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With a Spring in One's Step

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Introduction

In recent years, there has been a significant number of new developments in prosthetics in both North America and Europe. New concepts for socket molding, knee control, dynamic foot action, and the utilization of space-age materials have expanded prosthetic development and performance.

The traditional prosthetic foot had a keel and an articulated ankle. This concept has modern derivatives with multi-axis ankles, but the principle remains the same. The S.A.C.H. foot design is that of the solid ankle and cushioned heel. By virtue of a compressible heel of a selected rubber density, the wearer achieves a simulated ankle motion at heel strike.[1] This design has been a mainstay in prosthetic fabrication for several decades. These feet are both essentially passive and accommodating. The Seattle foot, with its cushioned heel and keel spring action, stores energy through the stance phase of gait and releases it at toe-off, thus imparting a dynamic component to gait.[2] An added feature of this foot is that of cosmetic molding.

The principle of dynamic toe-off to improve the mechanical efficiency of the prosthesis is an attractive one, and it forms the basis for the design of the Seattle foot. The purpose of this study is to evaluate the performance of the Seattle foot and subjectively and objectively determine whether or not it improves prosthetic gait.

Clinical Investigation

A questionnaire was designed to gather general demographic data and review foot function in general living situations. Thirty-three patients were identified in the last two years as having been fit with a Seattle foot, and 31 (94%) responded to the questionnaire. There were 27 males and four females. The age range was from 24 years to 72 years (Figure 1).

The weight of the patients ranged from 95 pounds to 195 pounds and their height ranged from 5′1″ to 6′4″.

Amputation dates ranged from 1930 to 1986, with over half of the respondents having been injured since 1975.

On average, each patient had 3.75 surgical procedures, with a range from 1 to 24.

The length of time from amputation to prosthetic fitting was, for the most part, under one year (Figure 2).

The original foot supplied in most cases was a S.A.C.H. foot. The next most frequent, in order, was a single axis ankle with a keel foot. The remainder are unknown. A significant number of the candidates had been using their original foot an average of 14 years before having it changed to a Seattle foot. For the

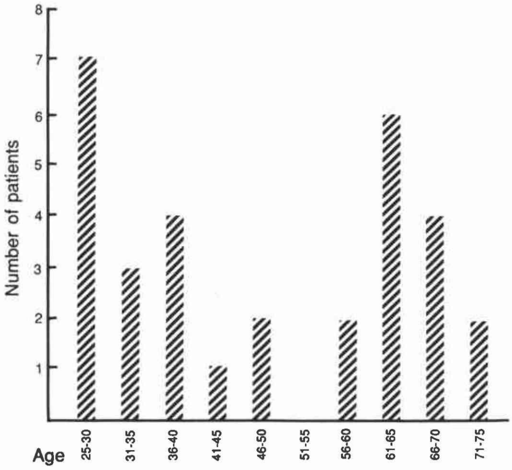


Figure 1. The age range was from 24 to 72 years.

most part, people were attracted to the Seattle foot because of a better design and newer technology. They wished for added spring, flexibility, and mobility in the foot. Some simply tried it because it was recommended by staff, or because they liked the cosmetic appearance.

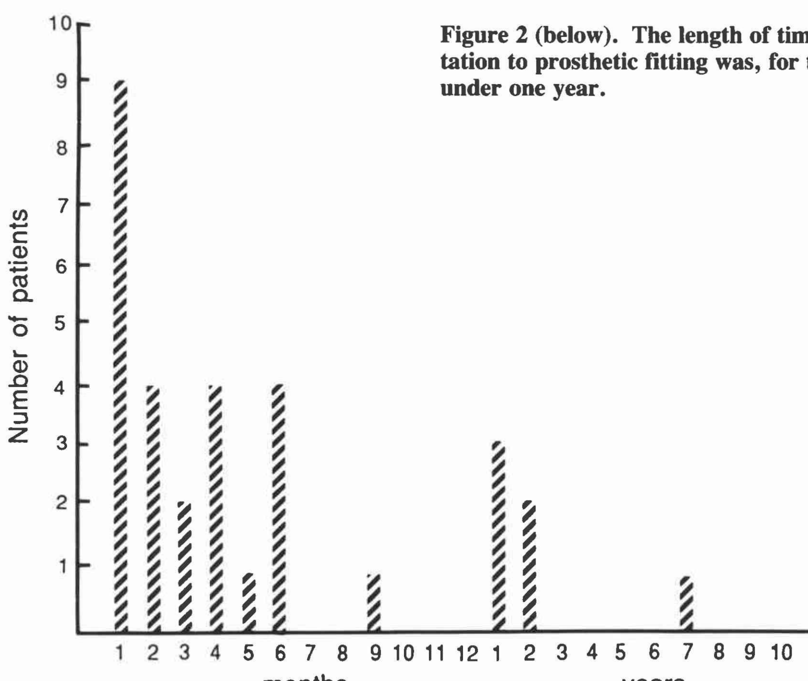
The length of time for use of the Seattle foot ranges from one month to two years with an average of 8.5 months (Figure 3).

