A FINITE ELEMENT ANALYSIS ON THE EFFECT OF SOFT TISSUE THICKNESS ON PLANTAR PRESSURES IN SUBJECTS WITH DIABETES AND PERIPHERAL NEUROPATHY

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INTRODUCTION

Excessive localized peak plantar pressures (PPP) are known to contribute to skin breakdown in people with diabetes (DM) and peripheral neuropathy (PN). Previous work has shown a correlation between plantar soft tissue thickness (STT) under the metatarsal heads (where most ulcers occur) and PPP in subjects with DM and PN [1,2]. The purpose of this study was to use a validated finite element analysis (FEA) model to determine the effect of reducing STT on PPP in subjects with DM and PN and a history of plantar ulcers.

METHODS

Data were collected on 4 males with DM & PN. Mean age was 53$\pm$26 years, mean BMI was 34$\pm$9, and mean duration of DM was 19$\pm$9years. All subjects had dense PN (unable to sense 6.10 Semmes Weinstein monofilament) and a history of a plantar neuropathic ulcer.

The 3D internal structure was determined using data from SXCT [3], the reference pressure distribution was measured using the F-Scan system [3], and soft tissue properties were estimated using an indentor testing device and confirmed with values in the literature for each foot.

Individual two-dimensional FEA models in the sagittal plane were developed for metatarsals 2 and 3 using the p-version FEA program StressCheck with the foot in a push-off position for each subject. Bones included a support bone (tibia, talus, calcaneus, navicular, cuneiform), metatarsal and 3 phalanges. Cartilage with linear elastic material properties was included between the bones to simulate the composite stiffness between bones. Fascia and the long flexor tendon were included and the properties were assumed to be linearly elastic. Material properties of bone, fascia, and tendon were obtained form the literature.

The model's ability to predict plantar pressure distribution was tested against measured pressure distribution and found to be good, as reported elsewhere [4]. The effect of reducing STT under the metatarsal head was accomplished by translating the bones, tendon, and fascia vertically downward in 1 mm increments within the soft tissue envelop and keeping the skin outline and boundary conditions unchanged.

RESULTS AND DISCUSSION

Initial STT, PPP, and the % increase in PPP with 1-3 mm reduction in STT for the 2nd and 3rd metatarsal heads are contained in Table 1. Figure 1 shows the change in plantar pressure distribution for a specific subject (D07). There was a strong inverse relationship (r=-0.99) between the reduction in STT and the increase in PPP. According to the model, PPP will increase 14 to 24% under met heads 2 & 3 with a 3 mm reduction in STT depending upon other factors such as the shape and position of the metatarsal head.

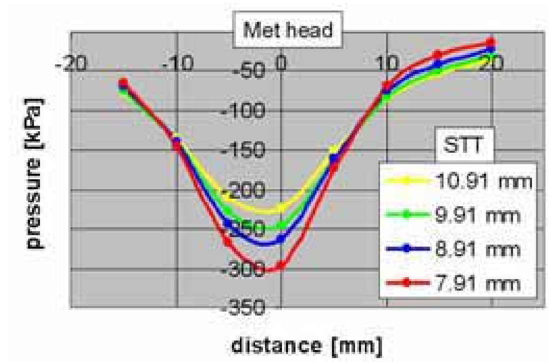

Figure 1: Change in pressure distribution 15 mm proximal to 20 mm distal 3rd met head with changes in STT (3mm).

Although this model is limited by being static and 2D, the results are robust and underlying assumptions for this application seem reasonable, but the effect of reducing STT on PPP may be even greater in reality. Methods currently are underway to establish a 3D model.

CONCLUSIONS

The results have important implications for understanding the factors contributing to skin breakdown in patients with DM and PN. STT has been correlated with PPP [1,2], and these results indicate a reduction in STT is highly correlated to an increase in PPP. Therefore, specific reductions in STT at a localized area, perhaps as a result of previous skin breakdown, could result in higher PPP at that site making it more susceptible to future skin breakdown. We plan to expand the FEA model further to develop strategies to evenly distribute pressures across the plantar foot.

REFERENCES

1. Mueller MJ, et al. *J Biomech* **36**, 1009-1017, 2003.
2. Abouaesha F, et al. *J Am Podiatr Med Assoc 94,39-42, 2004*
3. Commean PK, et al. *Arch Phys Med Rehab*, **183**, 497-505, 2002.
4. Actis RL, et al. *Proceedings of ASME*, IMECE, Anaheim, CA, 59400-2004.

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	STT (mm)	PPP (kPa)	%ΔPPP/PPP at –1mm	%ΔPPP/PPP at –2mm	%ΔPPP/PPP at –3mm
2nd met head X $\pm$ SD	10.5 ± 3.0	450 ± 147	4.6 ± 1.5	9.0 ± 2.6	15.4 ± 2.1
3rd met head X $\pm$ SD	10.0 ± 2.4	264 ± 48	7.8 ± 1.9	13.9 ± 1.9	21.0 ± 3.0

Table 1: Percent increase in PPP for 1-3 mm reduction in STT under the 2nd and 3rd metatarsal heads