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Symmetry of Body Weight Pressure Distribution on Sound Limb Foot of Unilateral Amputees During Walking

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Abstract

Background and purpose: Gait asymmetry represents one of the primary issues for individuals with unilateral amputations of the lower limbs in order to prevent excessive stress on the sound leg.

Aim of the work: To analyze pressure distribution through the foot of the sound limb to evaluate the mechanical risk factors in unilateral amputees.

Patients and methods: We included 30 subjects classified into 15 traumatic unilateral trans-femoral or trans-tibial amputees without advanced osteoarthritic changes or foot deformities and 15 normal individuals as a control group. All patients have undergone careful history-taking, including a sound limb investigation for skin integrity and sensation, muscle power, and joint range of motion, along with pressure distribution with my Walkway Tekscan device.

Results: A comparison study between the two groups in the examined population demonstrated a significantly significant decrease in S-A surface area in the amputated limb in the case group in comparison with the control group ($P < 0.001$). Moreover, we discovered a highly significant decrease in SA force in the amputated leg in the case group in comparison with the control group ($P < 0.001$). Furthermore, comparative research between the two groups demonstrated a very significant increase in SA area% change and S-A force% change in the case group in comparison with the control group ($P < 0.001$).

Conclusion: To conclude, our study found that when comparing cases to controls, both sound limb to amputation area and force % changes were considerably larger in cases, indicating overloading on the sound limb when walking.

Keywords: Amputees, Pressure, Symmetry, Walking

1. Introduction

Amputees of the lower limb are significantly more active now than they were in previous decades. Amputees' capacity to adjust to the partial loss of their lower legs has improved as a result of amputation procedures, after-surgery rehabilitation, and prosthetic improvements. In unilateral lower-extremity amputees, asymmetry is connected to adaptation to the loss of function of one or more joints. Previous studies have observed muscle asymmetry, with atrophy on the amputation side and hypertrophy on the intact leg, as well as loading asymmetry, with the intact limb having a larger vertical ground response force than the prosthetic extremity.

There are around 2 million people living with limb loss in the United States (1). The most common reasons for limb loss include trauma (45%), vascular diseases (54%), which include peripheral artery disease and diabetes, and cancer (<2%). Up to 55% of diabetics who have had a lower extremity amputation may need a second leg amputation within the next 2–3 years.1

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The fundamental objective of therapy for amputees of the lower limbs is to re-establish as much of their normal gait as possible. The most appropriate components should be used in prosthetic systems to facilitate normal gait function. Gait asymmetry is a key issue for those who have had a unilateral lower extremity amputated in order to minimise undue stress on the sound limb.

Asymmetrical elements of amputee gait have been described using kinematic and temporal data. Temporal variables such as stride length, cycle length, and stance time for trans-tibial and trans-femoral amputees have demonstrated a longer stance time on the intact limb due to a reluctance or inability to spend more time in single support on the prosthetic limb, and thus a shorter swing time on the intact limb to maintain walking speed.

This study was carried out to examine the mechanical risk factors in unilateral amputees by evaluating pressure distribution through the foot of the sound limb.

2. Patients and methods

2.1. Patients

In our case-control research, 30 people participated.

Patients were picked up from the Armed Forces Physical Medicine, Rheumatology, and Rehabilitation Centre in Cairo.

Age: 18–60, Sex: men and females, traumatic amputation, and one limb amputation (Trans-femoral or Trans-tibial) were the inclusion criteria.

Exclusion criteria included surgery on a sound limb, diabetes, vascular disorders, peripheral artery illnesses, cancer, and congenital limb loss.

This research involved thirty patients. They were split into two groups: 15 traumatic unilateral trans-femoral or trans-tibial amputees without advanced osteoarthritic alterations or foot deformities and 15 healthy controls comprised the case group.

2.2. Methods

Patients underwent the following procedures: meticulous history taking, complaint, assessment of other systems, prior history, drug intake, surgical procedure or blood transfusion, and current medication.

My Walkway Tekscan gadget was used to do a thorough limb evaluation for skin integrity and feeling, muscle strength, joint range of motion, and pressure distribution.

Written informed consent was given by each patient.

2.3. Statistical analysis

Data entry, processing, and statistical analysis have been performed using SPSS 25. It was decided to use the tests of significance (Mann-Whitney, χ², and Spearman’s correlation).

3. Results

The 30 participants investigated were divided into 15 traumatic unilateral trans-femoral or trans-tibial amputees without advanced osteoarthritic alterations or foot deformity and 15 controls.

Patient age and Sex (P > 0.05) were not significantly different between the two groups, according to comparative examinations (Table 1).

Comparative investigations between the two groups demonstrated no statistically significant differences in the degree and laterality of amputation or sound limb (P > 0.05) (Table 2).