The Seattle foot was fit on 29 below-knee amputees and two above-knee amputees.

The heel stiffness in the Seattle foot was rated as acceptable in 80% of cases. Twelve percent (12%) felt it was too stiff. Eighty-one percent (81%) of respondents felt that they had good ankle motion with the Seattle foot, and 19% felt they did not. Seventy-four percent (74%) of respondents felt that the ankle motion was greater than with the previous foot, 16% felt it was the same, and 10% felt less ankle motion.

When questioned about the shock stress at the hip or knee, 55% felt there was decreased shock stress and 39% felt that there was no change.

Figure 2 (below). The length of time from amputation to prosthetic fitting was, for the most part, under one year.



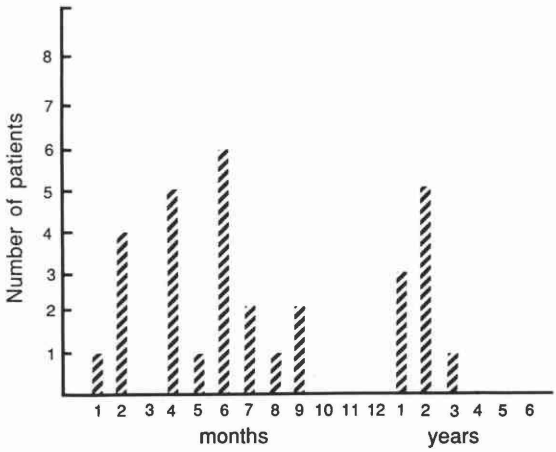


Figure 3. The length of time for use of the Seattle foot ranges from one month to two years, with an average of 8.5 months.

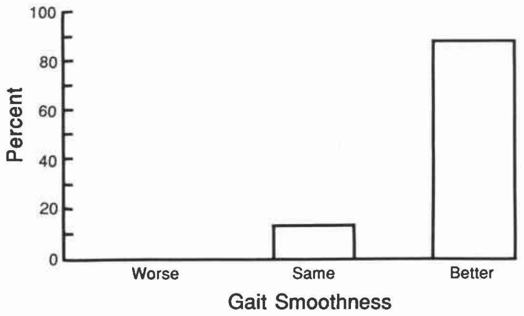


Figure 4. The greatest advantages with the Seattle foot were a more natural and smooth action.

When questioned about the effect of the Seattle foot on changing gait, 87% felt it was better and 13% felt it was the same.

Eighty-seven percent (87%) were aware of toe-off action in the Seattle foot and 13% were unaware of it. The toe-off action was most noticeable when accelerating quickly, climbing up or down, playing ball sports, and running or walking on uneven ground. Forty-eight percent (48%) of the respondents would have preferred greater toe-off action, whereas 52% were satisfied with the toe-off.

Half the respondents felt the Seattle foot had made a general difference to their recreational pursuits. When specific activities were rated, at least 50% of respondents felt that walking, going up and down stairs, hiking, dancing, and jogging were consistently easier than with the previous foot.

Balance and endurance on the prosthesis was felt to be easier by about 61% of the respondents and smoothness was better in 87%.

Uneven terrain was considered easier by 74%, but 3% said it was more difficult. In fact, the Seattle foot does not provide as much forefoot flexibility in the medial-lateral plane as with an articulated ankle joint.

Walking and running was easier for 67% of the respondents (48% of the patients jogged). Of the 61% who dance, 74% found it easier.

