Standing Pelvic Tilt Is Associated With Dynamic Pelvic Tilt During Running When Measured by 3-Dimensional Motion Capture

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Standing pelvic tilt (PT) is related to biomechanics linked with increased risk of injury such as dynamic knee valgus. However, there is limited evidence on how standing PT relates to dynamic PT and whether the palpation meter (PALM), a tool to measure standing PT, is valid against 3-dimensional (3D) motion analysis. The purposes of this study were to (1) determine the criterion validity of the PALM for measuring standing PT and (2) identify the relationship between standing PT and dynamic PT during running. Participants (n = 25; 10 males and 15 females) had their standing PT measured by the PALM and 3D motion analysis. Dynamic PT variables were defined at initial contact and toe off. No relationship between the 2 tools was found. Significant large positive relationships between standing PT and PT at initial contact (r = .751, N = 25, P < .001) and PT at toe off (r = .761, N = 25, P < .001) were found. Since no relationship was found between standing PT measured by the PALM and 3D motion analysis, the PALM is not a valid alternative to 3D motion analysis. Clinicians may be able to measure standing PT and gain valuable information on dynamic PT, allowing clinicians to quickly assess whether further biomechanical testing is needed.

Keywords: criterion validity, PALM, movement analysis, gait

Musculoskeletal injuries during running have been found to occur in up to 79% of runners and are associated with high medical costs.1 Musculoskeletal injuries can occur from a multitude of factors; therefore, researchers have begun to use a multifactorial approach to investigate factors that could be influencing injury.2 Static lower-extremity alignment (LEA) is one factor that has been connected to lower-extremity injury and biomechanics related to injury such as dynamic valgus.2–15 The kinematic chain theory describes how the static alignment of each segment and coupling between segments interact to influence the movement of the entire chain, supporting the idea of a relationship existing between LEA and movement.16,17 Deviations from normative LEA at the ankle, knee, and hip have been associated with increased rates of lower-extremity injury.3,5,15,18 As well as biomechanics rates to injuries such as greater hip internal and external rotation excursion, knee valgus collapse during drop landing, and increased maximum plantar pressure during running.7,9,11,19

Of the various LEA factors that have been examined, static and dynamic pelvic tilt (PT) position may be an important factor for clinicians to consider.20–22 Standing PT describes the angle of the pelvis in the sagittal plane during standing and is defined as either anterior or posterior PT. Studies have retrospectively connected greater anterior standing PT to ACL injury23,24 and to dynamic valgus in drop landing tasks.9 A value for increased or excessive anterior standing PT has not been established; however, during standing, the average runner will have approximately 7° of anterior standing PT.25 The pelvis stays in anterior PT during running and will typically range from approximately 10° to 15° (Figure 1) with the extremes occurring around the beginning and end of stance.26,27 Increased anterior PT during running has been exhibited as a compensatory movement for limited hip extension in terminal stance and is thought to allow for an increase in stride length typically displayed by rearfoot strike runners.27–30 Increased anterior PT at terminal swing right before initial contact has been connected to hamstring injuries in many athletic populations and has been attributed to poor lumbo-pelvic control.30–33 Although there is information about PT during running and its relationship to injury, there is limited information of how standing PT is related to pelvic motion during running, which we operationally define as dynamic PT. Even though standing PT has been connected to movements related to injury, PT was not included in a recent meta-analysis investigating LEA and running injury.34 Although standing PT and dynamic PT both are connected to potentially injurious biomechanics, the relationship between standing and dynamic PT has not been investigated. Further investigation between standing PT and dynamic PT is necessary to potentially gain a better understanding as to why we are seeing potentially injurious biomechanics with increased anterior standing PT. Determining whether standing PT is indicative of dynamic PT would help clinicians be informed about how the pelvis moves during running by measuring the simple standing PT. This would save clinicians time and expense for lengthy 3-dimensional (3D) gait analysis.

Although measuring LEAs can provide insights into biomechanics related to injury risk, the tools that clinicians use must be found to be reliable and valid. 3D motion analysis has been identified as the “gold standard” for measuring standing posture and dynamic motion during many tasks.35–37 Although 3D motion analysis is a precise tool for capturing dynamic data, it is expensive, requires training to use, and is time consuming to collect, making it difficult to use in a clinical setting. The current method that the majority of clinicians use to measure standing PT is the palpation meter (Performance Attainment Associates [PALM]) which is an inclinometer caliper combination tool with palpation tips (Figure 2).38 The palpation tips are placed on the anterior superior iliac spine and...
the posterior superior iliac spine of one side of the pelvis, and the inclinometer measures pelvic angle relative to horizontal (Figure 3). The PALM has high intertester and intratester reliability of .89 and .98, respectively, and has been used in many studies to measure standing PT.2,9,25,38,39 However, to our knowledge no studies have reported the criterion validity of the PALM against the gold standard 3D motion analysis. Therefore, using 3D motion analysis to evaluate the criterion validity of the PALM is needed to further confirm the appropriateness of the use of this measurement tool in clinical settings and whether it can accurately identify standing PT.

