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Research Article

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Analysis of Dynamic Balance during Gait Initiation in Young Adults with Complete Anterior Cruciate Ligament Rupture

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Abstract

Introduction: *Anterior cruciate ligament (ACL) rupture causes instability and impacts gait biomechanics, necessitating neuromuscular adaptations. The initial phase of gait is critical for stability and fall prevention, influenced by postural control and motor coordination.*

Objective: *To analyze the behavior of the center of pressure (CoP) and neuromuscular adaptations during gait initiation in adults with a complete ACL rupture.*

Methodology: *Twenty adults with a complete ACL rupture were evaluated. The CoP trajectory was divided into three phases of gait initiation: anticipatory, first step execution, and second step execution. The amplitude and displacement velocity of the CoP in the anteroposterior and mediolateral directions were calculated.*

Results: *There was a significant decrease in CoP displacements in the anteroposterior and mediolateral directions throughout the gait phases, indicating progressive stabilization of movement.*

Conclusion: *Individuals with a complete ACL rupture exhibit adaptations in dynamic balance control during gait initiation, aiming for greater stability.*

Keywords: Anterior Cruciate Ligament Injury, Dynamic Balance, Gait Initiation, Center of Pressure

1. Introduction

Anterior cruciate ligament (ACL) rupture is one of the most frequent injuries among athletes and young adults, resulting in significant joint instability and functional impairment. This condition leads to notable biomechanical alterations during gait, necessitating neuromuscular adaptations that impact both the stability and functionality of the knee [1,2].

Recent studies reveal that ACL injury induces inhibition of quadriceps muscle activity, with a consequent increase in hamstring muscle activation. This phenomenon of muscle coactivation is a crucial neuromuscular adaptation for stabilizing the knee during gait. Moreover, after ACL reconstruction, although mechanical stability is restored, proprioceptive deficits may persist, resulting in biomechanical asymmetries during high-impact activities such as jumping and direction changes, thereby increasing the risk of new injuries [3,4].

Gait initiation is a critical phase that involves transitioning from a state of rest to movement. During this phase, dynamic stability is essential to prevent falls and ensure safe locomotion. In individuals with ACL rupture, gait initiation may be compromised due to joint instability and inadequate neuromuscular adaptations. Research indicates that patients with ruptured ACL exhibit altered center of pressure (CoP) displacement, reflecting deficits in postural control and motor coordination [5,6].

These changes are evident in the gait pattern, particularly during the initiation phase, where suppression of quadriceps activity can lead to a knee extension pattern, reducing the anterior tibial

translation force and knee flexion moment. While this adaptation reduces the load on the knee joint, it may increase axial force distribution, contributing to the development of tibiofemoral osteoarthritis and meniscal injuries [7-10].

Studies on gait initiation indicate that anticipatory postural adjustments (APAs) are essential for the preparation and execution of movement. These adjustments involve CoP displacements backward and toward the supporting foot, followed by the initial contact of the swing foot with the ground [9,10]. The ability to perform these adjustments is crucial for dynamic stability and fall prevention, especially in individuals with a ruptured ACL.

The objective of this study is to analyze the behavior of the center of pressure and neuromuscular adaptations during gait initiation in adults diagnosed with a complete ACL rupture. The hypothesis is that young adults with a complete ACL rupture exhibit altered patterns of dynamic balance and center of pressure displacement during gait initiation compared to healthy individuals.

2. Methodology

2.1. Participants

This study evaluated 20 adults of both genders, with a mean age of 31.62 years (±6.23), diagnosed with a complete ACL rupture. Detailed data are presented in Table 1.

AGE (YEARS)	HEIGHT (CM)	BODY MASS (KG)	INJURED KNEE
31.62 (±6.23)	173 (±8.41)	72.15 (±4.09)	Left
Legend: Data expressed as mean ± standard deviation.			

Table 1: Sample Characterization.

2.2. Ethical Aspects

This study was conducted in compliance with the highest ethical standards and received approval from the Research Ethics Committee under the number 24845019.2.0000.5083, in accordance with Resolution No. 466/2012 of the National Health Council (CNS). All participants provided informed consent by signing the Free and Informed Consent Form (TCLE), which clearly detailed the research objectives, procedures, potential risks, and benefits. In accordance with the ethical principles of autonomy and respect for individual decision-making, participants were assured the right to withdraw from the study at any time without any negative consequences.

Additionally, the research was conducted in compliance with the General Data Protection Law (LGPD, Law No. 13.709/2018), ensuring the proper collection, treatment, and protection of all participants' personal information.

2.3. Variables Analyzed

The trajectory of the Center of Pressure (CoP) during gait initiation was divided into three distinct phases [11]:

• **Phase 1 - Anticipatory:** This phase begins at the start of the movement and extends to the most lateral position of the CoP towards the swing foot.

• **Phase 2** - Execution of the First Step: This phase starts at the end of the anticipatory phase and extends to the most lateral position of the CoP towards the support foot.

• **Phase 3** - Execution of the Second Step: This phase starts at the end of the execution of the first step and extends to the end of the movement when the CoP moves forward.

For each phase, the amplitude of CoP displacement in the anteroposterior direction (CoPAP) and the mediolateral direction (CoPML), as well as the displacement velocity of CoP in the anteroposterior direction (VELAP) and the mediolateral direction (VELML), were calculated.