Of those people responding negatively to the Seattle foot, the pattern was either negative responses throughout the questionnaire (by four respondents) or negative responses for certain

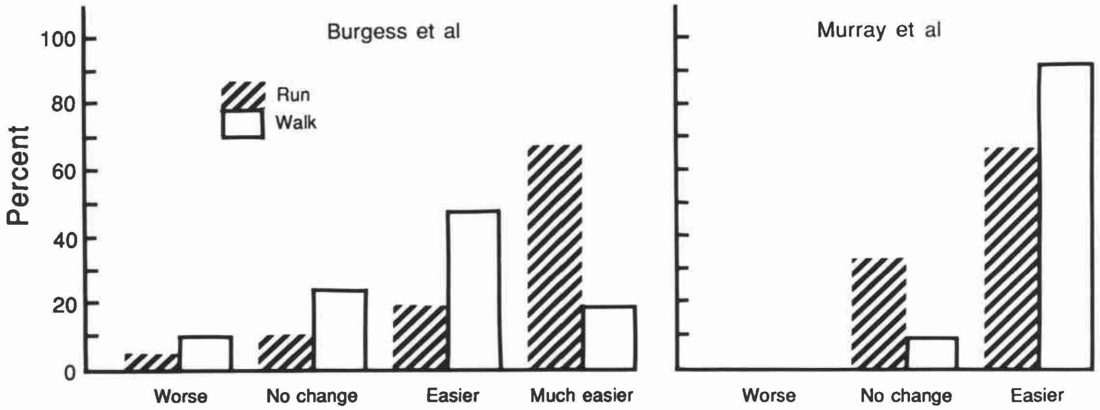


Figure 5. A comparison of two clinical surveys of the Seattle foot for running and walking.

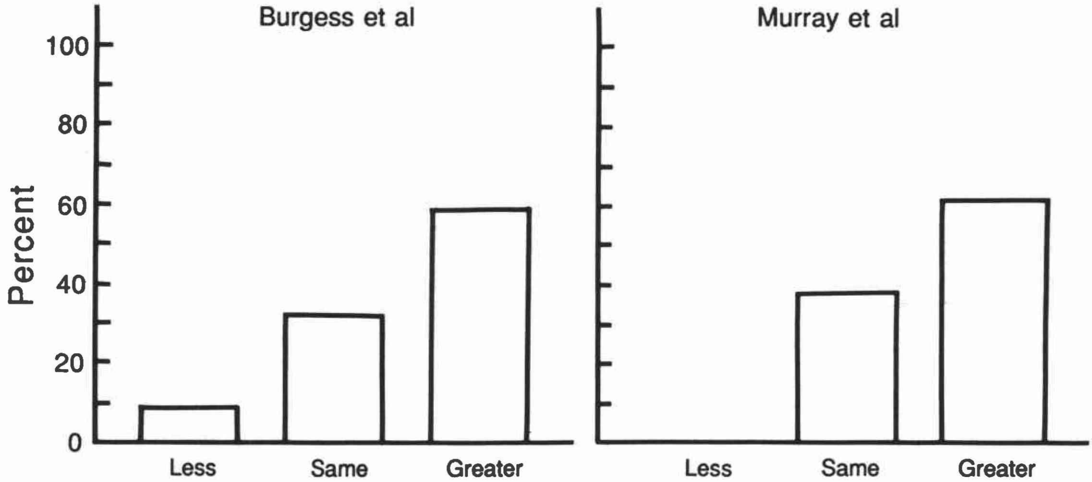


Figure 6.

