Simulated Ankle Equinus Affects Knee Kinematics During Gait

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Abstract *Background:* It is critical to distinguish gait compensations from true abnormalities when planning interventions to improve gait in individuals with neuromuscular disorders. *Questions/Purposes:* The aim of this study was to determine the effect of isolated ankle equinus on knee kinematics during the initial contact phase of gait. *Methods:* Ten healthy subjects (29±4.3 years) participated, and testing occurred in a motion analysis laboratory. This cross-sectional study investigated five gait conditions in each subject: shoe alone, shoe with unilateral ankle foot orthosis locked at neutral, 10°, 20°, and 30° of fixed ankle plantar flexion. Gait kinematics were recorded and calculated with 3D motion analysis. The difference between the shoe and each brace condition was analyzed by repeated-measures ANOVA. The primary outcome was knee flexion at initial contact. *Results:* With greater than 10° simulated ankle equinus, the primary gait compensation pattern was increased knee flexion at initial contact. A significant degree of knee flexion occurred ranging from 7° to 22°. *Conclusion:* Our data suggests that observed knee flexion at initial contact may be a compensation pattern in individuals with

>10° ankle equinus. However, in individuals with ≤10° ankle equinus, observed knee flexion may represent a true gait deviation. This has clinical significance in the realm of cerebral palsy for treatment planning to improve gait.

Keywords equinus · gait · knee kinematics · cerebral palsy · knee flexion · gait compensations

Introduction

A true equinus gait pattern is defined by ankle plantar flexion (PF) throughout stance and swing phases of gait [10, 22]. Ankle equinus, due to a contracture of the gastrocnemius-soleus complex, and equinus gait patterns are especially common in individuals with spastic cerebral palsy [7, 10, 12, 21, 23]. During normal gait, the knee is fully extended and the ankle is neutral at initial contact [21]. As the degree of fixed ankle equinus increases, full knee extension at initial contact may not occur resulting in improper pre-positioning of the foot. In individuals with cerebral palsy, observed knee flexion at initial contact may be due to a hamstring contracture or only a compensation pattern secondary to an ankle equinus contracture.

The most common clinical measure used to assess hamstring length is the popliteal angle; however, it has high inter-rater variability [25, 26] and should not be the only variable used for surgical decision making. Gait analysis is a valuable tool to assist in decision-making when planning musculoskeletal surgery. It has been shown to alter decision-making and improve functional outcomes [2, 3, 9, 11, 15, 17, 18, 28, 29]. Overlengthening of the hamstring muscle could result in adverse effects such as increased anterior pelvic tilt, resulting in increased hip flexion and crouched gait [4, 8, 30]. Therefore, it is imperative to clarify the presence or absence of a hamstring contracture and identify whether or not a lengthening is necessary. Research and any tests and measures that improve the accuracy of this decision-making have substantial clinical value.

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Few studies have identified compensation patterns that are exclusively due to fixed ankle equinus. Upon literature review, the best study was done in ten typically developing children looking at the effect of ankle equinus on gait kinematics. They found ankle equinus resulted in: increased hip and knee flexion at initial contact, increased knee flexion or hyperextension during stance and increased anterior pelvic tilt [14]. Previous studies in the cerebral palsy population found there is a direct correlation between ankle range of motion and knee kinematics [1, 5]. A study in ten children with spastic cerebral palsy specifically tested our question and concluded changes in knee angles are related to changes in ankle dorsiflexion range of motion during mid-stance and terminal swing [19]. However, this same study also concluded knee angles during gait are dependent on many factors, other than just ankle range of motion, and one must ensure the other factors are not simultaneously causing opposite effects during gait [19]. Thus, testing knee kinematics during gait in typically developing individuals is beneficial to take out confounding factors such as weakness, contractures, spasticity and deficient selective motor control. Overall, the literature is lacking absolute agreement on the direct effect of ankle equinus on knee kinematics during the initial contact phase of gait.

The purpose of this study was to determine if fixed ankle equinus, of increasing magnitude, results in compensatory knee flexion at initial contact, in the absence of any knee or hamstring contracture. The specific aim of this study was to assess the effect of fixed ankle equinus on knee flexion kinematics and determine if increasing angles of equinus result in more knee flexion at initial contact.

