Biomechanical trade-offs in the pelvic floor constrain the evolution of the human birth canal

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Compared to most other primates, humans are characterized by a tight fit between the maternal birth canal and the fetal head, leading to a relatively high risk of neonatal and maternal mortality and morbidities. Obstetric selection is thought to favor a spacious birth canal, whereas the source for opposing selection is frequently assumed to relate to bipedal locomotion. An alternative, yet under-investigated, hypothesis is that a more expansive birth canal suspends the soft tissue of the pelvic floor across a larger area, which is disadvantageous for continence and support of the weight of the inner organs and fetus. To test this 'pelvic floor hypothesis' we generated a finite element model of the human female pelvic floor and varied its radial size and thickness while keeping all else constant. This allowed us to study the effect of pelvic geometry on pelvic floor deflection (i.e., the amount of bending from the original position) and tissue stresses and stretches. Deflection grew disproportionately fast with increasing radial size, and stresses and stretches also increased. By contrast, an increase in thickness increased pelvic floor stiffness - i.e. the resistance to deformation - which reduced deflection but was unable to fully compensate for the effect of increasing radial size. Moreover, larger thicknesses increase the intra-abdominal pressure necessary for childbirth. Our results support the pelvic floor hypothesis and evince functional trade-offs affecting not only the size of the birth canal but also the thickness and stiffness of the pelvic floor.

pelvic floor | human birth canal | biomechanics | evolutionary trade-off | finite element modeling

Introduction

Humans are characterized by a close match (and occasional mismatch) between the dimensions of the maternal bony pelvis and fetal size. This tight fetopelvic fit leads to a comparatively difficult birth process in humans. Without medical intervention, fetopelvic disproportion often leads to maternal and neonatal death. Birth-related morbidities such as pelvic organ prolapse (i.e., the pathological descent of organs into or through the vagina or rectum) and incontinence affect millions of women worldwide, which can have serious social and health consequences (1). In western countries, a quarter to more than half of women report suffering from one or more pelvic floor disorders, with the reported prevalence of urinary incontinence ranging from 15% to 69% and of prolapse ranging from 6% to 41% 2–5. Although their prevalence increases with age and parity, pelvic floor disorders are also common among young and nulliparous women 4–6. Understanding the evolutionary origins of obstructed labor thus is a pressing and highly debated challenge 7–12.

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Significance Statement

The relatively small human birth canal has arisen from an evolutionary trade-off between multiple antagonistic selective forces. We present evidence that a large pelvic floor is disadvantageous for maintaining continence and supporting the weight of the inner organs and the fetus through multiple finite element analyses of pelvic floor models varying in size and thickness. An increase in pelvic floor size led to a disproportionately large deflection as well as higher tissue stretches and stresses. Increased pelvic floor thickness considerably reduced deflection by increasing stiffness. However, as a side effect, it increases the intra-abdominal pressure necessary for childbirth, thus reflecting another evolutionary trade-off affecting not only the size but also the thickness of the pelvic floor.

All authors contributed to the conception and design of the research. ES created the FE models and ran the experiments. ES and KK analyzed the data. All authors critically interpreted the results and all authors drafted and critically revised the manuscript.

Authors have no competing interests.

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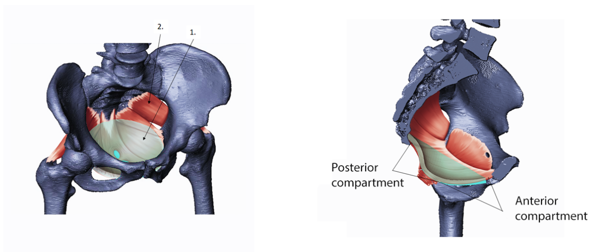

a. b.

Fig. 1. Placeholder image of a frog with a long example legend to show justification setting.

Table 1. Comparison of the fitted potential energy surfaces and ab initio benchmark electronic energy calculations

Species	CBS	CV	G3
1. Acetaldehyde	0.0	0.0	0.0
2. Vinyl alcohol	9.1	9.6	13.5
3. Hydroxyethylidene	50.8	51.2	54.0

nomenclature for the TSs refers to the numbered species in the table.

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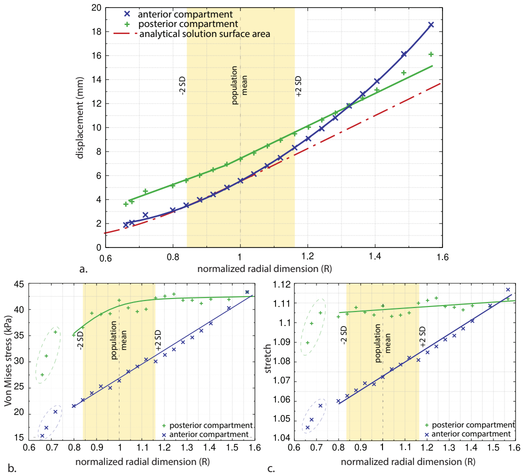

Fig. 2. This legend would be placed at the side of the figure, rather than below it.

$$
\begin{aligned}
(x+y)^3 &= (x+y)(x+y)^2 \\
&= (x+y)(x^2+2xy+y^2) \\
&= x^3+3x^2y+3xy^3+x^3.
\end{aligned} \qquad [1]
$$

1. S Arrowsmith, EC Hamlin, LL Wall, Obstructed labor injury complex: obstetric fistula formation and the multifaceted morbidity of maternal birth trauma in the developing world. *Obstet. Gynecol. Surv.* **51**, 568–574 (1996).