Shape Changes in Midsagittal Sacrum and Coccyx Shape During Pregnancy and After Delivery: Main Research Article

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December 6, 2020

Abstract

Objective The shape of the sacrum-coccyx was defined and compared in nulliparous, pregnant, and parous women to provide insight into anatomical adaptations that afford vaginal delivery. Design A retrospective study comparing midsagittal anatomical measurements based on MRI of the sacrum and coccyx from 63 subjects. Setting Magee-Womens Research Institute and Northshore University HealthSystem. Population 23 nulliparous, 14 pregnant, and 26 parous women who had an MRI taken that included the necessary bony anatomy. Methods Twelve measurements were taken on scans between the ages of 20 and 49 that had a pelvic MRI scan with or without contrast were analyzed. Subjects were categorized based on parity and gravidity. Main Outcome Measures Length, angles, and curvature indices describing midsagittal sacrum and coccyx shape Results Overall pregnant women had a significantly straighter and more posteriorly oriented coccyx when compared to nulliparous women. This was reflected by a change in 3 measures at the univariate level. The coccygeal curvature index was higher in pregnant (89.2 ? 10.0) women relative to nulliparous (78.7 ? 6.6, p=0.003) and parous (80.0 ? 5.5, p=0.004) women. The sacrococcygeal curvature index and sacrococcygeal angle also increased in the pregnant as compared to the nulliparous group (73.3 ? 5.8 versus 79.2 ? 3.7, p=0.016; 92.8? ? 10.9? versus 109.3? ? 9.4?, p=0.002, respectively) with no difference between pregnant and parous groups for these measurements. Conclusions Pregnancy-induced posterior motion of the coccyx, which allowed for the combined sacrum-coccyx shape to straighten, effectively widens the obstetric outlet for vaginal delivery.

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Conflict of Interest: The authors report no conflict of interest for this study

Paper Presentation: Summer Biomechanics, Bioengineering, and Biotransport Conference (June 2020)

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Short Title: Midsagittal Sacrum and Coccyx Shape Quantification

Word Count: 2937

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Design

Retrospective study comparing midsagittal anatomical measurements based on MRI of the sacrum and coccyx from 63 subjects.

Setting

Magee-Womens Research Institute and Northshore University HealthSystem.

Population

23 nulliparous, 14 pregnant, and 26 parous women who had an MRI taken that included the necessary bony anatomy.

Methods

Twelve measurements were taken on scans between the ages of 20 and 49 that had a pelvic MRI scan with or without contrast were analyzed. Subjects were categorized based on parity and gravidity.

Main Outcome Measures

Length, angles, and curvature indices describing midsagittal sacrum and coccyx shape

Results

Overall pregnant women had a significantly straighter and more posteriorly oriented coccyx when compared to nulliparous women. This was reflected by a change in 3 measures at the univariate level. The coccygeal curvature index was higher in pregnant (89.2 ± 10.0) women relative to nulliparous (78.7 ± 6.6, p=0.003) and parous (80.0 ± 5.5, p=0.004) women. The sacrococcygeal curvature index and sacrococcygeal angle also increased in the pregnant as compared to the nulliparous group (73.3 ± 5.8 versus 79.2 ± 3.7, p=0.016; 92.8° ± 10.9° versus 109.3° ± 9.4°, p=0.002, respectively) with no difference between pregnant and parous groups for these measurements.

Conclusions

Pregnancy induced posterior motion of the coccyx, which allowed for the combined sacrum-coccyx shape to straighten, effectively widens the obstetric outlet for vaginal delivery.

Funding

Swanson School of Engineering Undergraduate Research Grant and NSF GRFP Grant #1747452

Keywords

Angle, Childbirth, Curvature index, Length, Maternal bony pelvis, MRI, Parity

Tweetable Abstract

In pregnancy the coccyx moves posteriorly allowing the combined sacrum/coccyx to straighten and widen the obstetric outlet.

Introduction

Hormonal changes during pregnancy cause tissue remodeling, resulting in connective tissue softening to facilitate vaginal delivery[1]. Throughout the female lifespan, the levator ani muscles and pelvic connective tissues act to close the levator hiatus. During vaginal delivery, the pelvic floor undergoes stretching to allow passage of the fetal head[2]. Biomechanical and finite element modeling have been used to identify and clarify the amount and location of the maximum muscle and connective tissue stretch during vaginal birth[3,4]. The majority of the research in this area has concentrated on the pelvic floor musculature, pubic symphysis, and sacroiliac joints[1,5,6]. However, previous work from our lab demonstrated the potential need for tissue softening at the sacrococcygeal joint to accommodate the fetal head. During simulations of vaginal delivery, mechanical loads introduced as the fetal head pushed the tip of the coccyx posteriorly, forcing the muscles and connective tissues engaged with the coccyx to stretch[7]. Posterior motion of the coccyx about the sacrococcygeal joint has also been noted in studies that conducted magnetic resonance imaging (MRI) during vaginal delivery, but has yet to be quantified[8].

