IDENTIFICATION OF COMPENSATORY MOVEMENT PATTERNS IN PATIENTS WITH AMPUTATION USING SEPARATION OF ANGULAR MOMENTUM

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INTRODUCTION

Rehabilitation practice following amputation uses gait training to improve ambulation and reduce adverse effects of overloading the musculoskeletal system [1]. These patients exhibit compensatory movement patterns, which are difficult to treat, and are prone to misidentification through observation. Quantitative biomechanics provides a combination of variables that identify movement compensations (e.g. kinematics, inverse dynamics) [2], which lacks the standardization needed for clinical translation.

Assessing individual angular momentum components of each segment within the context of total angular momentum is a potential method for describing clinical movement compensations. The principal of angular momentum separation indicates two components of total momentum [3]:
1. Transfer Momentum: angular momentum of the segment with respect to the point of reference.
2. Rotational Momentum: angular momentum of the segment with respect to its center of mass (COM).

Referencing transfer momentum to the foot mimics inverted pendulum dynamics, which accurately represent the stance period during gait [4]. Within this framework, these components indicate the ability to achieve forward progression and coordination of segmental rotations.

The objective of this investigation was to assess compensatory movements in patients with amputation using angular momentum separation. We hypothesized that patients with amputation would have similar performance (transfer momentum), but with different segmental strategies (rotational momentum) in all three planes compared to controls.

METHODS

Seven male participants with dysvascular transtibial amputation (age: 54.5±3.8 years, BMI: 27.9±1.0 kg/m²) and seven healthy male control participants (age: 63.7±6.7 years, BMI: 26.1±2.6 kg/m²) performed three gait trials at 1.0 m/s. Motions were recorded from 64 skin markers (100 Hz) and used to create a 15-segment model (Figure 1). Inertial properties of the amputated limb were modified [5].

![Figure 1. Total angular momentum (h_{foot}), transfer momentum (h_{i/foot}), and rotational momentum (h_{i}) with respect to the amputated foot COM (right foot for controls) was calculated for each segment (i). All vectors are expressed in path coordinates (e_{frontal}, e_{sagittal}, and e_{transverse}) defined by the velocity vector of the body COM.](image)

Segment momenta were scaled by participant mass, body height, and walking speed for visualization. Peak (minimum and maximum) transfer momentum during stance period and rotational momentum during entire gait cycle were compared between groups using an ANCOVA (covariates: mass and height) and level of significance set as α=0.05.

RESULTS AND DISCUSSION

The transfer momentum had similar waveforms across segments and progressively larger magnitudes associated with superior segments...
Which corresponds well with the inverted pendulum model of forward progression during gait. Sagittal plane transfer momentum was not different, which corresponds to the similar rate of forward progression (functional performance) between groups (Figure 1). In the frontal and transverse planes, maximum peak momentum of the pelvis was smaller in patients with amputation compared to controls ($P=0.02$, $P=0.01$, respectively) (Figure 2b), and occurred during weight acceptance (0-12% of gait cycle). Smaller momentum during weight acceptance may be a protective strategy adopted at the hip to increase stabilization by reducing segmental speed with respect to the involved limb.

The rotational momentum waveforms were dissimilar across segments (Figure 3). In the sagittal plane, peak momentum of the pelvis was larger in patients with amputation in comparison to controls ($P=0.01$), and occurred during weight acceptance and contralateral heel strike (Figure 3b). Higher momentum of the trunk during weight acceptance is consistent with Trendelenburg gait and increased momentum at contralateral limb heel strike may be a result of impactful loading (exaggerated braking) caused by the lack of the ankle plantarflexor muscle function on the amputated limb. In the transverse plane, peak momentum of the trunk was larger in patients with amputation in comparison to controls ($P=0.02$) (Figure 3a), which is likely a result of decreased rotational stabilization at the hip and pelvis.

**CONCLUSION**

This investigation demonstrates the segmental contributions of transfer and rotational components of total angular momentum taken with respect to the stance foot in patients with amputation and healthy controls during gait. These results indicate that the loss of the ankle plantarflexor muscle function resulted in altered trunk and pelvis momentum in all three planes. Compensatory movement patterns observed at the pelvis and the trunk likely indicate coordination between the hips and low back during gait, which is consistent with previous findings [6]. The compensatory strategies used by patients with amputation may have long-term adverse effects caused by asymmetric and abrupt loading patterns.

**REFERENCES**