ORIGINAL ARTICLE

# Three-Dimensional Motions of Trunk and Pelvis During Transfemoral Amputee Gait

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ABSTRACT. Goujon-Pillet H, Sapin E, Fodé P, Lavaste F. Three-dimensional motions of trunk and pelvis during transfemoral amputee gait. Arch Phys Med Rehabil 2008;89:87-94.

**Objectives:** To identify characteristics of upper-body kinematics and torque transmission to the ground during locomotion in a group of patients with transfemoral amputation as compared with a group of asymptomatic subjects; and to investigate the influence of walking velocity and residual limb length on several characteristics of upper-body motion.

**Design:** Three-dimensional gait analysis with an optoelectronic device.

**Setting:** Gait laboratory.

**Participants:** Twenty-seven patients with transfemoral amputation and a control group of 33 nondisabled subjects.

**Interventions:** Not applicable.

**Main Outcome Measures:** Three-dimensional kinematics of the pelvis and the thorax and ground reaction force for amputees and control subjects.

**Results:** For subjects with transfemoral amputation, it was observed that upper-body angular ranges of motion (ROMs) increased globally as walking velocity decreased. For these subjects, specific patterns of pelvic rotation and torque transmission by the lower limbs around the vertical axis were found. The counter-rotation between the pelvic and scapular girdles was reduced. This reduction proved to be linked with the decrease of walking velocity. Walking velocity also affected all the parameters describing the motion of upper body. Pelvic ROM increased with the length of the limb decreasing.

**Conclusions:** The huge differences found between subjects with and without amputation suggest that the motion of the upper body must be considered to enhance gait.

**Key Words:** Biomechanics; Gait; Kinetics; Motor skills; Rehabilitation.



THE GAIT OF PEOPLE with transfemoral amputation differs from that of nondisabled people. Particularly, transfemoral amputees have to adapt to the lack of a physiologic knee, which causes coping response of the entire body. In the literature, many studies on the gait of transfemoral amputees focus on kinematic and kinetic changes of the lower limbs.[1-3]

Other studies show the essential role of trunk movement in human gait. The interaction between the pelvis and the thorax[4,5] seems to have particular importance. Typical patterns of motion are available for pelvis and trunk[6-8] during the gait of healthy subjects. The motion of pelvis and trunk is 3-dimensional, so it is essential to define planes and axes used to describe the movements. Throughout this article, we use terminology proposed by Baker.[9] Obliquity occurs in the sagittal plane, which is defined by the $z$ axis pointing to the right. Tilt is the movement around the $x$ axis, occurring in the frontal plane and defined by the $x$ axis pointing forward. Finally, rotation is the movement occurring in the transverse plane, defined by the $y$ axis pointing upward. The relative phase between the pelvic and the thoracic transverse rotations is often used[10] to quantify the counter-rotation that occurs between the 2 segments. For example, a relative phase of 180° signifies a perfect counter-rotation between pelvic and thoracic girdles. Upper-body coordination depends on the control of this counter-rotation. This relative phase is sensitive to walking velocity[11] and load carriage.[12] This sensitivity reflects the importance of upper- and lower-body coordination during gait.

Wagenaar[13] and Van Emmerik[14] and colleagues both show a decrease in counter-rotation between the pelvis and the thorax, characterized by a reduction of relative phase differences, for hemiplegic and parkinsonian patients. This decrease is also observed by Selles et al[15] for patients with low back pain (LBP). Selles explains this loss of counter-rotation by an increase of axial rigidity of the trunk. To quantify counter-rotation of pelvis and thorax, Van Emmerick, Wagenaar, Selles and colleagues[11,13-15] used the mean relative phase calculated between the 2 curves of pelvic and thoracic rotations in the transverse plane. In these studies, walking velocity is controlled using a treadmill. Thus, Van Emmerik[11] showed the predominant effect of walking velocity on the different parameters describing pelvic and thoracic motions in the transverse plane. Moreover, some authors[4,12] suggest that the upper torso and lower torso counter-rotate to reduce the net angular momentum of the body. Thus, a modification of upper-body kinematics should involve a modification of lower-body kinetics.

Few studies have investigated upper-body motion in transfemoral amputees. Cappozzo et al[16] used both the axis passing through acromial processes and the axis passing through tubercules of the iliac crests to determine thoracic and pelvic angular positions. In their study, Cappozzo calculated the angles of the projections of these lines on the frontal and transverse planes during gait. Cappozzo performed a Fourier analysis to study the harmonics that compose the signals. Their study shows that compared with normal gait, the gait of transfemoral amputees is characterized by remarkably larger amplitudes in all rotations considered. Cappozzo found a superior tilt of the pelvis on the side of the swinging leg in contrast to asymptomatic subjects. Finally, Cappozzo described a different pattern of pelvic rotation during the stance phase for transfemoral amputees. The limitation in Cappozzo's conclusions lies in the fact that the study did not perform a 3-dimensional analysis and the subject group was limited to 4 patients.

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Sjödahl et al[17] focused on pelvic motion in the frontal and transverse plane before and after special gait re-education, but did not study thoracic motion. The findings are consistent with those of Cappozzo as they relate to the angular pattern of the pelvis in the frontal plane. Moreover, the study showed that asymptomatic pattern is not recovered after re-education for this motion.

Tazawa[18] examined 3-dimensional pelvic and thoracic movements of 12 patients with transfemoral amputation. He identified a group of "good walkers" among these patients and compared the good walkers with the others. He concluded that the good walkers had more limited range of motion (ROM) for the pelvis and the shoulder in the frontal and transverse planes. However, he did not analyze the relative motion of the 2 segments and did not report any curves representing the evolution during gait of the shoulder and pelvis angular positions.

