8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Fluid structure interaction modeling of pulsations in the fetal umbilical cord

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KEY WORDS: *Fluid structure interaction, fetal umbilical cord, wave propagation*

ABSTRACT

The umbilical cord connects the fetus to the placenta and contains one umbilical vein and two umbilical arteries. The umbilical arteries transport deoxygenated blood from the fetus to the placenta and the oxygenated blood returns to the fetus through the umbilical vein. Recent clinical research has shown various degrees of constriction of the umbilical vein as it enters the fetal abdomen through the umbilical ring affecting fetal and placental growth, cord length and thickness, and degree of blood velocity pulsation [1,2]. Here we address the venous pulsations.

A relationship between vascular constriction and umbilical venous pulsation is suggested based on clinical observations of 283 human fetuses [2]. The cross-sectional area and blood velocities in the umbilical vein were measured in these fetuses using ultrasound at three locations: the umbilical cord, the umbilical ring, and the intra-abdominal part of the umbilical vein. The umbilical vein diameter at the umbilical ring was found to be significantly smaller than in the cord and insignificantly smaller compared to the intra-abdominal portion. The Doppler measurements showed visible pulsations at the umbilical ring for most of the investigated fetuses, which was significantly more common than in the cord or intra-abdominally. Local umbilical venous compliance has been suggested as an important factor influencing pulsation in fetal veins. The contracting fetal heart is likely to be the origin of the observed venous pulsations. However, whether the waves propagate upstream through the ductus venosus and the umbilical vein, or whether they propagate downstream in the umbilical arteries and are then transmitted through the arterial and venous wall, is an open

question. In the present study we test former explanation assuming that pulsations observed at the umbilical ring are caused by reflections at this point due to mismatch in impedances.

The hypothesis is tested by means of axisymmetric fluid structure interaction (FSI) simulations of the intra-abdominal umbilical vein umbilical ring and the extra-abdominal umbilical vein. Pulsatile boundary conditions are imposed on the intra-abdominal vein and none-reflecting boundary conditions on the extra-abdominal vein. The FSI simulations apply a strongly coupled partitioned approach using Fluent and a structural solver [3,4]. The mechanical properties of the umbilical vein are taken from fetal sheep experiments [5], whereas the imposed velocities in the model are obtained from ultrasonic measurements in human fetuses [2].

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