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Investigating the role of haematocrit in foetal circulation: a multi-compartment lumped parameter model

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Introduction

Foetal circulation is a complex system that differs from the corresponding neonatal and adult system. Current understanding of the foetal haemodynamics is limited[1], while the role of haematocrit at different gestational ages has not yet been investigated extensively. Computational models can aid elucidate circulation haemodynamics[2]. To this end, this contribution proposes a multi-compartment lumped parameter model of the foetal circulatory system to investigate the effect of haematocrit variations on the systemic arterial flow.

Methods

A multi-compartment lumped parameter model (LPM) of the foetal circulatory system is developed using Simulink®. The model describes 19 elastic arterial segments and 12 peripheral vascular beds, represented respectively by electrical circuits and a 3-element Windkessel model[2,3]. Inflow and boundary conditions were calculated based on previous data[1,2] and were adjusted using allometric laws[4] for a 33-week gestational age and foetus weight. Two validation studies were conducted: validation study-1 included only the ascending aorta and the brachiocephalic trunk, and was compared against adult flow waveforms[5]; validation study-2 assessed the accuracy of the developed foetal LPM by investigating the flow waveform at the position of aortic isthmus against reference data[6]. The Isthmic Flow Index was additionally calculated and compared with reported data[7]. Several different values of haematocrit (Hct) were investigated (spanning from 10% to 80% Hct) to represent a range of anaemic, healthy, and polycythaemic conditions respectively.

Results & Discussion

Both validation studies yielded results in good agreement with previous investigations[5-7]. The developed foetal LPM enabled computations of blood flow waveforms at various arterial positions, similar to previous estimations[2]. Simulations of the foetal flow with 10%, 45%, and 80% Hct were further performed to demonstrate the effect of haematocrit on the arterial circulation. Our results indicated a clear difference between the 45% and 80% Hct models at the position of the ascending aorta, whereas no apparent difference was detected between the models for 10% and 45% Hct. A similar trend was manifested at the positions of the aortic isthmus, the thoracic aorta, and the umbilical artery. However, at the position of the ductus arteriosus there was no difference between the models. Finally, the calculations revealed an almost exponential relationship between systemic vascular resistance and haematocrit.

Conclusion

The present lumped parameter model reveals that haematocrit variations result in changes in the systemic vascular resistance and the pulsatility indices of the flow-rate waveforms. This in turn has shown that haemoatocrit has an important effect on the foetal circulation. However, further investigation is required to improve the robustness of the LPM with respect to the inflow and boundary conditions adopted.

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