Dynamic Analysis of Human Upper Arm Model for Oscillometric Blood Pressure Measurements using ANSYS

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Summary

This study is the first to simulate oscillometric blood pressure (BP) waveforms using ANSYS software. An investigation of BP estimation with changing oscillation patterns shows a variation for systolic (SBP), diastolic (DBP) and Mean Arterial Pressure (MAP), with a change in brachial artery stiffness, if the fixed ratio algorithm is used.

Introduction

The effect of biomechanical factors on oscillometric BP measurements has long been a subject of research. Previous studies have investigated their influence by simulating oscillometric waveforms [1], but only a few studies have used Finite Element Analysis (FEA). Lan et al. [2] simulated oscillometric signals using FEA with Abaqus®. Although the model was adequate for preliminary investigations, it cannot be extended to include the effects of blood flow with Fluid-Structure Interaction (FSI) or Computational Fluid Dynamics (CFD) simulation. In contrast, ANSYS provides CFD modules and can co-simulate structural and CFD components. Because no published research has simulated oscillometric signals in ANSYS, and a fully functioning structural model is required for meaningful FSI investigations. Therefore, this study presents a complete structural model using ANSYS to simulate oscillometric signals. Furthermore, a comparative analysis to investigate the effects of artery mechanical properties on blood pressure oscillations was performed.

Methods

The human upper arm was modeled in ANSYS using geometry from Ref. [2]. Hyper-elastic material properties of brachial artery material taken from the literature [3, 4] are presented in Figure 1 (a), while the soft tissue was assumed to be elastic with Young's modulus, $E_T = 47.5$ kPa and Poisson's ratio, $\nu_T = 0.45$. Artery's hyperelastic response was described using second-order Ogden formulation. A bonded connection was assumed between the artery and soft tissues, following tie contact in Abaqus®. The internal artery pressure was set up 110/70 mmHg and the cuff pressure, uniformly distributed on tissue, was quickly raised to 150 mmHg and then linearly reduced to 0 mmHg at a rate of 5 mmHg/s, with total maneuver of 40s. The pressure transmitted to the brachial artery through the soft tissue was evaluated for comparison, and fluctuations in lumen area of the artery were tracked to generate pressure oscillations.

Results and Discussion

Pressure transmission analysis showed little effect of E_T, in comparison ν_T when varied from 0.40 to 0.49 increased pressure transmission by 13.23 % [Figure 1 (b)]. The results are in accordance with reported FE studies [2]. The model also successfully simulates the oscillometric signal, as shown in Figure 1 (c), where the waveform for the low stiffness artery has a larger amplitude. The maximum amplitude of oscillations was observed at about 80 mmHg when the MAP was 83 mmHg. Compared with Abaqus®, the model underestimates the MAP by about 1 mmHg, this is potentially due to hyperelastic model-fitting frameworks used in both the software packages. Normalized envelopes for both waveforms reveal a stark difference in oscillation patterns due to varying artery properties. The envelope for low stiffness artery is narrower, whereas for high stiffness artery is broader and flatter. The estimation of SBP, DBP and MAP is different by about 10, 2 and 1 mmHg for both artery stiffness, if fixed ratio method is used.

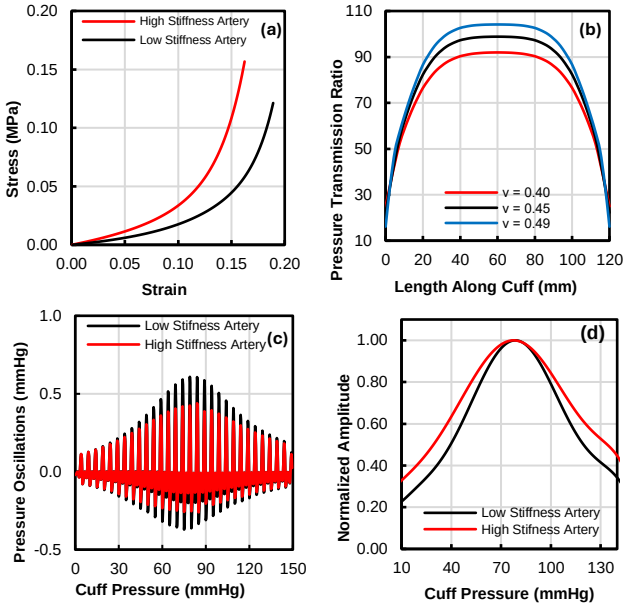

Figure 1: (a) Brachial artery properties for high and low stiffness (b) simulated pressure transmission ratio (c) simulated oscillometric waveform (d) envelope difference for high and low artery stiffness.

Conclusions

Pressure transmission increases by 13.23% when ν_T varies from 0.40 to 0.49. The amplitude of oscillations and the resulting curve pattern are different for varying artery stiffness, leading to differences in BP estimations by 10, 2 and 1 mmHg for SBP, DBP and MAP respectively. The model has the potential to be scaled up for future FSI analysis.

References

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