2.4. Statistical Analysis

Data were analyzed using Minitab 21 software. The normality of distributions and data homogeneity were verified. To determine differences between the evaluated groups, Tukey's non-parametric test was applied, considering a p-value ≤ 0.05 as statistically significant. Results were presented as mean and standard deviation, providing a clear description of the data.

3. Results

Table 2 presents the results of the Center of Pressure (CoP) behavior during the phases of gait initiation in adults diagnosed with a complete rupture of the Anterior Cruciate Ligament (ACL).

	FASE 1	FASE 2	FASE 3	Valor de P
CoPAP (cm)	10,67 (±2,30)	7,77 (±4,23)	6,48(±2,24)	0,03*
CoPML (cm)	16,34 (±2,37)	9,64 (±5,70)	8,61 (±2,90)	0,03*
VELAP (cm/s)	8,16 (±1,92)	5,44 (±1,91)	9,23 (±6,30)	0,07
9,58 (±3,51)	9,58 (±3,51)	7,07 (±2,60)	8,37 (±3,80)	0,08
Legend: Phase 1 = Anticipatory Phase; Phase 2 = Execution of the 1st Step; Phase 3 = Execution of the 2nd Step. *Tukey's test significant ($p < 0.05$). Data are presented as mean values ± standard error.				

Table 2: CoP Behavior during the Phases of Gait Initiation.

The anteroposterior displacement of the CoP (CoPAP) significantly reduced across the phases of gait initiation. In Phase 1, known as the Anticipatory Phase, the mean was 10.67 cm (±2.30). In Phase 2, corresponding to the Execution of the 1st Step, the mean was 7.77 cm (±4.23), while in Phase 3, involving the Execution of the 2nd Step, the mean was 6.48 cm (±2.24). The obtained p-value was 0.03, indicating a statistically significant difference.

The mediolateral displacement of the CoP (CoPML) also showed a significant reduction. In Phase 1, the mean was 16.34 cm (±2.37). In Phase 2, the mean was 9.64 cm (±5.70), and in Phase 3, it was 8.61 cm (±2.90). Again, the p-value was 0.03, indicating a statistically significant difference.

The anteroposterior velocity of the CoP (VELAP) varied among the gait phases. In Phase 1, the mean was 8.16 cm/s (±1.92). In Phase 2, it was 5.44 cm/s (±1.91), and in Phase 3, it was 9.23 cm/s (±6.30). However, the p-value was 0.07, indicating no statistically significant difference.

On the other hand, the mediolateral velocity of the CoP (VELML) did not show a significant reduction among the phases. In Phase 1, the mean was 9.58 cm/s (±3.51). In Phase 2, the mean was 7.07 cm/s (±2.60), and in Phase 3, it was 8.37 cm/s (±3.80). The p-value was 0.08, indicating no statistically significant difference.

These results indicate that, in patients with complete ACL rupture, there is a significant reduction in both anteroposterior and mediolateral CoP displacement as gait progresses. However, only the anteroposterior velocity showed a non-significant variation, while the mediolateral velocity also did not show a statistically significant difference.

4. Discussion

The presented data indicate a significant decrease in the displacements of the Center of Pressure (CoP) in the anteroposterior (CoPAP) and mediolateral (CoPML) directions throughout the phases of gait initiation. This reduction suggests a progressive stabilization of movement. Individuals with a complete anterior cruciate ligament (ACL) injury often exhibit knee instability, which can lead to increased CoP displacements due to the difficulty in maintaining stability during the transition from a static to a dynamic position [12,13].

The analysis of anteroposterior (VELAP) and mediolateral (VELML) velocities did not reveal statistically significant differences between the gait phases. In patients with a complete ACL injury, the ability to control CoP velocity may be affected due to reduced proprioceptive function and knee stabilization capacity. Literature shows that CoP stabilization does not necessarily directly influence velocities in these specific directions but plays a crucial role in maintaining overall stability during gait [14,15].

Complete ACL injury is associated with greater postural instability and an increased risk of falls, especially during postural transitions. This injury therefore alters functional and biomechanical aspects of the knee joint [16].

ACL injury compromises gait control ability, resulting in compensatory adjustments that can increase CoP displacements. Studies indicate that the duration of anticipatory postural adjustments (APAs) may be an indicator of balance control ability during gait initiation [17-19]. Patients with ACL injury tend to have longer durations of APAs, suggesting increased difficulty in maintaining stability during this critical transition.

Thus, mediolateral stability control of the CoP (CoPML) is crucial for the efficiency of gait initiation, as the mechanical energy in the lower limb joints plays a fundamental role in the transition from a static to a dynamic state, an aspect compromised in patients with ACL injury [19-21].

The data indicate a significant reduction in CoP displacements, aligning with the literature that highlights the importance of progressive stabilization during gait initiation. In patients with complete ACL injury, this stabilization is essential for the functionality and safety of movement, helping to mitigate the risks associated with postural instability.

5. Conclusion

The study demonstrated that individuals with complete ACL rupture exhibit adaptations in dynamic balance control during the initial phase of gait. These adaptations include the reduction of CoP displacements in the anteroposterior and mediolateral directions, indicating an effort to achieve greater stability. However, CoP velocity did not show significant differences between the gait phases, suggesting that other compensatory mechanisms may be involved in maintaining balance.

In conclusion, complete ACL rupture impacts dynamic balance control during gait initiation, resulting in compensatory adjustments aimed at increasing stability. Understanding these adaptations is crucial for developing therapeutic interventions targeted at rehabilitation and fall prevention in individuals with this injury.

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