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Effect of Tibia Marker Placement on Kinematics in Pathological Gait

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Abstract

This study aimed to determine the effect of tibia marker placement on walking kinematics in children with pathological gait. Three-dimensional lower extremity gait data was collected using both a traditional tibia wand (protruding laterally from the distal shank) and a tibia crest marker on 25 children with pathological gait. Kinematic variables during walking and quiet standing were calculated using each marker and the “Plug-in Gait” implementation of the conventional gait model. For walking, average differences in kinematics between tibia markers ranged from 0.1° to 1.9° at the knee and ankle, except in the transverse plane where differences were 6.0° to 7.2°. No significant differences were found during quiet standing, indicating that differences in kinematics derive primarily from dynamic sources, which likely affect the tibia wand more than the tibia crest marker. These results suggest that the tibia crest marker can be used in place of the traditional tibia wand in clinical gait analysis.

Keywords

Gait Analysis; Marker Placement; Kinematics; Motion Analysis

Introduction

Gait analysis is often used to better understand the effect of injuries and pathologies on movement and is a helpful tool in orthopaedic treatment and surgical decision-making^{1–3}. It is, therefore, crucial to ensure the best possible kinematic data is collected while still maintaining a test that is efficient and feasible for the patient. One of the initial aspects of gait analysis includes selection of a marker set to define segments and an appropriate biomechanical model^{4,5}. Markers are often surface mounted and attached directly over the skin representing the underlying anatomical landmarks of interest⁶. Modifications to marker locations are frequently made to address specific issues that may arise such as inter-marker

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movement from soft tissue artifact or high impact movements⁷. For example, moving the thigh marker from the lateral thigh to the patella has been shown to improve the accuracy of hip rotation measurements⁸.

The conventional gait model is commonly employed in pediatric gait laboratories and involves a minimal configuration approach; this model traditionally includes tibia and thigh wands to define the shank and thigh segments, respectively⁶. Wands are retro-reflective markers mounted to a small (several centimeters long) stick and attached to the segment of interest. Markers and joint centers are used to define body segments, which are modeled as rigid⁴. Markers moving relative to each other and to the underlying bone may create noise and error in calculated body segment orientations and therefore decrease accuracy of the kinematic results.

The tibia wand marker may be prone to movement during certain activities that increase the probability of soft tissue artifact and wand “wobble” such as change in direction drills, high impact sport maneuvers, and hard foot contacts. Pathological gait, such as scissoring and jump knee gait in cerebral palsy, often involves forceful motions that can generate movement artifact from the wand marker⁹. Additionally, assistive devices used to stabilize walking during testing can easily displace the wand because it laterally protrudes from the shank. Peters et al. have suggested using a tibia crest marker instead of a lateral wand to define the tibia segment because of the minimal soft tissue artifact on the tibia crest⁷. Wren et al. found more accurate tracking of dynamic hip range of motion when using a patella marker in place of the traditional thigh wand⁸. To our knowledge, no studies have investigated the difference in kinematic output between the tibia crest and wand markers.

The purpose of this study was to examine the effect of tibia marker placement on walking kinematics in children with pathological gait. Specifically, we sought to compare the tibia wand and crest markers using (1) quiet standing kinematics, (2) average kinematics over the gait cycle, (3) average kinematics over loading response, (4) root mean square differences over the gait cycle and (5) maximum differences over the gait cycle. We hypothesized that a marker placed over the tibia crest would yield similar lower body kinematics compared to the traditional tibia wand.

Methods

Participants

Three-dimensional gait data from 25 children (mean $\pm$ standard deviation (SD) age: 10.1 $\pm$ 3.8 years, height: 135.0 $\pm$ 29.9 cm, weight: 44.4 $\pm$ 31.2 kg) with gait abnormalities including cerebral palsy (13), spina bifida (3), club foot (2) and other movement related conditions (7) was examined. Eighteen participants had bilateral lower extremity involvement, and seven had unilateral lower extremity involvement. All study procedures were approved by our Institutional Review Board. Written assent and consent were obtained from participants and their guardians; some retrospective patient data was accessed under a waiver of consent granted by the Institutional Review Board.

