# COMPUTER-AIDED ENGINEERING FOR FOOTWEAR DESIGN AND EVALUATION

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## INTRODUCTION

Because of large variations of footwear products and individualized subject response, consistent outcomes are lacking and conflicting results are common in terms of functional or therapeutic effects of footwear. The use of computer-aided engineering (CAE) approach considering utilization of comprehensive computational models of human soft tissue and bony structures and footwear components can allow objective and economic evaluations of footwear performance. Finite element (FE) analysis can provide fruitful biomechanical information from interfacial pressure between foot and footwear to internal soft tissue and joint loading distribution during simulated locomotions. In this paper, the protocol to establish realistic compuational simulations of foot-shoe interface for the parametric footwear design and evaluation is presented.

## METHODS

Establishing efficient and comprehensive computational simulation of foot and footwear require the acquisition of accurate geometrical, material and loading properties. High resolution MR images of about 0.5 to 1 mm intervals are required for 3D reconstruction of foot soft tissues and bones. Footwear model can be built using computer-aided design (CAD) software or based on a reverse-engineering approach using laser or CT scan data. Segmentation of MR and CT images in Dicom format was done using Mimics (Materialise, Inc.). Segmented surfaces in Stl format were then exported into Rapidform (INUS Technology, Inc.) to undergo surface optimization and smoothing for the creation of solid models. Parametric CAD models can be created for geometrical design purpose. Foot and footwear structures created from different sets of image data can be merged or aligned within Rapidform environment. Figure 1 depicts the reconstructed 3D model of human foot from MRI and CT based shoe model consisting of shoe upper, insole, midsole, outsole, soft heel component and reinforcement shank piece. Solid models in Iges format were imported into FE software, ABAQUS (SIMULIA) for creation of FE models.

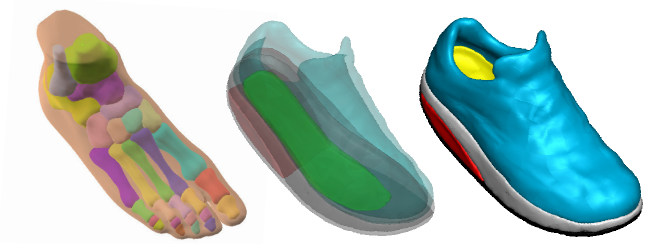

**Figure 1**: Reconstructed 3D models of foot and shoe.

Density of shoe components determined from CT data was used to select their mechanical properties based on previous material tests [1]. The soft tissue and shoe sole were defined as hyperelastic while the foot bones, ligaments, ground support and shoe upper were assumed as linearly elastic. Surface contact among the major joints, foot-insole and shoe-ground interfaces were considered. The FE barefoot model was validated against previous cadaveric experiment on plantar pressure and foot deformation [2]. Standing simulations were established with the developed foot-shoe model to quantify the deformations and stress distributions of shoe soles and foot tissue.

## RESULTS AND DISCUSSION

Imaged based geometrically accurate FE models of human foot and footwear were established. Figure 2 shows the deformed plots of the foot-shoe model showing the von Mises stress distribution of human foot and shoe during balanced standing on heel and pivot of the shoe.

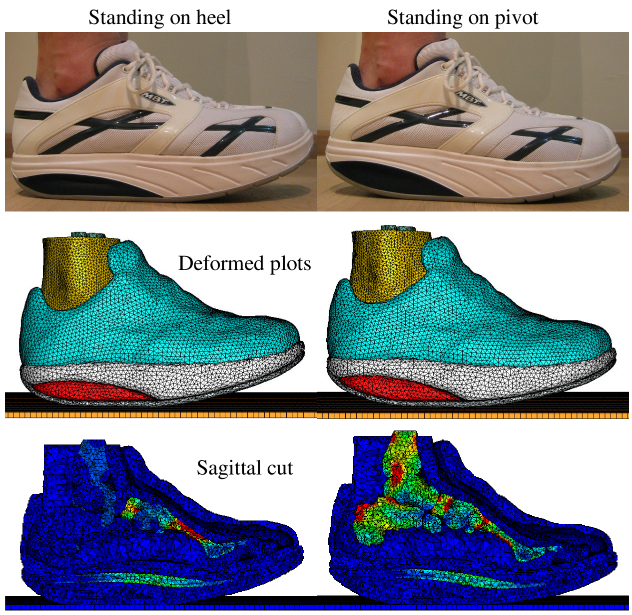


**Figure 2**: FE standing simulation of foot-shoe interface.

Parametric analyses on different footwear components are now being conducted. Further FE simulations and experimental validations will include physiological movements such as walking, running, jumping and cutting.

## CONCLUSIONS

The established CAE approach allows design and evaluation of footwear in an objective, well-controlled and efficient virtual environment. Results from future parametric studies will help optimize shape, sizing and material configurations of footwear for specific functional and therapeutic requirements as well as different foot types.

## ACKNOWLEDGEMENTS

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## REFERENCES

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2. Cheung JT, et al., *Clin Biomech.* **21**:194-203, 2006.