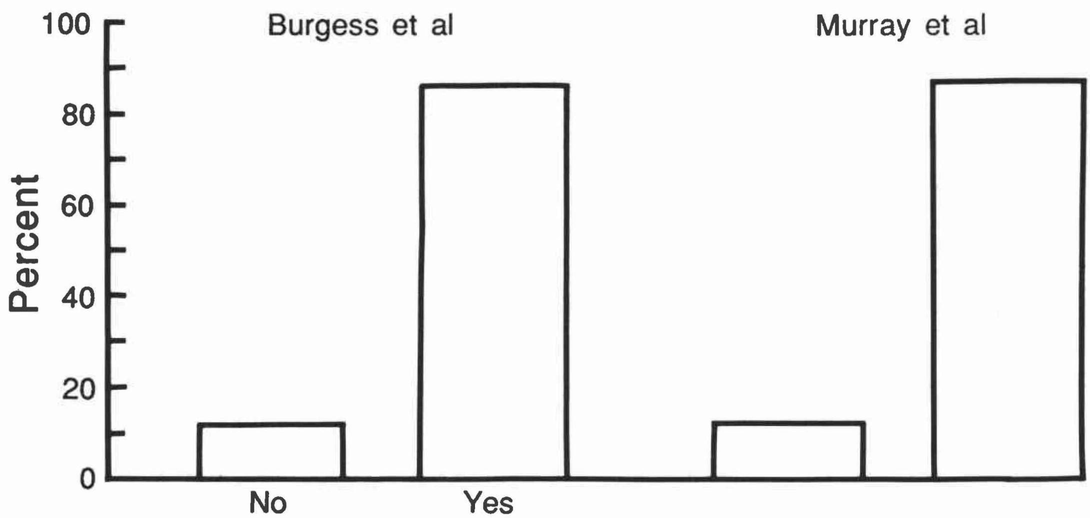


Figure 7.

functions, such as the half who felt there was no difference in the recreational pursuits. Of these negative responses, there was no pattern either in terms of age, weight, or amputation site.

The greatest advantages with the Seattle foot were reported to be a more natural and smooth action, resulting in an improved gait (Figure 4), better ability to handle stairs and uneven ground, and improved abilities in sports.

The cosmetic design and the anatomical detail were appreciated by 97% of the respondents.

Residual limb pain was felt to be decreased in 39% of respondents and unchanged in 45%. Sixteen percent (16%) did not respond to this question. The foot design had not been expected to have any effect on this problem.

Skin problems were felt to be decreased in 55% of the respondents. Thirty-five percent (35%) said there was no change. The foot design was not expected to improve this clinical problem either.

The Department of Veterans Affairs in Seattle has reported an evaluation of the Seattle foot.[3] Although a comparison of amputee

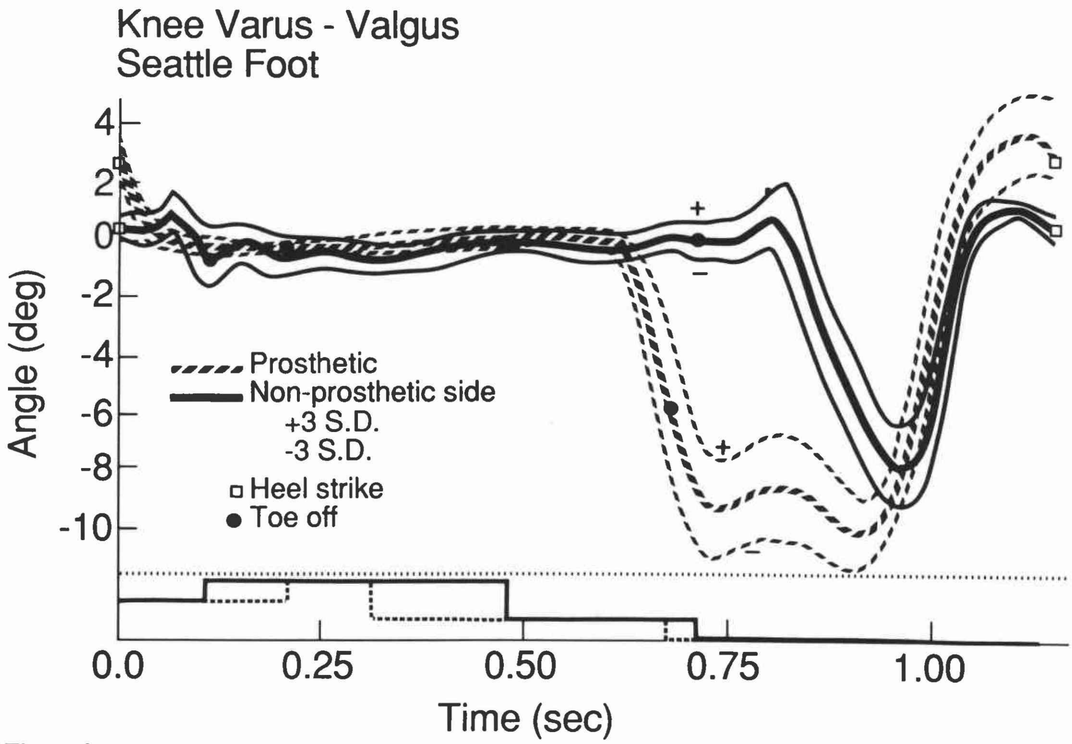


Figure 8.