Therefore, the purposes of our study were to: (1) determine the criterion validity of the PALM for measuring standing PT and (2) identify the relationship between standing PT and dynamic PT during running. We hypothesize that the PALM measures of standing PT will be valid against 3D measures of standing PT and that there will be positive relationships between standing PT and dynamic PT during running.

**Methods**

**Design and Setting**

A cross-sectional design was used in a laboratory setting.

**Participants**

Twenty-five healthy, physically active individuals (10 males; 15 females; age 26.6 [8.1] y; height: 1.70 [0.1] m; mass: 69.86 [12.4] kg) volunteered for our study. A web-based questionnaire that prompted for inclusion and exclusion criteria was sent out to the potential participants. Inclusion criteria included the following: rear foot strike pattern, being physically active (engaging in physical activity, which frequently included running, at least 3 times per week for at least 30 min), and being between the ages of 18 and 45 years. Individuals were excluded from the study if they had midfoot or forefoot running patterns, current or previous injury to the lower extremity within the last 6 weeks resulting in >3 days of time loss, a major surgery in the lower extremity, or were currently pregnant.

**Procedure**

If the individuals appeared to meet the study criteria, the primary investigator (PI) a virtual video meeting to confirm and complete the informed consent process. Once consent was obtained, they completed the Godin Physical Activity Questionnaire and a modified running and injury history questionnaire, which asked questions about the participants running habits, any running form modifications, training information, and injury history. Rearfoot strike pattern was confirmed on the day of data collection by the PI observing the participant running on a treadmill to confirm whether the heel contacted the ground first.41 Rearfoot strike pattern was further confirmed using the guidelines recommended by Altman and Davis,42 defined by having dorsiflexion of >8° at initial contact.

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and/or a visible impact peak following initial contact identified with vertical ground reaction force (vGRF) graphs. Ensuring that all participants have a rearfoot strike pattern controls for differences in biomechanics that occur with varying foot strike patterns.43 Participants reported to the University of Wisconsin-Milwaukee Biomechanics laboratory on the day of data collection and changed into tight-fitting clothing and were provided with standardized laboratory shoes (Saucony Jazz). Standardized laboratory shoes were provided to control for variability in running biomechanics between subjects caused by differences in footwear within the participant population.26 All the data were collected by a single researcher who was a PhD student with 3 years of experience in 3D kinematic and kinetic data. Static variables were collected first and included body height (in meters), body mass (in kilograms), and standing PT. The PALM was used to measure standing PT (PALM-PT) as the angle formed by a line from the anterior superior iliac spine to posterior superior iliac spine, relative to the horizontal plane of the dominant side, which was defined by asking the participant “which leg would you kick a ball with.”

The 3D kinematic data were collected using a 10 camera Motion Analysis Eagle System (Motion Analysis Corp). Reflective markers were placed on anatomical landmarks and rigid plates with marker clusters were placed on the lateral thighs, lateral shanks, and calcaneus bilaterally, and the standing calibration trial was completed (Figure 3). After calibration, all the reflective markers were removed except for the anterior superior iliac spine, posterior superior iliac spine, and the thigh, shank, and heel tracking cluster markers. To define running gait events, vGRF data were collected at 1000 Hz by an embedded force plate within the runway (model OR-6-1; AMTI Inc). Each participant was familiarized with the overground running task and equipment by practicing running over the force plate to ensure their foot lands on the center of the plate. Once participants consistently hit the force plate while running, data were collected from 5 successful running trials. A trial was considered successful if the participant’s foot landed close to the center of the force plate and no major gait compensations occurred (shortening or lengthening their stride to hit the force plate). Participants chose a preferred speed during their practice trials that fell within the speed range of 4.0 (0.5) m/s.44 The participants’ preferred speed was then applied during the running task and was monitored by SimpliFaster timing gaits (model Freelap Pro BT112, SimpliFaster). Implementing the speed range minimizes the variability in biomechanics that can occur with different running speeds.44

