subjects were collected. Six different marker sets consisting of up to 26 markers and two clusters were simultaneously attached to the subjects' lower limb and pelvis. The results show that particularly, the knee joint angles in the frontal and transverse plane showed the greatest differences between marker sets with in part contrary joint angle directions and great differences in angle magnitude. In addition, the amount of joint load was dependent on the marker set used for analysis. These results show that one must be careful when interpreting and comparing data of the frontal or transverse plane during high dynamic movements.

Keywords: frontal and transverse plane; knee angle and moment; motion analysis; protocols.

Introduction

Sport injuries often occur during landing. For example, nearly 80% of cruciate ligament (cl) injuries originate

during non-contact situations [1]. For this reason, the instability of the knee during landing is a frequently mentioned risk factor for cl injuries. Especially knee valgus and knee abduction moment seem to play an important role in cl injuries [2]. Further, this information is used to design orthopedic devices or physiotherapy interventions. To receive information about knee stability, the kinematics and kinetics during landing are often analyzed. Therefore, motion capture systems and different marker sets are used. The marker sets differ in the definition of anatomical coordinate systems of the specific segment and in the location or position of tracking markers. In case of gait analysis, it has been shown that the choice of marker set plays an important role when analyzing the joint kinematics and the net torques in the knee joint with inverse dynamical calculations [3]. This influence might be even higher for high dynamic sports motions where a lot of soft tissue motion occurs. Therefore, the aim of this study was to investigate the influence of six different commonly marker sets used mostly for gait analysis on the knee kinematics and joint moments during single-leg landings.

Methods

Twelve healthy subjects (six male; six female; age 25.9 ± 2.4 years; mass 68.8 ± 8.0 kg; height 1.8 ± 0.1 m) participated in this study. Subjects wore tight fitting shorts and identical shoes (Samba, Adidas, Germany) to reduce possible variability in cushioning.

Six different common marker sets (Plug in Gait® (PiG) [4], rigid marker set with clusters (RMS) and without using clusters (RMS_oC) [5], six degree of freedom (6DOF) [6], Helen Hayes (HH) [6], functional approach (FAPA) [7]) were used. Therefore, 26 markers and two clusters were simultaneously attached to the subjects' lower limb and pelvis. For each subject 10 jumps from a 0.40 m high box into one legged stance (dominant leg) were analyzed in a time window between 250 ms before and 500 ms after initial ground contact ($t=0$). Initial ground contact was defined when the raw vertical ground reaction force reaches 10 N.

A motion capture system (15 Oqus cameras, Qualisys, Gothenborg, Sweden) collected marker trajectories at a sampling rate of 400 Hz and a force plate (Kistler 9287C, Winterthur, Switzerland) measured ground reaction forces at 800 Hz. As recommended for high impact movements [8], marker trajectories and force data were low pass filtered with the same filter frequency (Butterworth, 15 Hz, 2nd order). All models were implemented in Visual3D® according to their description in literature. The knee joint angles and joint moments for each marker set were calculated in Visual3D® and normalized in relation to a static trial. Joint angles were calculated using the YXZ

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Cardan rotation sequences, where Y represents flexion/extension, X adduction/abduction (varus/valgus) and Z internal/external rotation. Joint moments were calculated using inverse dynamics and normalized to body mass. External joint moments were presented and referenced to the proximal segment. Positive values describe extension, abduction, and external rotation moments. Due to differences in segment definition the joint moments could not be calculated in Visual3D® for the FAPA approach.

Mean curve of the 10 trials per subject was calculated, and from that, mean knee angle and moment curves were built over the 12 subjects.

Results

For the knee angle in sagittal plane only minor differences between the marker sets can be observed (see Figure 1A). In contrast, the knee angles in the transverse and frontal plane show partly contradictory results when using different marker sets (see Figures 1B, C). In the frontal plane, for two marker sets an adduction movement is found after initial ground contact, while in contrast, when using two other marker sets mostly abduction movement is measured after landing. The highest differences occur immediately after initial ground contact and are smallest directly prior to landing. Furthermore, in addition to the curves running in opposite directions, the range of motion also differs. Especially, the results of PiG show unphysiological range of motion. In the transverse plane, large differences were found in the maximum extent of rotation. The use of clusters instead of single markers seems to increase the measured rotation. In the frontal as well as the transverse plane oscillation occur after initial ground contact.

Differences between the six marker sets used can also be determined for the estimated joint moments (see Figure 2). In contrast to joint angles the direction of joint load does not differ between the marker sets especially in the frontal plane. However, the difference is most noticeable in the amplitude of the joint moments.

Interestingly, the results of HH and PiG differ most from the other three marker sets. This difference is once again smallest in the sagittal plane. In this case lower joint loads are measured with the use of these two marker sets. On the other hand, the measured joint loads in the frontal and transverse plane are almost twice as high for the two marker sets compared to the other three.

