BIOMECHANICS OF CERVICAL FUNNELING IN HIGH-RISK PREGNANCIES

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Background

- Currently no accurate way to predict preterm birth [1]
  - Preterm birth is defined as delivery before 37 weeks gestation) [2]
- Clinical standard for preterm birth prediction is sonographic measurement of the cervical length (Fig. 1, 2).
- Cervices shorter than 25mm are considered to be at high-risk for preterm birth
  - This method is only captures 50% of cases and is even lower in nulliparous cases [3].
- Cervical funneling is also considered evidence of being at high-risk for preterm birth [4].
- Previous computational studies have shown the progression of cervical funneling, but have not characterized the method through which it occurs [5].
- Our goal is to ascertain the biomechanics of cervical funneling through the use of parametric patient-specific computational models of high-risk pregnancies.

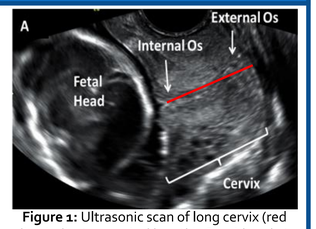

Figure 1: Ultrasonic scan of long cervix (red line indicates cervical length). Considered at low-risk for preterm birth.

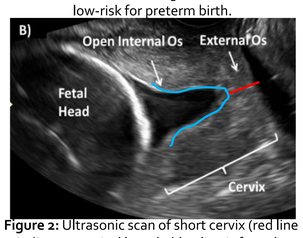

Figure 2: Ultrasonic scan of short cervix (red line indicates cervical length, blue line is funnel). Considered at high-risk for preterm birth.

Methods

- Ultrasounds from 5 women at high-risk for preterm birth at 19-24 weeks gestation taken at Columbia University Irving Medical Center.
- Measurements taken from ultrasounds characterize uterine size, uterine thickness, cervical size, and cervical placement.
- Aspiration measurements taken using the Pregnolia System to characterize cervical stiffness (Pregnolia, Schlieren, Switzerland).
- Patient-specific cervical properties found using inverse finite element analysis, where the cervical fiber stiffness (ξ) was determined .
- Two parametric patient-specific model built for each patient according to method outlined in Westervelt et al. [6]; one with patient-specific cervical stiffness and one with "normal" cervical stiffness (90 mbar) [7].
- Quarter-model is used to decrease computation time (Fig. 3).
- Fetal membrane, uterus, and cervix modeled as a solid mixture (neo-Hookean ground substance with a continuous fiber distribution), abdomen modeled as a neo-Hookean.
- Fetal membranes sliding on uterine wall and cervix, uterus tied to abdomen, cervix sliding along abdomen & vaginal canal, model fixed along outside surface.
- Gestational intrauterine pressure applied to fetal membrane surface.
- Finite element analysis performed in FEBio 2.8.5.

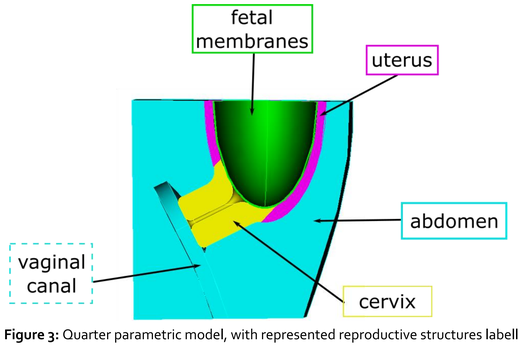

Figure 3: Quarter parametric model, with represented reproductive structures labelled.

