Internal Hip Rotation and Swing Phase Knee Flexion in Adolescent Gait

Case Study

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Abstract

Introduction: Stiff knee gait (SKG) is a common gait deviation in patients with cerebral palsy that can significantly impact walking function. SKG is often treated surgically with a distal rectus femoris transfer, however some researchers have documented mixed outcomes using existing patient selection criteria. It may be that other factors, such as hip internal rotation due to increased femoral anteversion, are playing a role in SKG, though this has not been explicitly studied.

Methods: This descriptive case study involved a convenience sample of two 14-year-old adolescent girls, one with idiopathic increased internal hip rotation and one without. Lower body joint angles were calculated from motion capture data collected during normal overground walking. Two variables were extracted from each of 60 gait cycles (30 per side): peak knee flexion in swing, and average hip rotation in early swing. Two-way ANOVAS with participant and leg as factors, followed by Welch t-tests for significant interactions, were used to compare participants statistically. Given the non-independence of gait cycles within participants, a conservative threshold of $p<0.001$ was applied.

Results: The participant who presented with idiopathic increased femoral anteversion walked with atypically high internal hip rotation in early swing compared to the participant without clinically increased femoral anteversion. In addition, the participant with higher internal hip rotation exhibited decreased peak knee flexion during swing. Statistical comparisons confirmed significant between-participants differences in both variables for each leg ($p<0.001$).

Conclusions: Increased internal hip rotation in the early swing phase of gait may be a factor in the decreased swing phase peak knee flexion characteristic of SKG. Given the importance of patient selection for the treatment of SKG, further study in a larger sample with a wide range of severity of femoral anteversion may be warranted.

Key Words: gait analysis, stiff knee gait, anteversion

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Introduction

Stiff knee gait (SKG) is a gait deviation characterized by delayed and diminished peak knee flexion during the swing phase of walking and can have a significant impact on function. Commonly exhibited by clinical populations such as children with cerebral palsy, the most apparent functional impact of SKG is an increased frequency, or risk, of tripping and falling.

Treatment of SKG is generally surgical for the child with cerebral palsy, with the goal of reducing the extensor effects of muscles around the knee, particularly the rectus femoris (RF) muscle. The rectus femoris transfer (RFT)[1,2] is the most common surgical intervention. Atypical electromyographic activity of the rectus femoris (RF) muscle during swing has been a primary indicator for an RFT under the premise that the primary cause of SKG was spasticity of the RF. Rapid knee flexion in pre-swing resulted in a stretch response in the RF, interfering with the knee flexion necessary for toe clearance mid-swing. RFT is intended to modify the effect of the RF muscle as a knee extensor by separating the RF from the other quadriceps and transferring the tendon to the posterior aspect of the knee[1,3]. While the procedure has been shown to improve SKG for many limbs[4,5], outcomes following RFT have been shown to be mixed[6,7]. Unpredictable outcomes suggest that patient selection criteria may be inappropriate, with some research calling into question the use of swing phase RF muscle activity as the primary indicator for RFT. Notably, SKG and swing phase RF muscle activity have been found to be poorly correlated[2,8,9].

With a question of patient selection criteria, it is reasonable to explore other possible contributors to SKG. One potential contributor is another prevalent physical impairment in children with cerebral palsy, increased femoral anteversion. On clinical examination, this congenital bony torsion condition results in an internal hip rotation bias in the prone position. While walking, the effect of this bony torsion is increased internal hip rotation throughout the gait cycle, often with internal foot progression. Increased internal hip rotation during gait means that the knee axis for flexion is rotated internally. Given the passive nature of swing phase knee flexion during gait, it is possible that the malrotation of the knee axis could diminish the effectiveness of that passive swing mechanism and lead to decreased peak knee flexion.

While the co-occurrence of femoral anteversion and SKG is clinically recognized, the potential contribution of internal hip rotation to reduced swing phase knee flexion has not been directly studied in human participants. Studying the relationship between internal hip rotation and peak knee flexion in swing in children with cerebral palsy would be complicated by the presence of concomitant impairments such as spasticity, weakness, and contracture, as well as the slower walking speeds typical of this population. Typically developing adolescents with idiopathic femoral anteversion therefore offer a cleaner context in which to examine this relationship in isolation. Therefore, the purpose of this study was to provide preliminary descriptive evidence of this relationship in two typically developing adolescent girls, one with idiopathic femoral anteversion and one without, as a foundation for future mechanistic investigation.

