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BRIEF REPORT

Mediolateral Joint Powers at the Low Back Among Persons With Unilateral Transfemoral Amputation

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Abstract

Objective: To analyze mediolateral joint powers at the low back during gait among persons with and without unilateral transfemoral amputation to better understand the functional contributions of tissues in and around the low back to altered lateral trunk movements in this population.

Design: Retrospective analysis of biomechanical gait data.

Setting: Gait laboratory.

Participants: Twenty persons with unilateral transfemoral amputation and 20 uninjured controls (N=40).

Interventions: Not applicable.

Main Outcome Measures: Net joint powers, and total generation (+) and absorption (−) energies, at the low back (L5/S1 spinal level) were analyzed in the frontal plane using inverse dynamics analyses on over-ground gait data collected at self-selected walking speeds (∼1.3m/s).

Results: Compared with uninjured controls, 4 distinctly larger positive phases of mediolateral joint power at L5/S1 were evident in persons with transfemoral amputation, occurring before and after each heel strike. Total generation energies throughout the gait cycle were also larger ($P<.001$) among persons with transfemoral amputation (4.8±1.4J) than among uninjured controls (1.3±0.7J).

Conclusions: Larger positive phases of joint power at L5/S1 in the frontal plane support previous suggestions that persons with transfemoral amputation use a more active mediolateral trunk movement strategy, although such an active trunk movement strategy with transfemoral amputation may contribute to higher metabolic energy expenditures and low back pain risk.

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Regulation of mediolateral balance while walking requires precise control of the body's center of mass within the base of support.[1,2] Lateral displacements of the trunk, despite its substantial mass, are thought to be the result of a relatively passive process, in that the trunk falls toward the stance limb.[3] Persons with unilateral transfemoral amputation walk with increased trunk lateral flexion than do able-bodied individuals.[4,5] Such movements may be a reactive adaptation to walking with a prosthesis, or an active trunk neuromuscular/movement strategy to compensate for weak (or missing) musculature in the residual limb (eg, reducing external adduction moments at the hip or the knee). Existing studies presenting only trunk kinematics in persons with lower-limb amputation cannot entirely explain the net muscular contributions to observed movement patterns. Joint powers, however, are often used to estimate the flow of mechanical energy (ie, generation or absorption) and infer the causes of segmental motions.[6] To provide a better understanding of the functional contributions of tissues in and around the low back to lateral trunk movements in gait among persons with unilateral transfemoral amputation, the primary goal of this study was to calculate mediolateral joint powers at the low back (L5/S1 joint) during over-ground walking. Given that mediolateral trunk movements in uninjured individuals are mostly passive (ie, minimal positive joint power at the low back), we hypothesized that persons with transfemoral amputation would have larger positive (generative) powers at the L5/S1 joint throughout the gait cycle, supporting a more active trunk movement strategy in the frontal plane.

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Methods

Participants

After approval by the local institutional review board, biomechanical data were retrospectively compiled from 20 men with traumatic, unilateral transfemoral amputation and 20 uninjured men who had completed gait evaluations at Walter Reed Army Medical Center or Walter Reed National Military Medical Center and who were analyzed as part of a previous investigation.[7] Specific inclusion criteria were a self-selected walking speed between 1.25 and 1.40m/s, independent ambulation without assistive devices or powered prostheses, and no reported musculoskeletal/neurologic conditions (other than amputation) or pain that may have affected their gait. Participants in the uninjured (control) group were intended to demographically match participants with transfemoral amputation in terms of age, stature, body mass, and self-selected walking speed (table 1). Mean ± SD time since amputation was 3.1±1.4 years.

