BIOMECHANICAL MODELING OF CERVICAL TISSUE: A QUANTITATIVE INVESTIGATION OF CERVICAL FUNNELING

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The biomechanical integrity of the cervix is critical in maintaining a healthy gestation. In normal pregnancies, the cervix remains firm and closed throughout gestation, while uterine smooth muscle is relaxed. Cervical stroma undergoes substantial restructuring during pregnancy, especially in the final stage nearing delivery, where the balance of the constituent elements of the extracellular matrix (collagen, glycosaminoglycans, elastin, water) is continually evolving. As labor begins (usually near term), the cervix softens and dilates. This "maturation" process occurs over the course of the last week of pregnancy and is a prerequisite for a normal course of labor and delivery. Cervical incompetence is commonly defined as a condition in which gradual, progressive, painless dilation of the cervix leads to spontaneous pregnancy loss between the second and early third trimesters of pregnancy. Cervical incompetence is often associated with an altered biochemistry of the extracellular matrix, which either mirrors the normal maturation process but occurs prematurely or, in some cases, is a congenital condition predating pregnancy. Despite the introduction of new diagnostic technologies, cervical incompetence continues to be an elusive, often misdiagnosed condition and it remains one of the leading causes of morbidity and mortality in newborn infants. Our aim is to develop a quantitative, biomechanical model that integrates cervical geometry, tissue properties and loading conditions to demonstrate the biomechanical etiology of the premature cervical dilation associated with a diagnosis of cervical incompetence.

A critical element of this study is the development of a constitutive model for the cervical tissue. Here we introduce a phenomenological fully three-dimensional constitutive model for the large strain, time dependent mechanical behavior of cervical tissue. The proposed model captures specific aspects of the complex biomechanical response of cervical stroma: it incorporates the ability to account for the contributions of each constituent and for the cooperative nature of the tissue response. We rely on in vitro mechanical tests to determine representative constitutive parameters for normal (non-pregnant) tissue before it undergoes the maturation process. These parameters are then altered to mimic the effects of the modified biochemical equilibrium associated with a condition of cervical incompetence. The constitutive model is integrated with pelvic anatomy to obtain a finite element model of the cervix in pregnancy. The effects of the altered tissue properties on the ability of the cervix to maintain the pregnancy are investigated, and the biomechanical conditions leading to premature cervical dilation are demonstrated.