ROLE OF INTERNAL FRICTION IN THE ATTENUATION OF TERMINAL IMPACT NOISE IN ABOVE-KNEE PROSTHESES

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INTRODUCTION

Prosthetic noise is an important functional criterion influencing individuals' overall satisfaction with their prostheses [1,2]. The most prevalent source of noise in above-knee (AK) prostheses is during terminal swing impact (TSI), as the knee joint fully extends and stops against an end stop [3,4]. The causal factors of TSI noise relate to both the biomechanics of an individual's gait and to the characteristics of the prosthetic components, specifically the swing-phase control mechanism. TSI results when the shank is not sufficiently decelerated prior to full knee extension. This is predominantly associated with non-cadence responsive swing-phase control (non-fluid-based systems), or swing-phase controllers that have not been properly adjusted to match the gait characteristics of the user.

Although extensive research has been conducted in the development and testing of various swing-phase control mechanisms, very little has been directed toward the understanding and minimization of TSI noise in knees where the application of sophisticated, cadence-responsive mechanisms is impractical due to size, weight, and/or cost constraints. This includes most of the prosthetic systems used by children, and geriatric patients. The reason for this work came about during the clinical testing of two models of the same prosthetic knee joint that produced considerably different levels of TSI noise when worn by the same child. The louder knees, producing a 'clunking' sound at TSI, were regarded as unacceptable chiefly by the parents, but also by the children, therapists, and prosthetists. The lower noise levels were generally produced by newer components, which tended to have tighter running fits between the shafts and bushings and therefore produced more internal friction.

The main goal of this study was to examine the effects of internal friction on TSI noise in paediatric prosthetic knee joints.

METHODOLOGY

<u>Determining TSI velocities of AK gait</u>

To determine TSI velocities, gait analysis was conducted using a seven-camera VICON 370 motion capture system. Five children with AK amputations, ages 10 to 13 years, participated. Reflective markers were placed on the lower-limbs, defining local coordinate systems for each segment. Gait trials were performed along a 10-meter walkway. Children were instructed to walk at their regular, self-selected walking speeds. Data were collected once with a commercially-available knee joint (Total knee junior, Össur hf.) and once with a single-axis prototype knee[5]. Data were sampled at 60hz, and knee angular velocities derived from angular displacements of the shank and thigh coordinate systems.

<u>TSI noise measurement in prosthetic knees</u>

Figure 1 shows the apparatus used to simulate knee extension. A mass of 0.5kg (representative of a prosthetic foot and footware) was attached to a 0.36m long prosthetic pylon. Knee angular velocities were measured with an electrogoniometer and data were sampled using a 16-bit data acquisition card. Sound data were recorded using a microphone.

The same two knee joints that were used in the gait analysis were used in these bench tests. The prototype knee was tested with three swing-phase friction resistance levels including no friction (NF), low friction (LF) and high friction (HF). Three Total Knees were tested including a brand new component with internal friction (BF), a used component with internal friction (UF), and a used component with essentially no internal friction (UN).

During testing the shank (pylon and mass) was lifted and released from different heights thus achieving angular velocities from 0 to about 500 deg/s. Kinematic data were sampled at 4kHz and sound data at 22kHz.

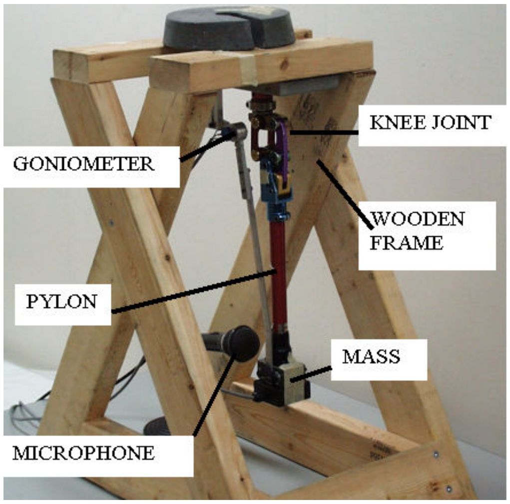

Figure 1: TSI testing apparatus

A commercial torque cell was used to quantify the frictional resistance for the LF and HF conditions.

RESULTS

TSI angular velocity was calculated as the mean angular velocity measured over the last five degrees of knee extension, just prior to TSI. From this, non-linear regression analysis was used to generate lines of best fit for data shown in figure 2. The mean R^2 value for all knees was 0.862.