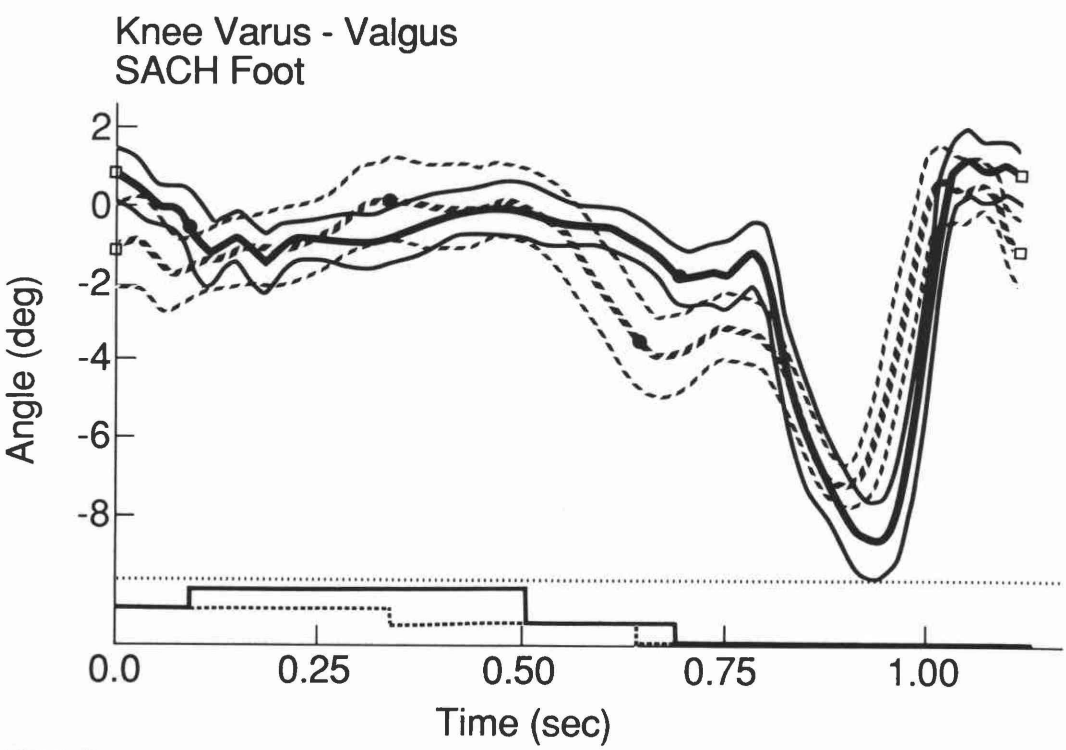


Figure 9.

groups was not possible, the results of this clinical survey compare favorably with the original study. Figures 5, 6, and 7 graphically demonstrate the comparison.

Laboratory Investigation

Electrogoniometric Evaluation

A gait study using a single amputee with many years experience with a S.A.C.H. foot and several years experience with the Seattle foot was undertaken at the G.F. Strong Gait Laboratory.

Motion in the lower extremity was analyzed using a computerized electrogoniometric system. This system accurately measures movement in three planes at the hip, knee, and ankle and stores data for subsequent analysis.[4] The S.A.C.H. foot, Seattle foot, and non-prosthetic side were compared.

Patterns of movement measured at the hip were similar for the S.A.C.H. and Seattle feet and resembled those seen on the non-prosthetic side. At the knee, the Seattle foot produced a more repeatable pattern of internal-external rotation and varus-valgus than did the S.A.C.H. foot (Figures 8 and 9).

The greatest differences between the S.A.C.H. and Seattle feet were seen at the ankle. The patterns of forefoot abduction-adduction, plantar flexion-dorsiflexion, and inversion-eversion were all more repeatable for the Seattle foot.

Also, the pattern of plantar flexion-dorsiflexion for the Seattle foot more closely resembled that of the non-prosthetic side (Figures 10 and 11).

In summary, the Seattle foot generally produced a more repeatable pattern of motion at the knee and ankle than the S.A.C.H. foot, and the pattern of plantar flexion-dorsiflexion for the Seattle foot appeared more normal.

Force Plate Evaluation

Through the facilities of Simon Fraser University Kinesiology Department, a force plate study was done on the same single subject. The vertical compression forces generated by the S.A.C.H. and Seattle feet during stance were measured. Figure 12 demonstrates typical forces measured during stance in a below-knee amputee on the non-prosthetic side. A maximum peak is seen immediately after heel strike. This is followed by a trough in mid-stance and a second, lesser peak at push-off.