Patients and Methods

Ten healthy subjects (29 ± 4.3 years old) were studied using a device that simulated ankle equinus during a single visit. The research protocol was approved by a hospital institutional review board and all subjects signed informed consent to participate. One custom hinged ankle-foot orthosis (AFO), women's left foot size 8, was designed for this study. The same brace and shoes were worn in all subjects for reliability and to reduce study costs. Therefore, subject participation was limited to healthy females with shoe size 7.5 to 8.5. Additional inclusion criteria included the following: no lower extremity disorders or surgery, 20–50 years of age, full knee and ankle range of motion and strength, and no hamstring contracture defined by straight leg raise of $>50^\circ$, according to Kendall [16]. All subjects participated in a brief physical therapy screen of hip, knee, and ankle range of motion, strength, and hamstring flexibility to ensure they met inclusion criteria prior to participation.

The AFO for this study was fabricated with a hinged ankle joint capable of locking at various PF angles with an Allen key not allowing any dorsiflexion or plantar flexion motion at the ankle joint (Fig. 1). Ankle AFO angles were measured with a standard goniometer [20] by the same clinician for all conditions in all subjects. The goniometer axis was placed along the lateral AFO hinge, at the lateral

Fig. 1. Image of ankle foot orthosis used in study.

malleolus, the proximal stationary arm was parallel to the longitudinal axis of the fibular head, and the moveable arm was parallel to the fifth metatarsal. A black line was marked on the brace along the fifth metatarsal to improve consistency of PF measurements between subjects and conditions.

Gait was tested for the following five walking conditions: shoe only, shoe with a unilateral AFO locked at neutral (0°), 10° , 20° , and 30° of PF. Gait kinematic data was captured at 100 Hz using a 12-camera system (Motion Analysis Corp., Santa Rosa, CA), utilizing the Cleveland Clinic marker set of 35 trunk and lower extremity markers. All markers remained the same during each condition for all subjects. Subjects walked across an 8-m gait laboratory for six to eight trials for each of the five conditions. To control for a learning effect, the order of the five walking conditions was randomized. Each subject was allowed to walk in the braced condition prior to data collection for a few minutes to ensure they could comfortably and safely walk. No verbal instructions on how to walk was given to the subjects. They walked at their own self-selected velocity. Each subject's speed was then controlled by verbal cues to be within 10% using a photo-electric timer; trials that were not within the 10% were excluded.

Kinematics for an average of at least eight consistent gait cycles was calculated in OrthoTrak (Motion Analysis Corp. Santa Rosa, CA). The primary outcome, knee flexion at initial contact, was calculated for each of the five conditions. The study main effect was analyzed by repeated measures analysis of variance (ANOVA) and pairwise comparison *t* test for between conditions with a post hoc pairwise comparison. All statistics were performed using SPSS software, and $p \leq 0.05$ was chosen as a level of significance.

Results

The primary gait compensation pattern observed for simulated ankle equinus was increased knee flexion at initial contact. A significant degree of knee flexion occurred ranging from 7° to 22° ($p=0.001$). The average knee angle at initial contact was 1° of knee hyperextension during the baseline shoe condition. Knee flexion in the ten subjects increased an average of $8\text{--}9^\circ$ during the 20° and 30° PF conditions (Table 1, Fig. 2). In the majority of subjects, ankle equinus results in compensatory knee flexion at initial contact as the primary gait compensation. Other compensation patterns were also observed in the $\geq 10^\circ$ PF conditions in three subjects. These gait compensation patterns included hip hiking (pelvic elevation), vaulting (increased plantar flexion of the opposite limb), and lateral trunk flexion.

The increasing angles of ankle PF resulted in more knee flexion at initial contact during $\geq 20^\circ$ PF conditions (Table 1, Fig. 2). There was no difference between 20° and 30° PF conditions; both demonstrated increased knee flexion of similar magnitude. Post hoc pairwise comparison had sufficient power between all conditions except between neutral and 10° PF and the 20° and 30° PF conditions.

