Impact and the Effects of Wear on Prosthetic Feet

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Introduction: Problems with the skin and soft tissue of the residual limb are common reasons why some lower extremity amputees are unable to pursue desired vocational and recreational interests. The cause of these problems can be attributed, in part, to the repetitive forces that arise when the foot contacts the ground during locomotion. Prosthetic feet, in series with other prosthetic components and footwear, have the potential to attenuate the forces of foot-ground contact but this capacity may deteriorate with wear. Related research on the lifespan performance of footwear has shown rapid loss of shock-absorbing capacity with wear. Cook [1] investigated the energy absorption characteristics of running shoes as a function of mileage and found shoes lost 25% of their initial shock absorption capacity after just 50 miles and more than 40% after 250 to 500 miles. Pratt [2] investigated the shock attenuation of four insoles over a one-year period and found two insoles were virtually useless after just 7 days, while a third insole started to deteriorate at 6 months, and deterioration of the fourth insole began at 9 months.

Given the precedents set with shoes and insoles, we hypothesized that the shock-absorbing characteristics of prosthetic feet would change with wear. To test this hypothesis, we conducted a pendulum impact test on two feet: one brand new and an identical one with three years of wear by a moderately active *transtibial* amputee.

Statement of Clinical Significance: In the U.S., more than 2% of the general population in the age group 45 to 64 years uses an artificial leg or foot [3]. While the incident rate of residual limb skin problems is unknown, lower limb amputees are certainly concerned with prevention. Knowledge of impact absorbing properties and how they change with wear can aid the rehabilitation physician and prosthetist in providing an appropriate prosthetic prescription to reduce the incidence of residual limb skin problems, as well as, provide a timeline for replacement.

Methodology: A pendular mass of 6.5 kg was used to duplicate the effective mass of the stance limb at the instant of foot-ground contact. This mass is less than the 12 kg mass used by others, [4] but the smaller mass was used to account for the lighter prosthetic limb in comparison to an intact limb. The pendular mass was instrumented with an accelerometer (±25g; Entran, USA) whose data was double integrated to obtain position during pendulum contact with the foot using conservation of energy. The prosthetic foot (Seattle Lightfoot[2]; Seattle Systems, USA) was situated at a 20-degree angle, to simulate the angle of the shank at initial foot-ground contact, and mounted on a load cell (AMTI, USA). All the data was low pass filtered at 100 Hz with a 2-pole Butterworth filter (Measurements Group, USA) and sampled at a rate of 1000 Hz. The release point of the pendulum was varied to achieve impact velocities of 0.2, 0.4, 0.6, 0.8, and 1.0 m/s to simulate the potential range of foot velocities experienced during walking and running. The integration of the hysteresis loop formed by the force-deformation curves yielded the attenuated energy.

Results: The force versus deformation curves (see figure 1) demonstrate the impact response of a three-year old foot is different than a brand new foot. The peak deformations of the old foot at each velocity were greater than the new foot while the peak forces were less. The dissipated energy for the new foot at each velocity was less than the old foot (see table 1). The difference between feet became more pronounced at higher impact velocities.

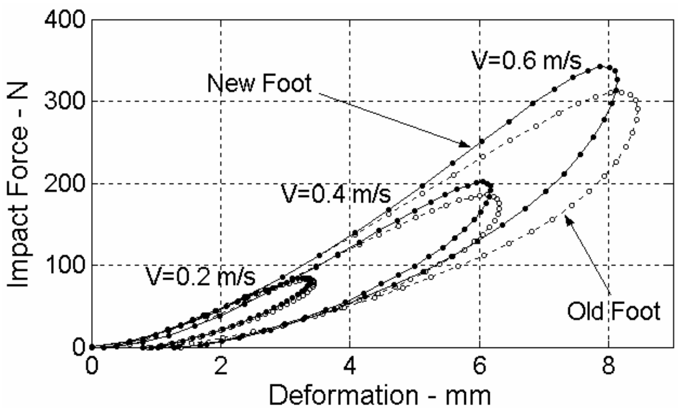

Figure 1: Impact force versus deformation for impact velocities of 0.2, 0.4, and 0.6 m/s on a new (solid lines, solid circles) and a three-year old (dashed lines, open circles) Seattle Lightfoot[2] prosthetic foot. Higher velocities (0.8 and 1.0 m/s) not shown for clarity.

Table 1: Energy dissipation (J) at each impact velocity.

	0.2 m/s	**0.4 m/s**	**0.6 m/s**	**0.8 m/s**	**1.0 m/s**
New Foot	0.0619	0.2531	0.5832	1.0736	1.6841
Old Foot	0.0631	0.2780	0.6298	1.1839	1.8924

Discussion: These results indicate the new foot is stiffer and dissipates less impact energy than the old foot. We had expected the opposite based on the compression set observed in cyclic tests on SACH feet [5, 6] and the decrease in energy absorption of insoles and shoes with wear [1, 2]. The effect of an old foot being less stiff and dissipating more energy might be considered analogous to walking on sand. It is a soft surface, but undesirable because significantly more effort is required to walk. What the pendulum impact test cannot reveal is the relationship between frequency and attenuation, a topic of our current research.

References:

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