Figure 13 illustrates the forces generated in the same individual during stance on his prosthetic side while using a Seattle foot. Figure 14 shows stance forces generated in the same individual on his prosthetic side using a S.A.C.H. foot.

The initial peak is greater for the S.A.C.H. than the Seattle foot. This suggests more effective shock absorption at heel strike for the Seattle foot than the S.A.C.H. foot. The second peak is less than that seen on the non-prosthetic side with both feet, but is greater for the Seattle foot than the S.A.C.H. foot. Thus, the Seattle foot more closely approximates normal push-off force than the S.A.C.H. foot. The trough at mid-stance is shorter with the S.A.C.H. foot than on the non-prosthetic side. The mid-stance trough for the Seattle foot more closely approaches that of the non-prosthetic side, suggesting a more normal pattern of foot-ankle motion than with the S.A.C.H. foot. In summary, the Seattle foot generally appears to produce a more normal pattern of vertical forces than the S.A.C.H. foot and produces a greater force at push-off.

Conclusion

The patient response to the questionnaire regarding the effectiveness of the Seattle foot was positive. Comparison with the Seattle Study revealed similar results. Gait studies undertaken tended to support the clinical impression with regard to both kinetics and kinematics. Overall, this dynamic foot design offers definite advantages to the prosthetic user. At best, prosthetic users seem to get an increased gait smoothness, with the dynamic toe action positively influencing their abilities on rough ground and inclines. At worst, their gait pattern is not negatively influenced by this spring action.

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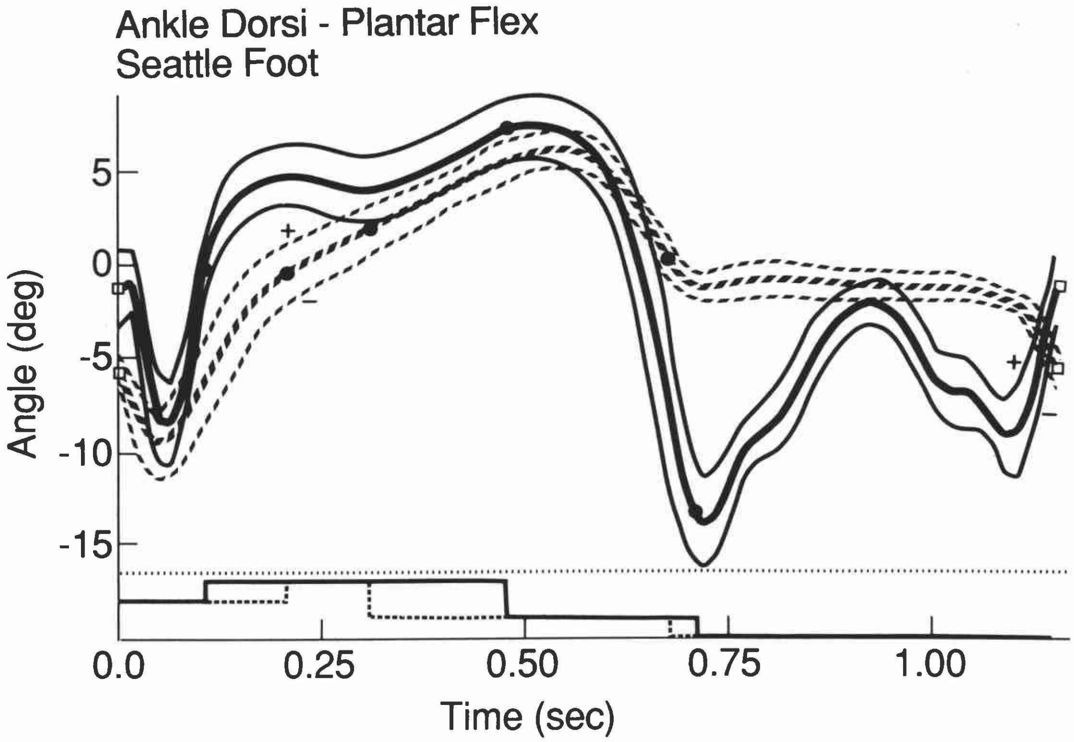

Figure 10.

