REDUCED AND ASYMMETRIC TRUNK STIFFNESS AMONG UNILATERAL LOWER-LIMB AMPUTEES DURING MULTI-DIRECTIONAL TRUNK PERTURBATIONS

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INTRODUCTION

Low back pain (LBP) represents a significant secondary disability among persons with lower-limb amputation [1]. Substantial biomechanical evidence suggests altered and asymmetric movements and muscular control strategies that could alter the mechanics of the spine during amputee gait and locomotion [2]. Spine biomechanics (e.g., loading and stability) are largely influenced by passive mechanical properties of the spine and surrounding trunk musculature. Viscoelastic tissues of the passive spine can develop altered mechanical properties in response to changing loading patterns, rates, and magnitudes [3]. Alterations in amputee gait and locomotion could therefore lead to musculoskeletal imbalances, contributing to further reductions in mobility and causing pain. The goal of the present study was to quantify alterations and/or asymmetries in passive trunk stiffness among unilateral lower-limb amputees (LLAs), using multi-directional trunk perturbations.

METHODS

Six male unilateral LLAs and six male, non-amputee matched controls participated (Table 1), after completing an informed consent procedure approved by the Virginia Tech IRB.

Table 1: Mean (SD) anthropometric characteristics.

	LLAs *(n=6)*	Controls *(n=6)*
Age (yr)	36.5 (19.8)	34.3 (14.5)
Stature (cm)	176.0 (3.2)	174.0 (3.2)
Body mass (kg)	76.7 (11.9)	81.7 (12.1)

Participants were randomly exposed to trunk perturbations in the following directions: anterior, right- and left-oriented lateral bending. During each sequence, participants stood upright and relaxed in a structure that restrained the pelvis and lower limbs. A pseudorandomly-timed sequence of 12 rapid (~40ms) horizontal position perturbations (±5mm) were applied to the trunk at ~T8 via a servomotor (Kollmorgen AKM53K, Radford, VA, USA), rigid rod, and chest harness. The harness was designed such that the rigid connecting rod can be attached with a quick-release pin for connection in both the anterior and mediolateral directions (participants were rotated 90˚ depending on perturbation direction; Fig. 1).

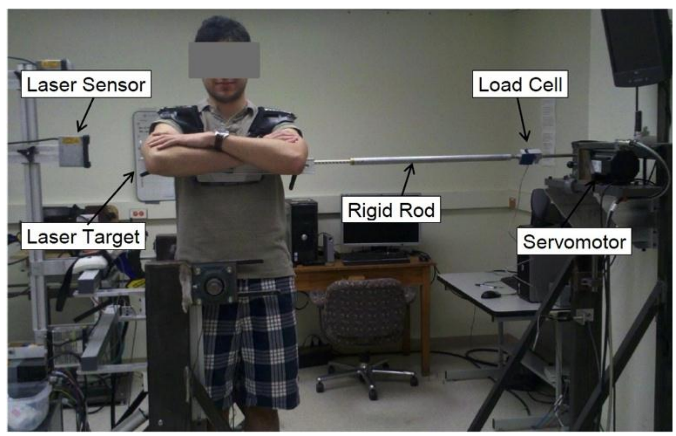

Figure 1: Experimental set-up demonstrating a participant in the left-oriented position. Participants' arms were similarly folded across the chest for all three perturbation directions.

During position perturbations, trunk displacements were measured with a CCD laser displacement sensor (Keyence LKG150, Osaka, Japan) and motor encoder. Applied forces were measured using a load cell in-line with the rigid rod (Interface SM2000, Scottsdale, AZ, USA). All data were sampled at 1000 Hz, and filtered with a 10Hz, bi-directional, low-pass filter [4]. Mechanical properties were estimated by relating measured trunk kinematics to trunk kinetics during each perturbation pulse, and by modeling the trunk/harness-rod connecting device as a 2DOF system [4]. Each degree of freedom has parameters of stiffness, damping, and mass, determined using a least squares curvefit algorithm in MATLAB^{TM}. Trunk damping was assumed to be negligible [5], and was forced to zero for these analyses to better represent changes in stiffness. Curve fits were restricted to the period of movement (~40ms) to ensure that there were no contributions from involuntary muscle reflexes.

Mixed-factor analyses of variance (ANOVA) were used to compare trunk stiffnesses between perturbation directions among LLAs and controls. Statistical analyses were conducted using JMP 9 (SAS Software, Cary, NC, USA), with a significance level of $p < 0.05$. Among LLAs, lateral bending perturbations were identified as ipsilateral or contralateral to the side of amputation, and results were pooled for both right- (n=4) and left-leg (n=2) amputees.

RESULTS AND DISCUSSION

Trunk stiffness was higher among controls than LLAs in all perturbation directions (Fig. 2), a difference that approached significance (p=0.063). There was also a significant group x perturbation direction interaction (p=0.001) on trunk stiffness. Among controls, trunk stiffness was higher (p<0.0001) in right- and left-oriented lateral bending perturbations [15.3 (3.1) kN/m] than anteriorly-directed [13.3 (2.9) kN/m], but bilaterally similar (p = 0.57; i.e., no asymmetries). Larger lateral bending stiffness of the trunk is consistent with previous research [6,7], and is likely caused by additional passive stiffness resulting from the geometry of the trunk musculature in the frontal plane [8]. Among LLAs, however, trunk stiffness was significantly lower (p<0.0001) during ipsilateral perturbations than contralateral perturbations (Fig. 2). Bilateral asymmetries in trunk stiffness may be a result of muscle atrophy ipsilateral to the side of amputation, and hypertrophy of trunk musculature contralateral to the side of amputation.

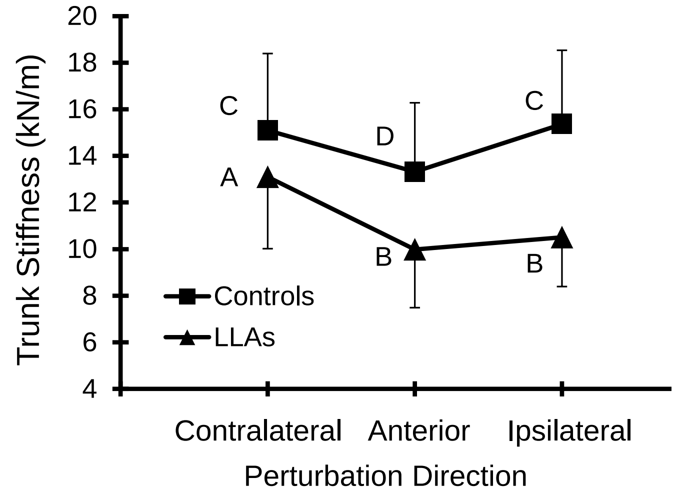

Figure 2: Trunk stiffness among LLAs and matched controls. Letters represent significant within group differences between perturbation directions. Error bars indicate standard deviations.

CONCLUSIONS

Reduced and asymmetric trunk stiffness among LLAs suggests substantial alterations in passive mechanical properties of the spine and surrounding trunk musculature. Further, muscle disuse atrophy could lead to reduced trunk stiffness among LLAs, specifically ipsilateral to the side of amputation, due to preferential use of the intact side of the body. Such reductions and asymmetries in trunk stiffness could represent an increased susceptibility for spinal instability, abnormal spinal loads, and thus an increased risk of LBP among persons with lower-limb amputation.

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