Methods

Participants

Two 14-year-old participants were invited to participate. Participants will be referred to as A and B going forward. Participant A presented with in-toeing gait secondary to increased femoral anteversion. Review of her most recent clinical consult with pediatric orthopedics, shared by the parents with the investigator, confirmed a clinically significant bias toward internal hip rotation bilaterally (70 degrees internal, 30 degrees external). Physician's assessment confirmed excessive femoral anteversion, bilaterally. While participant A was under clinical observation for this condition, her recruitment for and participation in this study was not part of her clinical care. Participant B presented with normal foot progression during gait, and no parent or clinical report of bony torsional alignment issues existed at the time of the study. Participant B was recruited solely as a typically developing comparator to participant A.

Protocol

Upon arrival at the Biomechanics and Motor Performance Lab, the study was explained to the parent and participant. Per our Institutional Review Board approved protocol, parents gave informed consent and participants signed assent forms. Participants wore shorts and a snug tank top and removed their shoes for the walking test. Anthropometric measures required for the VICON lower body Plug-in Gait biomechanical model were taken according to the reference guide[10] for this model. This was followed by placement of twenty standard sized (14-mm) reflective markers at specific locations on the pelvis, thighs, legs and feet as described for this well validated model[11,12]. A VICON motion capture system (Nexus 2.14, Vicon Motion Systems Ltd., Oxford, UK) equipped with 16 high-speed, high-resolution cameras was used to acquire the three-dimensional trajectories of each marker at a frame rate of 120 Hz. Participants were instructed to walk at their normal walking speed through the calibrated space in the laboratory, covering approximately 20 feet on each trial. A total of 15 trials were collected for each participant, which resulted in 3-4 full gait cycles for each limb per trial.

Preliminary data processing was performed in VICON Nexus (2.14) software where all lower extremity joint angles were calculated. For each trial, two gait cycles from each limb were included for analysis, resulting in a total of 30 gait cycles for each limb, for each participant. Data reduction continued in VICON's ProCalc (1.6) software where, for each limb and gait cycle, the two variables of interest were obtained: 1) the magnitude of peak knee flexion in swing, and 2) the average hip rotation between toe off and peak knee flexion was calculated. Calculating the average hip rotation over this short period was deemed to be the most relevant, as malrotation of the knee axis over this period would be more likely to impact the magnitude of peak knee flexion than the average hip rotation at any other period during the gait cycle. A two-way ANOVA was performed with participant and leg as factors; given the non-independence of gait cycles within participants, a conservative threshold of p<0.001 was applied.

Results

Participants were similar in age (A, 14.8 years; B, 14.3 years), height (A, 161.7 cm; B, 155.1 cm) and weight (A, 48.4 kg; B, 44.0 kg). Leg length, measured as part of the VICON Plug-in Gait model setup, was 0.85 m for participant A, and 0.83 m for participant B. Relevant average temporal-spatial gait parameters and kinematic variables of interest are presented in Table 1. Average time-series data for knee flexion and hip rotation can be seen in Figure 1.

Table 1. Relevant temporospatial gait data and mean kinematic measures of interest for each participant (n = 30 gait cycles for right and left sides).

	A		B	
Walking Speed (m/s)	1.22 ± 0.07		1.24 ± 0.04	
Cadence (steps/min)	116 ± 5.3		117 ± 3.4	
Stride Length (m)	1.27 ± 0.4		1.28 ± 0.4	
	Left	**Right**	**Left**	**Right**
Peak Knee Flexion in Swing (degrees)*	57.9 ± 2.3	55.8 ± 1.6	63.4 ± 1.4	61.8 ± 1.0
Avg. Hip Rotation Early Swing(degrees)*	15.2 ± 0.9	16.4 ± 0.8	-2.5 ± 1.7	4.4 ± 1.4

Data are Means ± SD. *Significant between-participant difference within each leg (p<0.001).

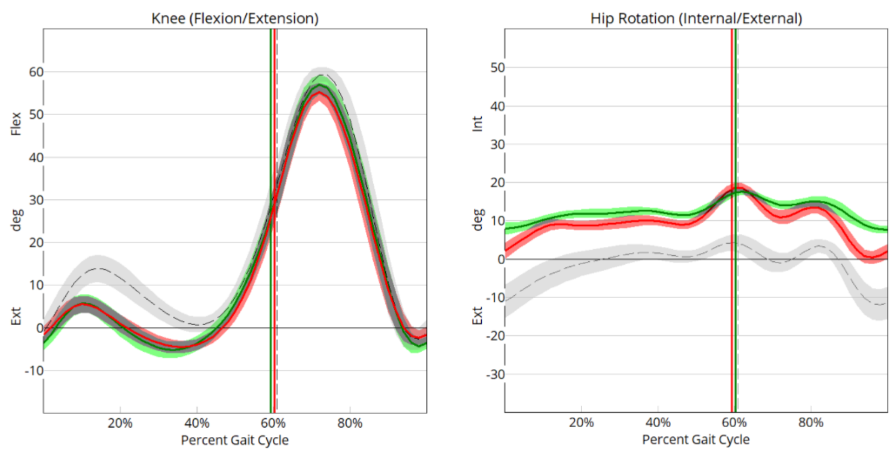

Figure 1. Average (± 1SD) knee flexion/extension and hip internal/external rotation curves for participant A (red = left leg; green = right leg) compared to B (grey band, bilateral).