Comparative examinations between the two groups found that there was no significant change in S-A average pressure in both amputee and sound limbs (P > 0.05). The S-A surface area in the severed leg (P 0.001) was significantly reduced in the case group. S-A surface area in the sound limb (P > 0.05) did not change significantly. A highly significant drop in SA force in the severed leg (P 0.001) has

Table 1. Age and sex comparisons between cases and controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Case (n = 15)</th>
<th>Control (n = 15)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>34.3 ± 13.1</td>
<td>30.3 ± 13.9</td>
<td>0.405*</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>11 (73.3)</td>
<td>12 (80)</td>
<td>1.000b</td>
</tr>
<tr>
<td>Female</td>
<td>4 (26.7)</td>
<td>3 (20)</td>
<td></td>
</tr>
</tbody>
</table>

* Mann-Whitney test.

b Chi-Square test, for quantitative variables.

Table 2. Level of amputation and sound limb comparisons between cases and controls.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Case (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT</td>
<td>10 (66.7)</td>
</tr>
<tr>
<td>TF</td>
<td>5 (33.3)</td>
</tr>
<tr>
<td>Amputee limb</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>4 (26.7)</td>
</tr>
<tr>
<td>Left</td>
<td>11 (73.3)</td>
</tr>
<tr>
<td>Sound limb</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>11 (73.3)</td>
</tr>
<tr>
<td>Left</td>
<td>4 (26.7)</td>
</tr>
</tbody>
</table>

Data described as number (percentage).
be observed in the case group. In the sound limb ($P > 0.05$), there was not a statistically significant change in SA force. Both the SA area% change and the S-A force% change ($P < 0.001$) were significantly higher in the case group. In terms of SA pressure% change ($P > 0.05$), there was no significant difference (Table 3).

Association tests on a case group of patients revealed a non-significant association between SA pressure, area, forces with their percent changes. 

Data described as median (25th-75th percentiles).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Case ($n = 15$)</th>
<th>Control ($n = 15$)</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average pressure A</td>
<td>705 (670–744)</td>
<td>773 (688–805)</td>
<td>0.065</td>
</tr>
<tr>
<td>Average pressure S</td>
<td>713 (631–733)</td>
<td>745 (673–788)</td>
<td>0.068</td>
</tr>
<tr>
<td>Area A</td>
<td>130 (111–154)</td>
<td>177 (166–198)</td>
<td>0.000</td>
</tr>
<tr>
<td>Area S</td>
<td>179 (166–189)</td>
<td>177 (157–189)</td>
<td>0.709</td>
</tr>
<tr>
<td>Force A (1000)</td>
<td>87.1 (82.6–101.2)</td>
<td>136.7 (115–152.8)</td>
<td>0.000</td>
</tr>
<tr>
<td>Force S (1000)</td>
<td>124.3 (115.2–131.9)</td>
<td>126.9 (112.4–140.8)</td>
<td>0.310</td>
</tr>
<tr>
<td>SA pressure % change</td>
<td>$-0.8 (-4.1–3.2)$</td>
<td>$-3.5 (-5.5 to -1.4)$</td>
<td>0.290</td>
</tr>
<tr>
<td>SA area % change</td>
<td>$40.4 (29.7–48.9)$</td>
<td>$-3.4 (-7.1–1.8)$</td>
<td>0.000</td>
</tr>
<tr>
<td>SA force % change</td>
<td>$34.3 (18.2–48.9)$</td>
<td>$-7.4 (-10.6–0.7)$</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Fig. 1. Distribution of Area A and Area S between cases and controls.

Fig. 2. Distribution of Force A and Force S between cases and controls.

Fig. 3. Distribution of SA pressure, area and force% changes between cases and controls.

Fig. 4. Distribution of SA force % changes between cases and controls.

Table 3. Comparison between cases and controls regarding SA Average.
sound limb (P > 0.05) and changes in SA pressure, area, or force% in the case group. Age and SA pressure, area, and force% changes (P > 0.05) in the case group did not significantly associate (Figs. 1–4, Table 4).

4. Discussion

This was case-control research with 30 people divided into 15 traumatic unilateral trans-femoral or trans-tibial amputees without advanced osteoarthritic alterations or foot deformities and 15 control persons.

Plantar pressure analysis yields a wealth of data that may be used to aid in the diagnosis of lower limb diseases, footwear design, body biomechanical faults, prevention of musculoskeletal impairments, and other applications.4

This study’s objective was to assess and analyze plantar pressure and force distribution across the foot of people who have suffered traumatic lower extremity loss versus able-bodied people when walking. According to de Castro et al. (2014), people with lower limb amputation exhibit worse physical function scores than their able-bodied counterparts, indicating restrictions in conducting daily life activities and asymmetry in gait.5

We employed platform systems in our study, which are made up of a rigid, flat array of pressure sensing devices organised in a matrix arrangement and implanted in the floor to permit natural stride. For this kind of research, dynamic, static, and postural research can be employed. One of the benefits of utilising the platform type is that it is more convenient to use since it is level and fixed, but the patient must become acquainted to ensure that he is walking in his normal stride. Furthermore, foot contact with the centre of the sensing area is critical for precise findings.4

In our analysis, we discovered that the majority of trans-femoral amputations (33.3%) and trans-tibial amputations (66.7%) were carried out. According to the 2007 National Amputee Statistical Database (UK) (NASDAB), 50% of lower limb amputations are trans-tibial, and trans-femoral amputations account for 34%.