Results & Discussion

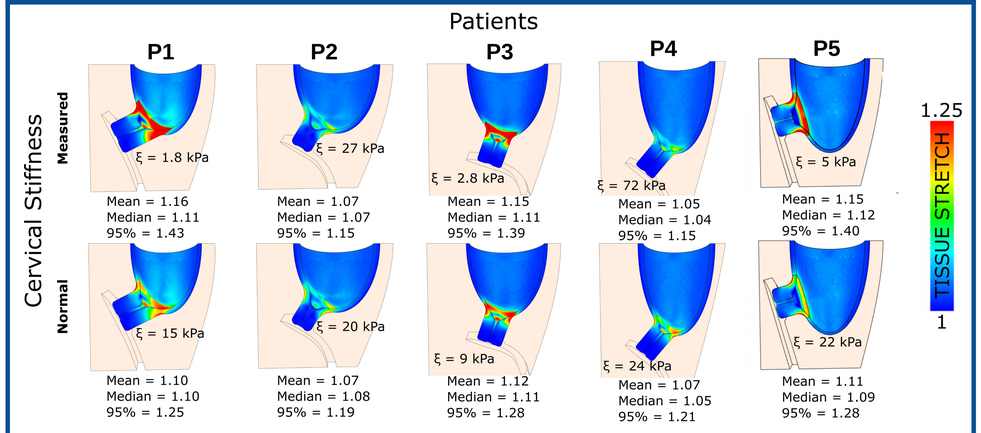

Figure 4: Mean, median, and 95th percentile first principle stretch from all models. The top row includes models where the measured cervical stiffness has been used, and the bottom row includes models where the "normal" cervical stiffness. ξ is the cervical fiber stiffness.

- For all patients, between the measured and normal cervical stiffness properties, the model which uses the softer properties result in greater than or equal to cervical stretch (patients 1,3, and 5 have measured cervical stiffnesses less than normal, and patients 2 and 4 have measured cervical stiffnesses greater than normal) (Fig. 4).
- Stretch is greater in the cervix than in the uterus for all patients and both cervical stiffnesses.
- Patients 1 and 3 delivered preterm, and these models had locations of maximum stretch occurring at the internal os, suggesting that location of greatest tissue stretch may have a correlation to birthing outcome.
- Patient 5 delivered at term, though the cervix was measured as softer than normal. This patient did not have large stretch at the internal os.
- When all the patients are given the same cervical stiffness, anatomical differences result is varying tissue stretch value and location, and patients who delivered preterm also still have the greatest stretch, besides patient 5, which also had large values at stretch, but which did not occur at the internal os.
- Over the course of simulation progression it is observed that cervical funneling is initiated through a compression of the lower uterine segment and then the pulling open of the cervix at the internal os.
- The model is only able to accurately capture simple funnel shapes (Fig. 5).
- More complex funnel shapes (patient 1-2) are not captured by the model.

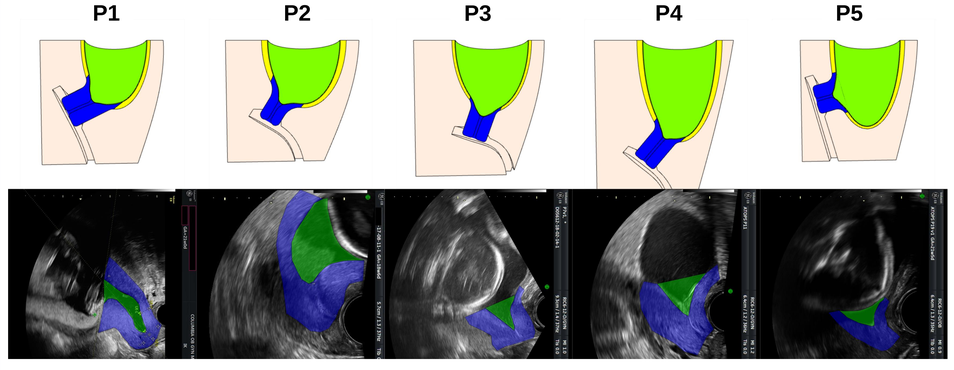

Figure 5: Top row is final funnel shape achieved by model, and bottom row is funnel shape observed in ultrasound (funnel in green, cervix in blue). Model is able to capture funnel shape will for patients with V-shaped funnel (patients 3-5), but not able to capture more complex funnel shapes (patients 1-2).

Conclusions

- Patients with softer cervices with greatest stretch occurring at the internal os delivered preterm, suggesting that cervical stiffness as well as maternal anatomy are important factors in the prediction of preterm birth.
- Accurate prediction of preterm birth will most likely involve taking into account the cervical length along with several other measurements of maternal anatomy, such as lower uterine segment thickness, as well as cervical stiffness.
- The method of cervical funnel initiation has been established, where the lower uterine segment is first compressed, and then the funnel begins by pulling open the internal os, though the underlying biomechanism by which cervical funneling occurs has yet to be established.
- The dataset is limited, with only 5 patients from which to draw conclusions, thus more patient-specific models must be examined to establish our findings. These data are in progress, as more high-risk patients have been measured.

References & Acknowledgements

References

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