Hip rotation

The two-way ANOVA with Participant and Leg as factors revealed significant main effects for average hip rotation in early swing, Participant: (F(1,116)=4102.27, p<.001), Leg: (F(1,116)=123.29, p<.001). In addition, a significant Participant x Leg interaction was found (F(1,116)=33.09, p<.001). Following the significant interaction, Welch t-tests comparing Participants within each Leg confirmed that Participant A exhibited increased internal hip rotation in early swing bilaterally compared to Participant B on both the right leg (t(46.16)=45.05, p<.001) and the left leg (t(45.12)=45.78, p<.001), consistent with her clinical presentation of increased femoral anteversion bilaterally. Both participants walked with more internal hip rotation in their right leg, compared with their left. Figure 2A conveys these differences and illustrates the distribution of each measure for each participant/leg combination. Notably, Participant B exhibited one outlier, with that average hip rotation more external than the rest of the gait cycles at -6°.

Knee flexion

The two-way ANOVA for peak knee flexion in swing likewise revealed significant main effects for Participant (F(1,116)=158.06, p<.001) and Leg (F(1,116)=19.62, p<.001), and a significant Participant x Leg interaction (F(1,116)=8.56, p=.004). Follow-up Welch t-tests confirmed that participant A walked with significantly less peak knee flexion in swing than participant B on both the right leg (t(49.08)=-12.76, p<.001) and the left leg (t(43.51)=-6.07, p<.001). For both girls, peak knee flexion for the right leg was lower than the left (Figure 2B). Participant A showed greater variability in peak knee flexion in swing compared to participant B, though two higher outliers in peak knee flexion are notable for participant B.

It should be noted that gait cycles analyzed within each participant are not fully independent observations, as they were drawn from the same individuals on a single testing day. Given this, statistical results should be interpreted with caution and in the context of the descriptive findings, rather than as evidence of a generalizable relationship between these variables.

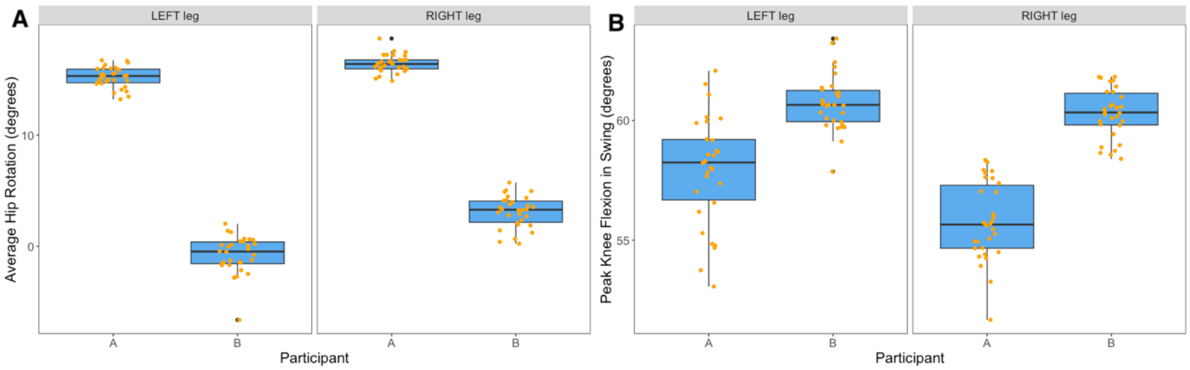

Figure 2. Box plots illustrating distribution of A) average early swing hip rotation and B) peak knee flexion in swing for both participants and each leg. Discrete values for each gait cycle are presented as scatter plot in orange overlaid onto the box plot. Outliers are noted in black.

Discussion

Results show that a participant with idiopathic femoral anteversion walked with measurably reduced peak knee flexion in swing, despite typical neuromuscular function. This raises the possibility that hip rotation contributes to stiff knee gait through a mechanism independent of rectus femoris spasticity and may have implications for patient selection criteria in surgical planning for SKG.