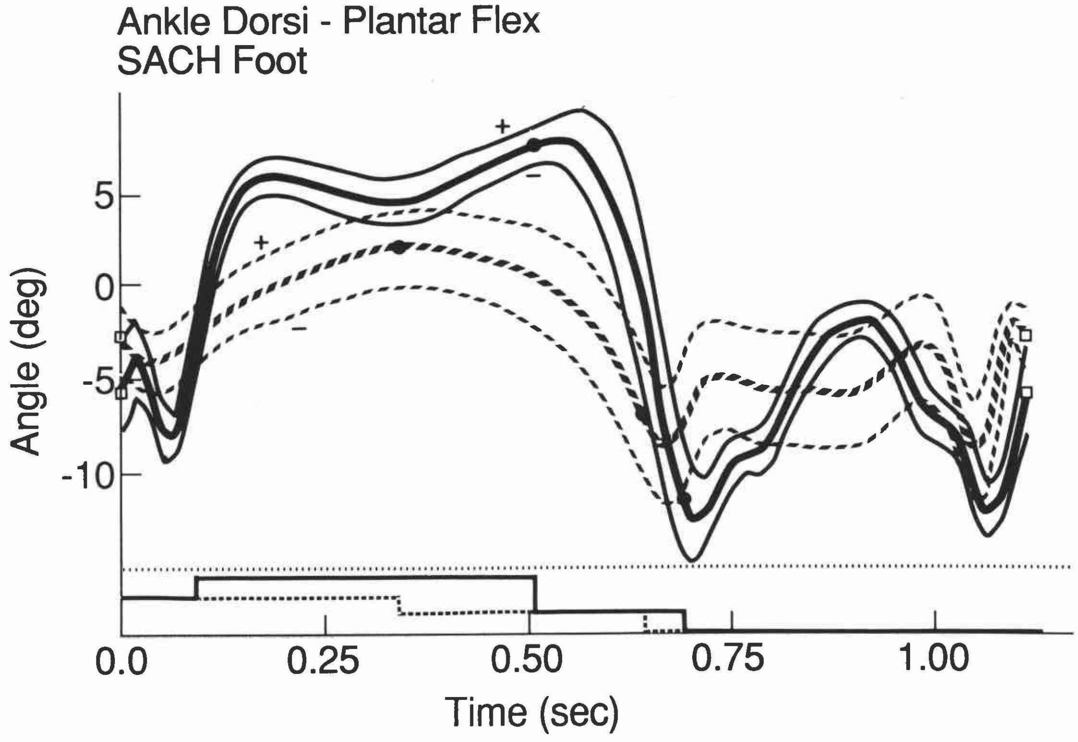

Figure 11.

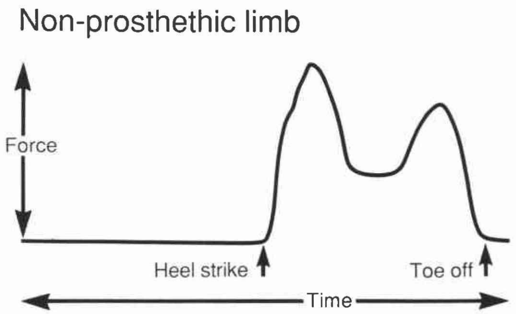

Figure 12. Typical forces measured during stance in a below-knee amputee on the non-prosthetic side.

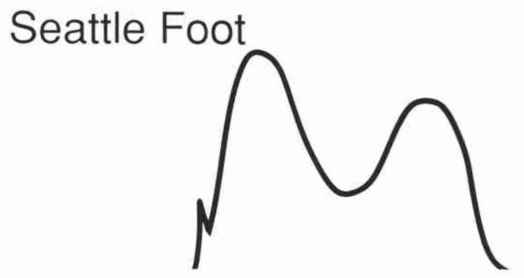

Figure 13. The forces generated in the same individual during stance on his prosthetic side while using a Seattle foot.

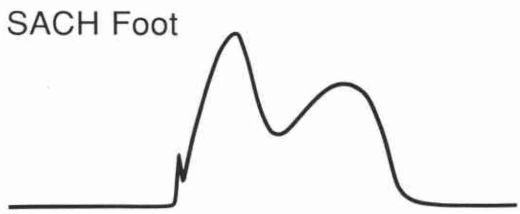

Figure 14. Stance forces generated in the same individual on his prosthetic side using a S.A.C.H. foot.

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Acknowledgments

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