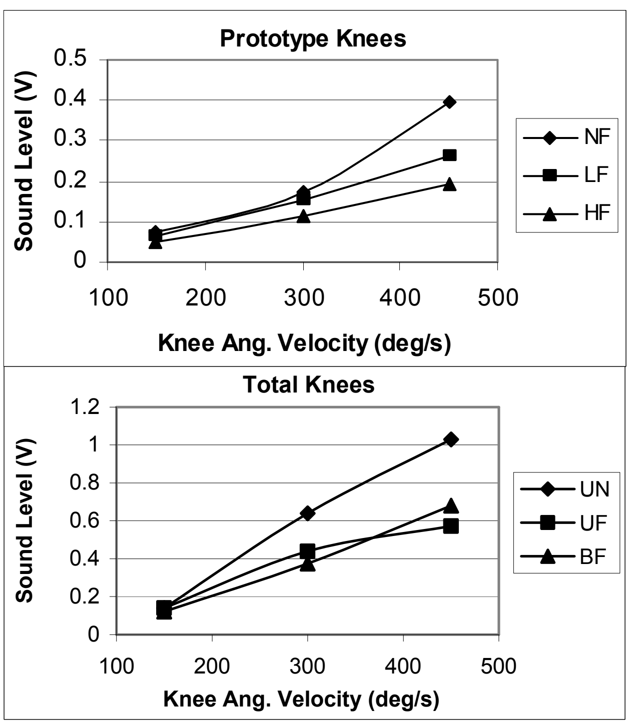

Figure 2: Relative sound level versus angular velocity at TSI for Prototype and Total Knees

For the LF and HF conditions, the frictional resistance was determined to be 0.230 (1 SD ±0.010) Nm, and 0.329 (1 SD ±0.007) Nm, respectively.

DISCUSSION

Maximum knee extension angular velocities for the subject group ranged from 331 to 567 deg/sec (mean 454 deg/s) and were in close agreement with those found in other studies[6]. Due to a low sampling rate during motion capture, it was not possible to accurately determine the angular velocity just prior to TSI in gait. Therefore, the peak knee extension velocity was used to establish the upper boundary for TSI angular velocities for the bench tests.

Across all conditions, releasing the sample from the same maximum heights produced only small differences in TSI angular velocities (Table 2). For the prototype knee, TSI angular velocities were reduced to 96.2% and 92.4% for the LF and HF conditions, respectively, when compared to NF. However, coinciding noise levels were reduced substantially, to 45.8% and 30.8% for the LF and HF conditions, respectively, when compared to NF. This along with the data in figure 2 suggests that internal frictional resistance acts to reduce TSI noise not by slowing down the shank prior to TSI, but rather by noise or vibration attenuation. Furthermore, friction levels producing resistance as low as 0.3 Nm appear to be effective.

Table 2: TSI angular velocities and corresponding noise levels for the Prototype knee obtained by releasing samples from the highest position possible.

Knee Setup	TSI Angular velocity		TSI Sound level	
	deg/s	% of NF	Volts	% of NF
NF	500	-	0.587	-
LF	481	96.2	0.269	45.8
HF	462	92.4	0.181	30.8

Both knees produced substantially higher TSI noise when the mechanism provided minimal or no resistance to knee extension (NF - Prototype and UN - Total). Although most commercially-available prosthetic knee joints provide some friction when new, over time as tolerances increase, the friction is eventually lost. In consideration of this, the prototype knees here utilized a mechanism with more reliable frictional braking comprising of friction washers backed by compressible rubber washers. Conventional designs do not use resilient parts, and therefore minute changes in tolerances, for example the fit of shafts and bushings as a result of wear, produce considerable reductions in frictional resistance. The effectiveness of this approach was successfully tested in long-term clinical trials.

Limitations of Study

The bench testing protocol used in this study facilitated the implementation of controlled experimentation. Although attempts were made to simulate the conditions during the TSI of gait, it would not be reasonable to expect that noise levels could be reproduced accurately in absolute terms. For this reason, a relative comparative analysis was provided. However, future work performed in situ, utilizing absolute measurement of sound levels may further improve the understanding of TSI noise.

CONCLUSIONS

Small levels of internal friction at the knee axis can substantially reduce TSI noise, not by reducing the TSI velocity but via vibration or noise attenuation. The design of non-cadence responsive swing-phase resistance should utilize resilient members to more reliably maintain frictional resistance during long-term use.

REFERENCES

[1] Legro, M. W., Reiber, G. D., Smith, D. G., del Aguila, M., Larsen, J., Boone, D., "Prosthesis evaluation questionnaire for persons with lower limb amputations: assessing prosthesis-related quality of life", *Arch.Phys Med Rehabil*, 79**,** 931-938, 1998.

[2] Grise, M. C., Gauthier-Gagnon, C., Martineau, G. G., "Prosthetic profile of people with lower extremity amputation: conception and design of a follow-up questionnaire", *Arch.Phys Med Rehabil*, 74**,** 862-870, 1993.

[3] Smidt, G., *Gait in Rehabilitation*, Churchill Livingston Inc., New York, USA, 1990.

[4] Mensch, G., Ellis, P., *Physical therapy management of lower extremity amputations*, Aspen Publishers, Inc. Rockville, USA, 1986.

[5] Andrysek, J., Naumann, S., Cleghorn, W., "Design and quantitative evaluation of a stance-phase controlled prosthetic knee joint for children", *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* 13**,** 437-443, 2005.

[6] Chakraborty, J. K., Patil, K. M., "A new modular six-bar linkage trans-femoral prosthesis for walking and squatting", *Prosthet.Orthot.Int.*, 18**,** 98-108, 1994.