Data Reduction and Analysis

3D tracked data were exported from Cortex and processed using Visual3D software (C-Motion Inc). Kinematic data were filtered using a fourth-order, zero-lag, recursive Butterworth filter with a cutoff frequency of 12 Hz, and the kinetic data with a cutoff frequency of 50 Hz.44,45 Kinematic data were normalized to 100% of stance with initial contact identified as first frame of vGRF >20 N, and toe off was identified as the instance vGRF drops back below 20 N.46 PT angles were calculated using a joint coordinate

Figure 3 — The marker set used to capture the 3-dimensional motion analysis data.
system approach. All pelvic angles were defined as the angle of the pelvis segment in the sagittal plane relative to horizontal. 3D-PT was derived from the standing trial of the 3D data. Dynamic PT variables were taken at initial contact and toe off. Initial contact was chosen since increased load placed on the joints at initial contact is related to running-related musculoskeletal injuries. All pelvic angles were defined as the angle of the pelvis segment in the sagittal plane relative to horizontal. 3D-PT was derived from the standing trial of the 3D data. Dynamic PT variables were taken at initial contact and toe off. Initial contact was chosen since increased load placed on the joints at initial contact is related to running-related musculoskeletal injuries. Additional, hamstring injuries associated with greater anterior PT typically occur right before initial contact in terminal swing. We chose toe off as our second time point because we know that increased anterior PT may be seen as a compensation for decreased terminal hip extension. In addition, PT angles at initial contact and toe off were extracted from each participant and averaged across all 5 trials; then, the mean and standard deviation were calculated across participants.

Statistical Analysis

All statistical analyses were conducted using SPSS statistical package (version 27). Prior to analysis, Levene test of equal variances and a Shapiro–Wilk test were conducted to test for normality of the data. The Levene test was insignificant, and although the 3D-PT variable was significant within the Shapiro–Wilk test, after examining the histograms and the quantile-quantile (Q-Q) plot, it was determined that the data were approximately normal. A priori test was conducted to determine whether sex differences were present in the sample to inform whether sex would need to be controlled for in analysis; since no sex differences were identified in any of the PT variables, sex was not included in the analysis.

To test the criterion validity of the PALM-PT compared with 3D-PT, a bivariate Pearson correlation, intraclass correlation coefficient (ICC), and a Bland-Altman plot with the associated 95% limits of agreement analysis were performed. The COSMIN checklist (COnsensus-based Standards for the selection of health status Measurement INstruments) recommends that correlations are the best means to identify whether a tool is valid when compared with the gold standard. ICCs have been used previously to compare the reliability and precision of 2 instruments. Bland–Altman analysis is also typically used to examine agreement between tools in a clinical setting. Two Pearson correlations were performed to determine the relationships between PALM-PT and 3D-PT at initial contact and PALM-PT and 3D-PT at toe off. The correlations were interpreted using the following scale: very strong correlation (>.90), strong correlation (.70–.90), moderate correlation (.50–.70), weak correlation (.30–.50), and negligible correlation (0–.30). The ICC was interpreted using the following scale: excellent reliability (>0.90), good reliability (.75–.90), moderate reliability (.50–.75), and poor reliability (<.50). Statistical significance was set a priori at 0.05.

Results

We found weak and not statistically significant Pearson correlations between the PALM-PT and 3D-PT measurements (r = .256, N = 25, P = .216). We found poor reliability between tools (ICC = .311). The mean difference between PALM-PT and 3D-PT was 2.46 which is relatively close to 0, and all but one data point fell between the 95% limits of agreement. However, the limits of agreement found between PALM-PT and 3D-PT difference were large (upper limit: 18.042; lower limit: −13.122). A wider range of differences in measurements between the 2 instruments can be interpreted as there being less agreement between the tools (Figure 4). The results indicated significant high positive correlations between 3D-PT and PT at toe off (r = .761, N = 25, P < .001) and 3D-PT and PT at initial contact (r = .751, N = 25, P < .001).

Discussion

To our knowledge, our study is the first study that tested the validity of the PALM against 3D motion analysis. We found a negligible relationship between the PALM and 3D motion analysis and a wide

![Figure 4](Bland-Altman limits of agreement between PALM and 3D motion analysis)

Bland–Altman limits of agreement between PALM and 3D motion analysis. The difference and mean of PT between tools are expressed in degrees of pelvic tilt. 3D indicates 3-dimensional; PT, pelvic tilt.
range of limits of agreement indicating that the PALM is not a valid alternative for 3D motion analysis for measuring PT. In addition, the reliability estimates between tools were poor. Figure 4 shows the Bland–Altman plot which presents the difference between PT measured by each tool (y-axis) and the mean PT across both tools (x-axis). Ideally, the plot should show a smaller range which is indicative of better agreement between the 2 tools. Figure 4 shows a wide range of limits of agreement, and we can interpret this as poor agreement. However, the mean difference between the 2 tools was relatively close to 0, indicating some level of agreement exists between the tools. Overall, the results from the Pearson correlation coefficient, ICC, and the Bland–Altman analysis do not support the PALM as a valid alternative to 3D motion analysis.

