Mimicking physiological rollover shape in a prosthetic foot with a single degree-of-freedom, constant stiffness ankle joint

Mimicking physiological rollover shape is important in prosthetic foot design to ensure correct gait kinematics, joint loading, and energy storage and return. In this study, we determine how closely an articulated prosthetic foot with a spring-loaded, single degree-of-freedom ankle joint can recreate a physiological rollover shape.

The foot was modeled as a rigid member attached to an ankle pin joint with a theoretical torsional stiffness $k$. Using previously published gait data\(^1\) for a female patient of body mass 56.7 kg and foot length 24 cm, the ankle moment versus ankle angle relationship was used to determine possible values for $k$, ranging from 6 N-m/deg to 12 N-m/deg. For each stiffness, the foot’s rollover shape was predicted by applying the correct ground reaction force and calculating the deflection of the foot at each point during stance phase of the gait cycle for which the center of pressure was in line with or distal to the ankle joint. Deflection of the foot was taken in the ankle-knee reference frame. The resulting rollover shape was then compared to physiological gait data. This process was repeated for the full range of investigated $k$ values and for ankle joints located 6 cm to 12 cm above the ground when the foot is flat. The position of the ankle pin joint along the proximodistal axis was fixed directly in line with the lateral malleolus marker in the gait data.

For each ankle height, a stiffness was found that yields a rollover shape very similar to the physiological rollover shape with $R^2$ of at least 0.956. For an ankle height of 8 cm, a stiffness of $k = 8$ N-m/deg results in a roll over shape with $R^2 = 0.957$ compared to the physiological data (Figure 1). The process and results presented in this paper may form a valuable design tool for prosthetic designers and practitioners. Able-bodied gait data for any foot size and body weight can be used to specify the stiffness and position of the ankle joint to achieve a rollover shape that is nearly identical to normative values while simultaneously maximizing energy storage and return.

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Figure 1: Predicted rollover shape for a prosthetic foot with a single degree-of-freedom ankle joint with constant-stiffness torsional spring versus physiological rollover shape ($R^2 = 0.957$). Ankle height = 8 cm and $k = 8 \text{ N-m/deg.}$