Procedure

Necessary anthropometric measurements for each participant were obtained by an experienced physical therapist. An 8 camera Vicon 612 motion capture system (VICON, Oxford, UK) was used to collect kinematic data. Seventeen (14mm diameter) retro-reflective markers were placed on the participant's lower body following the Plug-in-Gait (PiG) implementation of the conventional gait model^{2,7}; a patella marker was used in place of the thigh marker⁸; both tibia crest and tibia wand markers were attached (Figure 1). The tibia wand was placed on the lateral aspect of the distal shank, and the tibia crest marker was attached to the proximal one-third of the tibia over the tibia crest where soft tissue was minimal. Both tibia crest and wand markers were simultaneously worn for all static and dynamic trials. Static calibration was performed using knee alignment devices to define the knee flexion/extension axis. The ankle axis was defined using medial and lateral malleolus markers. The same static trial was used to align the technical coordinates for both tibia marker configurations; however the tibia segment was defined using either the wand or crest marker. Following static calibration, participants walked along a 15-meter walkway at a self-selected speed. Gait data was collected at 120 Hz until at least 10 representative strides per side had been obtained.

Data Processing

Kinematic variables were calculated in Vicon Workstation first using the tibia wand, and again using the tibia crest marker in place of the tibial wand. All other processing parameters were identical for both data sets. Standard filtering parameters were used (Woltring filter, quintic spline routine). Right strides were analyzed for participants with bilateral lower extremity involvement, while the more involved side was used in asymmetrical cases. Kinematic measures were examined during quiet standing and during gait. For gait kinematics, data was initially analyzed using both a single representative stride and data averaged over 5–10 representative strides per side. Since similar kinematic differences were found between single stride and average stride analyses, only single stride values are reported.

Because the markers being evaluated were below the knee, the primary kinematic variables of interest were ankle inversion/eversion, ankle rotation, dorsi-plantar flexion, foot progression, knee flexion/extension, knee rotation and knee varus/valgus.

Statistical Analysis

Kinematic measures were examined during quiet standing, as an average throughout the gait cycle, and as an average during loading response (2–12% of the gait cycle). Each kinematic variable was compared between the tibia crest and the tibia wand conditions using paired t-tests. Root mean square (RMS) and maximum differences across the gait cycle between the tibia crest and wand markers were also examined for each kinematic variable. All statistical analyses were performed in STATA (version 12.0, StataCorp LP, College Station, TX, USA).

Results

During quiet standing, no differences in kinematics were detected between tibia markers (Table 1). Static mean differences between the tibia crest and wand ranged from 0.005° (knee varus/valgus) to 1.1° (knee rotation). Measures in the transverse plane (knee and ankle rotation) differed the most between the two markers for quiet standing.

Significant differences were found in all three planes in average kinematic values across the gait cycle and during loading response (Table 1). Transverse plane motions displayed the largest differences between tibia markers, and differences tended to be larger in loading response (Figure 2). Knee rotation was significantly more external in the crest compared to the wand condition both in loading response and across the gait cycle. Conversely, ankle rotation was significantly more internal in the crest condition in both time periods. Knee flexion/extension and ankle dorsi/plantarflexion were lower (more knee extension and plantarflexion) in the crest compared to the wand condition in both time periods. Ankle inversion/eversion was also significantly lower (more everted) in the crest compared to the wand overall and during loading response.

RMS and maximum differences were slightly larger than the differences between average values during quiet standing, across the gait cycle and during loading response (Table 1). RMS differences between tibia markers ranged from 0.1° (foot progression in quiet standing) to 11.7° (knee rotation during loading response). Average maximum differences between tibia markers ranged from 0.2° (ankle dorsi/plantarflexion in quiet standing) to 15.6° (knee rotation across the gait cycle) (Table 1). Differences across the gait cycle and maximum differences for all subjects are shown in Figures 2 and 3.

