Mathematical model of early decelerations in labor

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Introduction

Difficult deliveries are characterised by low incidence and high risk. Simulation-based team training (figure 1) can be used to decrease birth trauma incidences [1]. Medical decisions are based on the cardiotocogram (CTG), i.e. the continuous registration of uterine contractions and fetal heart rate (FHR). In existing birthing simulators only predefined, operator-selected CTGs are available.

Figure 1: Medical team training with a birthing simulator.

Objective

To design and test a physiology-based model of the CTG, to enhance biofidelity of the team training.

Methods

The maternal and fetal circulatory system were modeled using a lumped parameter model, containing vessel, valve and heart components. The model was extended with oxygen transport and exchange in the placenta, an existing model of pressure and pO2 driven cardiovascular control [2], and an additional feedback mechanism causing FHR to depend on cerebral pO2. It was used to simulate early decelerations, i.e. temporary reductions of FHR, following from fetal brain hypoxia caused by uterine contraction and compression of the fetal head in the birth canal (figure 2).

Figure 2: Mechanism of early decelerations. After [3].

Results

Figure 3 shows simulated FHR in response to an increase of intra-uterine pressure by 50 mmHg and a decrease of cerebral vessel diameter from 4.6 to 3.8 mm [7]. FHR decreased by about 25 bpm. Cerebral flow reduced from 144 to 67 ml/min.

Figure 3: Modeled CTG showing reduced fetal heart rate (FHR) in response to increased intra-uterine pressure (IUP).

Discussion

The model links uterine contraction and head compression in labor to early decelerations in the CTG trace. Cerebral oxygen pressures, computed in the model during decelerations, provide more insight for the medical team. High frequency FHR variations, that are used as clinical diagnostic signal, are currently added in postprocessing but should eventually be predicted by the model. Next delayed reductions in FHR, ‘late decelerations’, that involve the baroreflex as well, will be simulated.

Validation

The modeled CTG will be validated in near future by clinical experts. Real CTG tracings of early decelerations will be mixed randomly with modeled tracings. Validation comments will be used for further model adaptations.

Literature