However, when other researchers examined the centre of pressure,6,7 lower limb kinematics,8 and joint moment,9 they discovered an uneven pattern when the person with trans-femoral amputation walked.

Royer and Koenig (2005) discovered indications indicating the possibility of early knee joint deterioration in the sound limb, indicating stress on the sound limb when walking.9

In terms of SA pressure, area, and force% changes among the cases alone, we discovered no statistically significant difference between trans-femoral and trans-tibial amputation level, side, or Sex. This is consistent with Nolan et al., 2003.10

For trans-tibial or trans-femoral amputees, Nolan et al. (2003) found no significant association among prosthetic and intact extremities at the 5% level for any variable.10

In our investigation, we discovered that both sound limb to amputation area and force% changes were substantially larger in cases than in controls.
with \( P = 0.000 \), indicating overloading on the sound limb when walking. The large change in surface area has an effect on the average pressure, which is reflected in the force. This is consistent with the findings of Nadollek et al., 2002, Nolan et al., 2003, Castro et al., 2014, Claret et al., 2019, Shojaei et al., 2019, Winiarski et al., 2021, Ichimura et al., 2022, and Kobayashi et al., 2023.

According to Nadollek et al., 2002, substantially greater weight was placed on the intact limb compared to the severed limb.\(^{11}\)

According to Nolan et al., 2003, the larger stress on the intact extremity might be a technique used by amputees to acquire more temporal symmetry for walking quickly. This hypothesis may also explain why the intact extremity experiences a higher incidence of degeneration of the joints.\(^{10}\)

Each of the participants also had a (non-significant) weight-bearing asymmetry favouring the limb that wasn’t severed. The dynamic balance control ratio revealed that the contributions of both legs to balance control were significantly unequal.\(^{12}\)

On the other hand, Schmid et al. (2005) found that there was an imbalance in both temporal and spatial dimensions of quantifying centre of pressure (CoP) patterns among the sound and the prosthetic leg.\(^{7}\)

According to Lloyd et al. (2010), four characteristics in the amputee group were asymmetrical in comparison with the control group. Asymmetry in knee flexion strength was only moderately correlated with the vertical ground response force of the intact limb, while asymmetry in knee extension strength was highly connected to asymmetry in the rate of knee adduction moment load.\(^{13}\)

Castro et al. (2014) also reported that the thrust, braking, and propulsive peaks, as well as the braking and propulsive impulses, had been significantly reduced in the severed leg in comparison with the intact limb (\( P = 0.05 \)) and able-bodied individuals (\( P = 0.05 \)).\(^{5}\)

The mean CoP distance, CoP velocity, and sway area all increased significantly (\( P = 0.001, 0.001, \) and 0.007) for amputees, according to Claret et al., 2019. Amputees took an unbalanced position.\(^{14}\)

Shojaei et al., 2019 also revealed that individuals with amputations had higher peak compression, medio-lateral (just during stand-to-sit), and anteroposterior shear forces than individuals without amputations, respectively, by 348 N, 269 N, and 217 N.\(^{15}\)

Furthermore, Shojaei et al. (2019) determined that although the spinal loads in individuals with amputations were higher, such loads were often lower compared to the established threshold for spinal damage. A very slight rise in spinal loads during routine daily activities such as walking, sitting to standing, and standing to sitting, however, may offer an elevated risk of fatigue failure for spinal tissues due to the repeated nature of these activities.\(^{15}\)

Winiarski et al. (2021) demonstrated that the symmetry function is a useful tool for finding areas of asymmetry and dominance of limbs during the walking cycle. According to the Symmetry Function, the pelvis and hip exhibited the biggest discrepancy between sides. The pelvis was asymmetrically tilted in the sagittal plane at 60% cycle time, achieving a maximum SF value of more than 25%.\(^{16}\)

Ichimura et al. (2022) also showed that the COP trajectories of UTFA patients had much more lateral asymmetry and variability than those of healthy controls, but not anterior-posterior variability.\(^{17}\)

Kobayashi et al., 2022 also observed that step frequency had substantial major impacts in various parameters (\( P = 0.01 \)). Peak ground reaction forces (GRF) and GRF impulse characteristics indicating strong primary impacts tended to decrease in magnitude as step frequency increased. Between the limbs, from 5% to 0% metronome frequency, the peak vertical GRF showed the most symmetrical values. With increasing step frequency, all factors that had a significant influence on the asymmetry ratio grew more asymmetric.\(^{18}\)

Between people who had unilateral trans-femoral amputation and people with normal health, Kobayashi et al. (2023) found statistically significant differences in the asymmetry ratios for peak vertical ground reaction force, anterior-posterior ground reaction force, anteroposterior shear, as well as mediolateral shear. Patients who have a unilateral trans-femoral amputation continue to experience asymmetrical loads during double-limb stance.\(^{19}\)

4.1. Conclusion

To conclude, our study found that when comparing cases to controls, both sound limb to amputation area and force % changes were considerably larger in cases, indicating overloading on the sound limb when walking.

Conflicts of interest

None.

References