Discussion and conclusion

The current results show differences especially in the frontal and transverse plane. These results are in common with the results of comparing different marker sets during

Figure 1: Mean curves of knee angle excursion for the three joint motions. Time point zero shows the time of initial ground contact; 6DOF = 6 degree of freedom; FAPA = functional approach; HH = Helen Hayes; PiG = Plug in Gait; RMS = rigid marker set, RMS_oC = rigid marker set without cluster.

gait analysis. For gait analysis, the greatest differences were also found in the out-of-sagittal plane motions. It was

Figure 2: Mean curves of knee moment excursion for the three joint loads. Time point zero shows the time of initial ground contact; 6DOF = 6 degree of freedom; HH = Helen Hayes; PiG = Plug in Gait; RMS = rigid marker set, RMS_oC = rigid marker set without cluster.

hypothesized that the differences are more associated with different definitions of the axis of rotation rather than differences in marker placement [3]. There were also great differences in anatomical coordinate system definition between the investigated marker sets in the current study. This might explain the high variations in joint angle.

In the frontal plane no typical knee movement can be observed. A cadaver study showed knee abduction and internal rotation during simulated landing [9], which corresponds to the knee angle measured by two of the marker sets (RMS and RMS_oC). In contrast, two other marker sets (PiG and HH) show an adduction angle after initial ground contact. This difference may have an influence in the case of patient care. Depending on which marker set is used, contradictory movement is identified and accordingly, e.g. the orthopedic assistive devices like foot orthoses or other interventions are designed differently. In the field of proof of efficacy, it must be ensured that the method used is able to determine the knee position and knee load with sufficient accuracy to obtain valid evidence about the effect of treatment. As knee valgus, is one main risk factor for cl injuries, study methods must ensure that especially the motion and loading in the frontal plane are measured correctly.

In contrast to the results of gait analysis where joint moments were less affected by the used marker set [3], the current results show large differences in knee joint moments in all three planes. These results show that in high dynamic movements the ground reaction forces do not play a predominant role in joint loading, but that the segment accelerations and angular accelerations as well play an important part in joint loading. Therefore, the segment movement must be measured with sufficient accuracy. For this purpose, the artifacts caused by skin movements must be kept as low as possible for high dynamic movements. For this purpose, tracking markers should preferably be attached to areas where skin movement artefacts are as small as possible [10].

In conclusion, the results show that the marker set used has a large effect on the results of motion analysis concerning knee kinematics and kinetics. Up to now, joint movements and loads could not be measured with sufficient validity. Therefore, caution is required when interpreting and comparing data. Methods must be developed that measure joint movement and especially joint loads with sufficient validity.

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References

1. Krosshaug T, Nakamae A, Boden BP, Engebretsen L, Smith G, Slauterbeck JR, et al. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *Am J Sports Med* 2007;35:359–67.
2. Hewett TE, Myer GD, Ford KR, Heidt RS, Colosimo AJ, McLean SG, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med* 2005; 33:492–501.
3. Ferrari A, Benedetti MG, Pavan E, Frigo C, Bettinelli D, Rabuffetti M, et al. Quantitative comparison of five current protocols in gait analysis. *Gait Posture* 2008;28:207–16.
4. Vicon. Plug-in Gait reference guide [Internet] [cited 2020 Jan 10]. Available from: <https://docs.vicon.com/display/Nexus26/PDF+downloads+for+Vicon+Nexus?preview=/42696722/42697399/Plug-in%20Gait%20Reference%20Guide.pdf>.
5. Fukaya T, Mutsuzaki H, Ida H, Wadano Y. Two different protocols for knee joint motion analyses in the stance phase of gait: correlation of the rigid marker set and the point cluster technique. *Rehabil Res Pract* 2012;2012. Article ID 586348. <https://doi.org/10.1155/2012/586348>.
6. Collins TD, Ghoussayni SN, Ewins DJ, Kent JA. A six degrees-of-freedom marker set for gait analysis: repeatability and comparison with a modified Helen Hayes set. *Gait Posture* 2009; 30:173–80.
7. Krauss I, List R, Janssen P, Grau S, Horstmann T, Stacoff A. Comparison of distinctive gait variables using two different biomechanical models for knee joint kinematics in subjects with knee osteoarthritis and healthy controls. *Clin Biomech* 2012;27: 281–6.
8. Kristianslund E, Krosshaug T, van den Bogert AJ. Effect of low pass filtering on joint moments from inverse dynamics: implications for injury prevention. *J Biomech* 2012;45:666–71.
9. Kiapour AM, Quatman CE, Goel VK, Wordeman SC, Hewett TE, Demetropoulos CK. Timing sequence of multi-planar knee kinematics revealed by physiologic cadaveric simulation of landing: implications for ACL injury mechanism. *Clin Biomech* 2014;29:75–82.
10. Monnet T, Thouzé A, Pain MTG, Begon M. Assessment of reproducibility of thigh marker ranking during walking and landing tasks. *Med Eng Phys* 2012;34:1200–8.