The major limitation of these 3 studies is the number of subjects who participated. The sample sizes do not allow us to quantify the effect of walking velocity on the different parameters but the studies on other pathologies[13,14] show its influence.

The aim of the present study was to identify specific 3-dimensional motion patterns for the pelvic and scapular girdles during gait of patients with transfemoral amputation using a wide patient sample with a specific focus on the relationship between the pelvic and scapular transverse rotations. One of the purposes was to investigate the effect of walking velocity on the parameters of pelvic and thoracic motions to determine how it affects these parameters for amputees compared with asymptomatic subjects. A number of parameters (amplitude of pelvis and thorax motion, relative phase, duration of stance phase, step lengths) were calculated for both groups. The first hypothesis of this study is that the amplitudes of pelvic and thoracic motions increase for patients with amputation, which can weaken stabilizing muscles like hip abductors. The second hypothesis is that the counter-rotation between the pelvis and the thorax decreases for transfemoral amputees (which has not been proven by anterior studies concerning upper-body motion of amputees during gait).[16-18] We suggest that this decrease is linked to a decrease of walking velocity for these subjects. Moreover, taking into account the narrow link between the dynamic angular momentum of the body and the external torque exerted on the body, the torque around the vertical axis transmitted by the lower limbs to the ground at the center of pressure is also examined. Finally, Jaegers et al[19] showed that there is an atrophy of muscles of subjects with above-knee amputation. In particular, the amount of atrophy of hip abductors depends on the level of amputation. The higher the amputation level, the more the muscles are atrophied. We consequently hypothesized that the amplitude of pelvic frontal motion is linked to the extent of musculature preserved by the amputation and so directly to the level of amputation. To prove this, we investigated the link between the amplitude of pelvic motion in the frontal plane and the residual limb length.

## METHODS

### Participants

We included 27 patients with transfemoral amputation (group A) and 33 asymptomatic subjects (control group) in this study. Patients' mean age was 50.9 years (range, 28–73y). None used an assistive device during gait. Each patient's prosthetic fitting and medical follow-up were done at the Centre d'Etudes et de Recherche pour l'Appareillage des Handicapés (CERAH). Residual limb length was measured by a physician between the anterosuperior iliac spine of the pelvis and the extremity of the residual limb. Clinical and prosthetic data are presented in table 1. The control group's mean age was 44.3 years (range, 28–61y).

**Table 1: Patient Characteristics for Amputees**

| Patient | Age (y) | Time Since Amputation (y) | Etiology | Length of the Residual Limb (mm) | Prosthetic Knee |
|---|---|---|---|---|---|
| S1 | 33 | 9 | Traumatic | 413 | Polycentric |
| S2 | 46 | 24 | Traumatic | 413 | Monoaxial |
| S4 | 38 | 34 | Traumatic | 413 | Monoaxial |
| S10 | 67 | 46 | Traumatic | 350 | Monoaxial |
| S12 | 39 | 22 | Traumatic | 413 | Monoaxial |
| S17 | 37 | 17 | Traumatic | 413 | Polycentric |
| S21 | 66 | 38 | Traumatic | 350 | Monoaxial |
| S22 | 64 | 41 | Traumatic | 316 | Monoaxial |
| S23 | 45 | 19 | Traumatic | 350 | Monoaxial |
| S24 | 34 | 11 | Traumatic | 320 | Monoaxial |
| S26 | 73 | 61 | Traumatic | 330 | Monoaxial |
| S27 | 46 | 19 | Traumatic | 390 | Monoaxial |
| S28 | 59 | 4 | Tumoral | 375 | Polycentric |
| S29 | 37 | 5 | Traumatic | 380 | Polycentric |
| S30 | 54 | 4 | Traumatic | 410 | Polycentric |
| S31 | 47 | 32 | Traumatic | 480 | Monoaxial |
| S32 | 71 | 30 | Traumatic | 420 | Monoaxial |
| S33 | 58 | 37 | Traumatic | 315 | Monoaxial |
| S34 | 59 | 56 | Congenital | 490 | Monoaxial |
| S35 | 57 | 38 | Traumatic | 430 | Monoaxial |
| S36 | 28 | 7 | Traumatic | 420 | Monoaxial |
| S37 | 37 | 13 | Traumatic | 460 | Polycentric |
| S38 | 32 | 15 | Tumoral | 280 | Polycentric |
| S39 | 71 | 49 | Traumatic | 340 | Monoaxial |
| S40 | 48 | 4 | Traumatic | 310 | Monoaxial |
| S41 | 67 | 47 | Traumatic | 345 | Monoaxial |
| S43 | 62 | 43 | Traumatic | 420 | Polycentric |

### Protocol

All experiments took place at the gait laboratory of CERAH. Both kinematic and kinetic data were collected according to the protocol described by Goujon et al.[20] Twelve Vicon[a] cameras and 2 forceplates[b] were used in the same way as in previous experiments.[20] Patients were asked to walk on a 9-m long path at their self-selected speed. For each patient, at least 10 trials were recorded.

### Method

To assess the movements of the upper-body during gait, we defined 2 segments: the pelvis and the thorax. We recorded the positions of 3 reflective skin markers pasted on each segment.

For the pelvis, the marker's location and the anatomic frame definition were chosen according to the recommendations of the International Society of Biomechanics.[21,22]

For the thorax, we placed the markers on the left and right acromion processes and over the C7 vertebra. The anatomic frame was calculated as follows: the origin was defined at the midpoint between the left and the right acromion processes; the $z$ axis was the line passing through the acromion and pointing to the right. It defined the sagittal plane. The $x$ axis was located in the plane defined by the acromion and C7 and pointed forward. It defined the frontal plane. The $y$ axis was orthogonal to the $x$,$z$ plane, pointing to the proximal part of the segment and defined the transverse plane. This kind of frame, based on