Discussion

Statistically significant kinematic differences were observed between the tibia wand and crest markers, but the differences were small for most variables and likely not clinically significant. While the magnitude of difference considered clinically significant is inherently subjective, a difference of 5° is often used. Sagittal and frontal plane kinematic differences between markers averaged less than two degrees with RMS differences 2.3° for all variables studied. Ankle and knee rotation showed the greatest variation between tibia markers, consistent with previous studies which found poorer repeatability of joint angle motion in the transverse plane compared to the sagittal and frontal planes^{10,11}. Despite the larger differences in the transverse plane, both knee and ankle rotation from kinematic data are rarely used in clinical evaluations, and thus differences in these variables may be inconsequential in clinical gait analysis. Although average differences seen between tibia crest and wand are either small or not typically used in clinical decision-making, it is important to be aware of the slight discrepancies when interpreting gait data collected using different marker configurations.

Although knee and ankle rotation are not typically used in clinical decision making for children with disabilities such as CP, these parameters may be of greater interest in other populations such as athletes since internal knee rotation increases strain on the frequently

injured anterior cruciate ligament. The selection of tibia marker location and biomechanical model may therefore be more critical in other applications of motion analysis. The differences in rotational kinematics observed in the current study indicate posterior movement of the wand relative to the crest marker during gait. There may also be coupling artifacts between knee rotation and knee flexion or soft tissue artifacts which differ between markers. In applications where knee or ankle rotation is important, greater attention should be given to consistent positioning of the tibia marker and use of a model other than the conventional gait model might be considered.

Differences in tibia crest and wand kinematics were observed during walking, but not during quiet standing, suggesting that the differences are due to dynamic soft tissue and/or wand artifacts. A previous study by Peters et al. found inter-marker movement to be relatively higher for the tibia wand compared to tibia crest markers ⁷. Tibia wand markers are not directly attached to the skin, instead protruding laterally on the wand on the distal shank. Wren et al. hypothesized in a similar study that thigh wand markers may be more susceptible to wobbling and inertial effects compared to more body conforming markers placed directly on body segments such as those on the patella and tibia crest ⁸. The smaller amount of soft tissue between the marker and bone and the marker being directly attached to the skin may have allowed better tracking of the shank for the crest markers versus the wand.

The accuracy of the tibia crest versus wand marker in determining gait kinematics cannot be directly assessed without a “gold standard” such as bone pins or dynamic imaging. Therefore, a limitation of this study is that the reasons for kinematic differences between the markers can only be inferred. In addition, markers were only examined in walking and static conditions; future studies investigating the effect of marker location on kinematics in a broader scope of physical exercises are warranted. Nevertheless, it is clear that both tibia markers produce similar clinically relevant kinematic data for children with pathological gait. Data collected using both tibia marker configurations can be considered comparable, with the exception of rotational kinematic variables where large differences were found between tibia markers. While our results are specific to the model used, PiG is a commonly used model and should behave similarly to other implementations of the conventional gait model.

In conclusion, although kinematic measures differ slightly between tibia crest and wand marker locations, the differences are small and unlikely to impact clinical decision-making. Nevertheless, it is important to recognize the effects of marker placement modifications on kinematic data. Because of potential issues with stability of the tibia wand marker, the tibia crest marker should be considered as a possible replacement to improve the clinical utility of gait analysis.

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Fig 2.

Crest and wand single stride kinematic differences for all subject. All differences are calculated as crest – wand.

Fig 3.
Crest and wand maximum kinematic differences. All differences are calculated as crest – wand.

Table 1:

Values for select single stride kinematic variables (all values in degrees).