Experimental procedures and analyses

During each gait evaluation, participants walked at their self-selected walking speed across a 15-m level walkway. A modified Cleveland Clinic marker set was used to track (120Hz) full-body kinematics with a 23-camera motion capture system.[a] Ground reaction forces were simultaneously recorded (1200Hz) from 4 force platforms[b] centrally located and embedded in the walkway. A 15-segment rigid body model was used to compute net joint moments and joint angular velocities at the low back (L5/S1 spinal level) using a top-down approach.[7] Mediolateral joint powers were then determined as the product of net coronal joint moment at L5/S1 (normalized by total body mass) and relative (trunk to pelvis) joint angular velocity.[6] Total generation (+) and absorption (−) energies were calculated as the areas under the power curve across 5 strides, between consecutive heel strikes of the right (control) or intact (transfemoral) foot. Total positive and negative energies were then compared between groups using repeated-measures analyses of variance. All statistical analyses were performed using SPSS (version 21.0),[c] with significance concluded at $P<.05$. Summary values are reported as mean ± SD.

Results

Four distinct positive power phases at L5/S1 were evident among persons with transfemoral amputation, occurring just before and after each heel strike (fig 1). Total generation energies throughout the gait cycle were larger ($P<.001$) among persons with transfemoral amputation than among controls (4.8±1.4J vs 1.3±0.7J, respectively). Two distinct negative power phases at L5/S1 were also evident in both groups, coincident with the onset of single-limb stance (see fig 1), though total absorption energies were similar ($P=.15$) between persons with transfemoral amputation (−1.9±1.0J) and controls (−1.3±0.9J).

Table 1 Participants' characteristics for control and transfemoral groups*

Characteristic	Control Group (n=20)	Transfemoral Group (n=20)	*P*
Age (y)	28.1±4.8	29.2±6.7	.89
Stature (cm)	181.0±6.1	176.2±6.7	.51
Body mass (kg)	83.9±8.6	80.6±12.2	.77
SSW speed (m/s)	1.35±0.05	1.34±0.05	.82

NOTE. *P* values represent group comparisons from unpaired *t* tests.
* Self-selected walking speed is also indicated.

Discussion

Most of the work is performed by the lower limbs in the plane of progression,[8] with previous researchers suggesting that the trunk segment "goes along for the ride."[3] As such, joint powers at L5/S1 are relatively small, and predominantly absorptive in the frontal plane, as eccentric activity of the contralateral trunk musculature (and passive tissue elongation) help control pelvic lateral tilt and maintain an upright trunk posture in single-limb stance.[2] Consistent with this, 2 distinct negative power phases were observed in persons with and without transfemoral amputation. However, and in support of our hypothesis, 4 phases of positive joint power at L5/S1 were observed in persons with transfemoral amputation, which were distinct from those in uninjured controls.

Actively increasing mediolateral trunk sway has been used as an upper-body movement strategy for reducing external adduction moments at the hip/knee in able-bodied individuals.[9] Although previous research had identified increases in mediolateral trunk sway in persons with lower-limb amputation,[4,5] these studies presenting only trunk kinematics could not entirely explain the functional contributions of surrounding tissues to observed movement patterns. In the present study, larger positive mediolateral joint powers at L5/S1 with transfemoral amputation, particularly the phases before heel strike, support increased trunk movements as an active movement strategy. Such an active strategy could also help explain the previously reported relation between reductions in the first peak of internal hip abductor and knee valgus moments with larger lateral trunk lean,[10] though the studied population had unilateral transtibial amputations. The additional positive power phases during stance, while the lateral bend moment at L5/S1 is still acting opposite to the support limb, help return the trunk toward an upright posture for subsequent steps and may also assist hip musculature in controlling pelvic obliquity while facilitating adequate toe clearance during contralateral swing.[11]

Study limitations

Because the studied population consisted of young military personnel with traumatic amputations, the present results may not be generalizable to older or less active individuals with other amputation etiologies. Shorter residual femur length has also been strongly correlated with larger peak trunk lateral flexion in persons with transfemoral amputation,[12] attributed to a lack of hip stabilization from muscular deficiencies (eg, strength or attachment), though such effects on low back kinetics remain to be determined. Joint powers, as computed by the product of net joint moments and angular velocities, also cannot distinguish responses from active versus passive tissues, nor can they partition individual contributions from agonist and antagonist muscles (eg, cocontraction) or biarticular muscles. Collection of individual trunk (and hip) muscle responses would therefore be of interest in future work, allowing muscle-based dynamical simulations and improving causal support between muscle inputs and kinematic outputs.[13]