Some potential reasons why the PALM may have low agreement with 3D motion analysis are due to its design. Figure 2 shows that the PALM has rounded caliper arms attached at a fixed point, which makes it difficult to adequately measure individuals with larger bodies since the angle of the caliper arms becomes very large and shallow. An improvement to the caliper arms of allowing the caliper arms to extend width wise to account for more body shapes. In addition, adding a vertical inclinometer to ensure the PALM is being at held horizontal would decrease error that comes from tilting the PALM. We acknowledge that 3D motion analysis may not be accessible clinically and that the PALM may be the only tool available. The PALM has been found to be reliable over time and across practitioners, so it can still be useful in measuring change over time in clinical settings; however, the values should be interpreted with caution because of lack of criterion validity and poor agreement to the gold standard. To our knowledge, there are no normative data for standing PT that has been collected by a valid instrument like the 3D motion analysis. Future research should focus on identifying normative values for standing PT with valid instruments and focus on addressing the design issues with the PALM.

We found statistically significant positive relationships between standing and dynamic PT. To our knowledge, standing PT has never been connected to dynamic PT in any task. Standing PT has been found to influence biomechanics in both jump landing and in single-leg squats. Greater anterior standing PT has been connected to greater knee valgus in jump landing tasks when compared with those with neutral standing PT. Although previous research has indicated that standing PT plays a role in movement, there have been no explanations as to why we are seeing changes to biomechanics with increased anterior standing PT. Our study may explain one potential reason we are seeing changes in biomechanics with increased anterior standing PT since we now know that there is a relationship between standing PT and dynamic PT. Increased anterior standing PT is translated into increased anterior PT during running and is one potential factor in biomechanics that is related to injury. One potential reason that dynamic PT could be related in biomechanics that are related to injury could be due to poor lumbopelvic control. Although running has been thought to be a series of single-leg landings, poor lumbopelvic control could make this relationship applicable across other tasks, which may explain why we are seeing increased anterior standing PT and injury in a wide range of sport (ie, baseball Gaelic sports and soccer). Poor lumbopelvic control could also explain why we are seeing anterior standing PT in individuals who show dynamic knee valgus during a double-leg drop landing task. Interestingly, a study investigating LEA in single-leg squats found that less anterior standing PT predicted more injurious biomechanics such as greater hip internal rotation excursion and knee external rotation excursion. Potential reasons less anterior PT was observed could be that the methods involved keeping the participants in a more upright position which may decrease the movement in the lumbopelvic segment. In addition, since this task is more controlled and less dynamic like running or jump landing tasks, this may allow for more lumbopelvic control. Further research investigating why PT both in standing and in motion influences biomechanics across tasks. In addition future research should include measurement of dynamic PT during various tasks to investigate PTs’ influence over LEA and how that will influence movement.

One limitation of our study was that the sample size was small and relatively skewed toward younger individuals who were in college. Changes with age (eg, as fluctuations in body shape, muscle mass, and strength) could influence biomechanics, and therefore caution should be used when generalizing our results to other age groups. In addition, we used a fixed range of speed for the running task which helps to eliminate some confounding factors such as kinematic and kinetic differences with dramatically increased or decreased speeds, but this may not have been a comfortable speed for some individuals resulting in a compensatory in their running form. However, the participant was able to choose their preferred speed within the range provided, hopefully allowing the participant to be more comfortable with the speed. In an attempt to decrease variances that come with different types of running shoes, we chose to use standardized laboratory shoes which could alter a participant’s typical running biomechanics. One goal of our study was to look at healthy physically active individuals to identify the relationship between standing PT and dynamic PT during normal running. The relationship between standing PT and dynamic PT could change when looking at various tasks and motions. Although our study found strong relationships among standing PT and dynamic PT variables, these results focus on one segment within a single task which does not provide enough information about how the relationship between standing PT and dynamic PT may influence the rest of the kinematic chain. Further research is needed to investigate how the relationship between standing PT and dynamic PT influences movement of the rest of the kinematic chain and to solidify the relationship in other tasks.

We found the PALM may not be a valid alternative for 3D motion analysis for measuring standing PT. We found standing PT and dynamic PT are strongly related, which means that standing PT is indicative of dynamic PT and, therefore, can be measured by clinicians to provide information for whether further analysis, such as 3D gait analysis, is needed for dynamic PT.

References


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