Discussion

This study demonstrated knee kinematics at initial contact is directly related to ankle position, in the absence of hamstring spasticity or contracture. In our model of equinus gait, the 20° and 30° plantar flexion conditions resulted in clinically and statistically significant increases in knee flexion at initial contact. Although the 10° PF condition had statistical significance, the magnitude of the increase (1°) was marginal and most likely not enough to have any clinical significance. Unexpectedly, we did not find a difference in the knee flexion angles between the 20° and 30° PF groups, but post hoc analysis did not find sufficient power between these two groups so more subjects may be needed to determine if higher ankle PF angles result in more knee flexion.

The knowledge that equinus beyond 10° results in knee flexion at initial contact has substantial implications for clinical practice and surgical decision-making. We believe that individuals with an ankle equinus contracture of greater than 10° may display knee flexion at initial contact as a compensation pattern. Yet, individuals with $\leq 10^\circ$ ankle equinus observed knee flexion may represent a true gait

Table 1 Knee flexion outcome results

Outcome parameters	Shoe	Neutral brace (0°)	PF 10°	PF 20°	PF 30°	ANOVA $\alpha \leq 0.05$	Observed power = $1 - \beta$	Post hoc pairwise $p < 0.05^a$
Knee flexion ($^\circ$) at initial contact	-0.97 ± 2.5	1.86 ± 4.5	1.1 ± 3.3	8.4 ± 10.0	6.7 ± 7.9	$p = 0.001$	0.97	1–3, 1–4, 1–5, 3–4, 3–5

^aReference for post hoc conditions: 1=shoe, 2=neutral brace (0°), 3= 10° plantar flexion (PF), 4= 20° PF, 5= 30° PF

Fig. 2. Knee flexion in the ten subjects.

deviation. Knee flexion is a compensation for the inability of the ankle to dorsiflex during terminal swing resulting in altered pre-positioning at initial contact. Our study supports previous literature concluding ankle position alone does affect knee kinematics [14, 19] and affirms the study by Houx et al. in healthy children with similar findings that at least 10° of ankle equinus is needed to alter gait parameters [14]. This study enhances and supports the current literature that diminished ankle range of motion (equinus) directly affects knee kinematics at the initial contact phase of gait.

One of the main limitations of our study is the use of healthy adults as a model for individuals with cerebral palsy. Gait patterns mature in typically developing children between the ages of 3 to 7 years [6, 13, 24, 27]. Therefore, we believe it is appropriate to use a sample of adults as a model to determine the effects of isolated equinus on gait for both children and adults.

We purposefully chose to look at individuals without impairment to eliminate confounding variables of contractures, spasticity, weakness, and deficient selective motor control. This allowed us to conclude that the gait changes observed in these subjects were the result of the only variable we manipulated, ankle position. It is possible, however, that individuals with cerebral palsy, who have a true equinus contracture, over time develop various gait compensation patterns due to range of motion restrictions and weakness. This limitation could be addressed with future research investigating this phenomenon in individuals with cerebral palsy. Specifically, one could compare pre- and postoperative knee kinematics at initial contact in patients with CP who have had isolated surgical lengthening for ankle equinus contractures.

Another limitation of our study was the slight heterogeneity of our data, mainly that three of ten subjects used other compensation patterns (hip hiking, vaulting, and lateral trunk flexion). It is possible that these strategies are unique to healthy individuals forced to acutely change their gait. Nevertheless, various secondary gait compensations are common and the presence of the other patterns does not detract from the validity of our conclusions regarding increased knee flexion at initial contact.

This research has clinical significance to assist in planning interventions for individuals with equinus contractures. Clearly, the physical exam assessing knee range of motion and hamstring flexibility is always an essential part of decision-making. Particularly in the setting of ankle equinus beyond 10° , one must pay close attention to the knee clinical examination and ensure that a true contracture is present before proceeding with concurrent knee surgery, such as a hamstring lengthening. Research supports utilizing the physical exam and gait analysis results for optimal treatment planning and outcomes in children with cerebral palsy [5, 11, 17, 28].

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Disclosures

Conflict of Interest: Lisa C. Drefus, PT, DPT, Jocelyn F. Hafer, BS, MA, and David M. Scher, MD, have declared that they have no conflict of interest.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human

experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was obtained from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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