The mechanical basis by which internal hip rotation may influence peak knee flexion in swing has not been explicitly studied. However, when the hip is internally rotated because of increased femoral anteversion, the knee joint axis is no longer oriented in the sagittal plane. The resultant oblique position of the knee flexion/extension axis relative to the path of progression could reasonably be expected to diminish the effectiveness of the passive dynamics that account for knee flexion during swing[13,14]. Previous studies of passive dynamics have relied on simulations, a method that may more effectively elucidate any causal impact of internal hip rotation on peak knee flexion.

One factor that has been shown to directly influence peak knee flexion in swing is walking speed[15], so the finding that these two participants walked with very similar walking speeds is important (Table 1). This reduces the likelihood that observed differences in knee joint kinematics are related to gait speed. It is also important to note that while participant A walked with diminished peak knee flexion during swing, a characteristic of SKG, the timing of peak knee flexion was not delayed and the rate of knee flexion from pre-swing into swing was not reduced compared to participant B. Therefore, this otherwise typically developing adolescent walking with internal hip rotation did not exhibit all the features of a classic SKG pattern.

Participant A exhibited less trial-to-trial variability in hip rotation than participant B, which may reflect the constraining effect of fixed bony morphology on hip motion. In contrast, participant A showed greater variability in peak knee flexion, particularly on the left side. While this is counterintuitive given the constrained hip rotation pattern, the small sample size precludes any meaningful explanation, and these differences in variability likely reflect natural biomechanical noise rather than a systematic effect.

While the absolute difference in early swing hip rotation between these two participants was considerable (~12-16°), the difference in peak knee flexion was modest, with participant A walking with 5.5° and 6.1° less knee flexion on the left and right, respectively, compared to participant B. Despite the reduced peak knee flexion in swing exhibited by participant A, her values do not meet the threshold for a clinical diagnosis of SKG as defined in the cerebral palsy literature, where peak knee flexion is typically more dramatically diminished, and its timing is delayed. This is not an unexpected finding, considering that these are typically developing adolescents without the neuromuscular impairments that characterize cerebral palsy, and the purpose of this study was not to reproduce SKG in a healthy population. Rather, the goal here was to establish whether internal hip rotation is associated with any measurable reduction in peak knee flexion in swing, in the absence of these confounders, and which the data support, modestly but directionally consistent. Results here should be interpreted with caution, given that stride-to-stride variability in knee flexion in typically developing children is approximately 3°, and between-subject variability in the normative pattern approaches 5.4°[16]. For this study, this means that the differences between the two participants may not be attributable to the hip rotation profile difference alone. With further study in a larger sample of adolescents, exhibiting a broader range of bony torsional deformities in the femur, a mechanistic relationship between the two deviations may be inferred.

Several limitations of this study should be acknowledged, most notably the small sample size of this case series. While the inclusion of a comparator participant, without a femoral anteversion bony deformity, was intentional, the absence of a larger control group limits the ability to contextualize either participant's data against a larger normative reference set. Anthropometric differences between the two participants, including height, weight, and leg length are acknowledged as a limitation of this case study design. Notably, walking speed was nearly identical between participants, and as the variable known to most directly influence swing phase knee flexion, this similarity may mitigate the potential influence of those anthropometric differences on the outcomes of interest. The fact that both participants were adolescent girls, while useful for reducing confounding variables in this descriptive comparison, further limits the generalizability of these observations to the broader population.

Understanding the relationship between early swing internal hip rotation and reduced peak knee flexion in swing more precisely has clinical relevance, given that femoral anteversion is a common concomitant physical impairment in patients that present with SKG. If supported by future study in a larger cohort, these findings may have direct relevance for surgical decision-making in children with cerebral palsy who present with stiff knee gait. If internal hip rotation contributes mechanically to reduced swing phase knee flexion, femoral anteversion may be an underappreciated factor in the mixed outcomes reported following RFT. Future work examining whether the degree of femoral anteversion moderates RFT outcomes in this population is warranted.

Conclusions

While the limitations of this case study preclude inference to a broader population, the results suggest that internal hip rotation in early swing may be associated with a modest reduction in peak knee flexion during swing. These findings are directionally consistent with the proposed mechanism for this relationship, the oblique orientation of the knee's flexion-extension axis reducing the effect of passive dynamics typical in normal gait. To the author's knowledge, this is the first study to examine this relationship in human participants. By isolating the variables of interest in these typically developing adolescents, free from neuromuscular confounders of cerebral palsy, this work provides a testable mechanistic framework and preliminary data to inform the design of larger studies. Given the clinical implications for patient selection for surgical treatment of stiff knee gait, such investigation would be worthwhile.

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Conflict of Interest. The author declares no conflicts of interest.

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