Quiet Standing	Crest Mean $\pm$ SD	Wand Mean $\pm$ SD	Average Difference [95% CI]	P-value	RMS Difference [95% CI]	Max Difference* [95% CI]
Knee Flexion/Extension	3.1 $\pm$ 14.1	2.5 $\pm$ 14.4	0.6 [-0.4, 1.6]	0.27	0.8 [-0.1, 1.7]	0.8 [0.3, 1.3]
Knee Valgus/Varus	1.4 $\pm$ 4.4	1.4 $\pm$ 4.5	0.005 [-0.1, 0.1]	0.90	0.1 [-0.1, 0.3]	0.3 [0.1, 0.4]
Knee Rotation	-14.4 $\pm$ 18.1	-15.5 $\pm$ 18.0	1.1 [-1.6, 4.2]	0.42	1.4 [-1.1, 3.9]	2.5 [0.9, 4.1]
Ankle Dorsi/Plantarflexion	-2.2 $\pm$ 19.7	-2.3 $\pm$ 18.9	0.1 [-0.2, 0.5]	0.47	0.4 [0.1, 0.8]	0.2 [-0.1, 0.4]
Ankle Inversion/Eversion	0.5 $\pm$ 2.0	-0.1 $\pm$ 0.2	0.6 [-0.3, 1.5]	0.17	0.8 [0.1, 1.5]	1.0 [0.5, 1.4]
Ankle Rotation	3.8 $\pm$ 13.2	4.5 $\pm$ 13.8	-0.7 [-2.1, 0.6]	0.27	1.3 [-0.1, 2.7]	1.1 [0.6, 1.6]
Foot Progression	-16.4 $\pm$ 15.0	-16.4 $\pm$ 15.0	0.05 [0.0, 0.1]	0.25	0.1 [0.0, 0.2]	0.3 [0.0, 0.6]
Across gait cycle						
Knee Flexion/Extension	24.7 $\pm$ 10.3	25.6 $\pm$ 10.3	-0.9 [-1.2, -0.5]	<0.001	1.2 [0.3, 2.1]	1.8 [1.4, 2.1]
Knee Varus/Valgus	-1.1 $\pm$ 3.3	-1.0 $\pm$ 3.5	-0.1 [-0.3, 0.1]	0.55	0.4 [0.3, 0.5]	0.5 [0.4, 0.6]
Knee Rotation	-1.8 $\pm$ 8.3	5.4 $\pm$ 7.2	-7.2 [-10.5, -3.9]	<0.001	10.7 [7.2, 14.2]	15.6 [11.3, 19.9]
Ankle Dorsi/Plantarflexion	-6.0 $\pm$ 20.0	-4.1 $\pm$ 19.8	-1.9 [-2.7, -1.1]	<0.001	2.6 [1.4, 3.7]	4.1 [3.2, 5.0]
Ankle Inversion/Eversion	0.3 $\pm$ 8.6	0.8 $\pm$ 8.9	-0.6 [-1.3, 0.2]	0.12	1.8 [0.7, 2.9]	2.6 [1.8, 3.3]
Ankle Rotation	12.6 $\pm$ 15.5	6.6 $\pm$ 15.4	6.0 [3.1, 8.9]	<0.001	9.1 [6.0, 12.1]	14.0 [11.8, 16.2]
Foot Progression	-6.2 $\pm$ 18.2	-6.1 $\pm$ 18.0	-0.1 [-0.6, 0.4]	0.65	1.2 [0.1, 2.3]	1.6 [1.0, 2.1]
During loading response						
Knee Flexion/Extension	22.0 $\pm$ 11.7	23.1 $\pm$ 12.0	-1.0 [-1.5, -0.6]	<0.001	1.4 [0.9, 1.9]	1.3 [0.7, 1.9]
Knee Varus/Valgus	-0.5 $\pm$ 3.8	-0.5 $\pm$ 4.0	0.1 [-0.3, 0.3]	0.95	0.7 [0.3, 1.2]	0.6 [0.3, 0.8]
Knee Rotation	-2.8 $\pm$ 8.6	4.5 $\pm$ 8.9	-7.3 [-11.1, -3.5]	<0.001	11.7 [7.8, 15.5]	8.0 [5.2, 10.7]
Ankle Dorsi/Plantarflexion	-6.0 $\pm$ 18.9	-4.3 $\pm$ 19.7	-1.7 [-2.4, -0.9]	<0.001	2.3 [1.7, 3.0]	1.9 [1.1, 2.6]
Ankle Inversion/Eversion	0.6 $\pm$ 8.9	1.5 $\pm$ 9.4	-0.9 [-1.6, -0.1]	0.02	1.1 [0.3, 1.9]	1.2 [-0.1, 2.5]
Ankle Rotation	9.2 $\pm$ 13.7	2.8 $\pm$ 15.1	6.5 [3.2, 9.9]	<0.001	9.7 [6.5, 12.9]	7.4 [4.6, 10.2]
Foot Progression	-4.3 $\pm$ 18.8	-4.2 $\pm$ 18.1	-0.2 [-0.7, 0.3]	0.20	1.1 [0.6, 1.6]	0.5 [-0.4, 1.4]

* Maximum difference was calculated as absolute value