The sacrum and coccyx were chosen as the focus of this study as they provide an important attachment point for the coccygeus and levator ani. The coccygeus inserts on the superior two vertebrae of the coccyx (Co1 and Co2) and the most inferior vertebrae of the sacrum (S5). The coccygeus is distinct from the levator ani, which contribute to the support of the pelvic organs and help stabilize the coccyx. Among the levator ani, the iliococcygeus and anococcygeal raphe insert on the coccyx. In this way, a homeostatic relationship is likely formed between the coccygeus and the laxity of the sacrococcygeal joint, which would be driven by the connective tissues surrounding the joint and the tension generated by the iliococcygeus and anococcygeal raphe. Therefore, with any increase in pressure (e.g. increasing intrabdominal pressure generated by a growing fetus), change in muscle function, or change in the connective tissue stiffness at the sacrococcygeal joint would ultimately result in a measurable difference in the orientation of the maternal coccyx. Additionally, during delivery, physical interaction between the fetal head and the pelvic floor muscles could also cause a significant alteration in the orientation of the coccyx.

Other studies have shown significant movement of maternal bony pelvic structures during pregnancy, which can result in asymmetrical sacroiliac joints or pain localized to the coccyx[5,9,10]. While all women sustain stretching of their pelvic floor during birth, only some will experience injury resulting in pelvic pain, pelvic organ prolapse, urinary incontinence, and/or fecal incontinence that can develop immediately or decades after delivery[11,12]. Improved metrics quantifying the degree of remodeling during pregnancy and following delivery may provide insight into predictors of vaginal birth-related injuries and/or complications and pelvic floor disorders.

The objective of this study was to define changes in the position of the coccyx relative to the sacrum and the midsagittal shape of the sacrum and coccyx in women before, during, and after pregnancy. To do this, we aimed to measure variations in the combined sacrum-coccyx shape induced by pregnancy and delivery by comparing midsagittal lengths, angles, and curvature indices between nulliparous, pregnant, and parous women. We hypothesized that the orientation of the coccyx would be more posterior in pregnant women—providing more room in the pelvis for the fetus during delivery by increasing the anterior-posterior diameter of the obstetric outlet—and then return, but not completely, towards nulliparous values in parous women.

Methods

The funding for this research came from the Swanson School of Engineering Undergraduate Research Grant and NSF GRFP Grant #1747452. Funding sources had no involvement in the study design, data collection, analysis and interpretation of data, writing of the report, or decision to publish.

This retrospective study was approved by the Institutional Review Board at the University of Pittsburgh and Northshore University HealthSystem. Images from 63 female patients between the ages of 20 and 49 that had a pelvic MRI scan with or without contrast at Magee-Womens Hospital or Northshore University HealthSystem between 2005 and 2018 were included in this study. Exclusion criteria were history of pelvic surgery (not including cesarean delivery (CD)), pelvic masses, and incomplete scans (did not include the necessary bony anatomy) or incomplete birth history.

Subjects were categorized into groups based on parity and gravidity, which resulted in 23 nulliparous, 14 pregnant and vaginally nulliparous, and 26 parous women: For the purposes of this study the women that were placed in the nulliparous and parous groups were not currently pregnant and were at least one year postpartum To delineate the effects of pregnancy on the sacrum-coccyx shape, we then examined the pregnant and parous groups by their respective number of deliveries (CDs for the pregnant group, and combined CDs and vaginal deliveries for the parous group) and normalized those values with respect to the nulliparous average. These will be referred to as the pregnant and parous subgroups. The reasoning behind the relatively small sample of pregnant women is likely due to one of the exclusion criteria. Because we wanted to isolate the effects of pregnancy, we eliminated pregnant subjects that were vaginally parous. This is why all previous births of women in the pregnant group were from CD.

Using HOROS v3.3.5 (Nimble Co LLC, Annapolis, MD USA) the midsagittal plane of the sacrum and coccyx was identified. The sacrum was defined as the first 5 vertebrae inferior to the sacral promontory. Any remaining vertebrae were defined as the coccyx. This resulted in 3, 4, or 5 coccygeal vertebrae. Twelve length, angle, and curvature measurements were made using definitions from previous literature to define the sacrum, coccyx, and combined sacrum-coccyx shape[13]. These measures included a count (the number of coccygeal vertebrae), length (measured as both a straight and curved length), angle, and curvature index. A curvature index was defined as a ratio between a straight length (the shortest distance between the top and bottom of a structure) and curved length (the average of the anterior and posterior borders of a structure) multiplied by 100. A curvature index of 100 indicates that a structure is perfectly straight. The sacrococcygeal straight length, curved length (anterior, posterior, and average), and curvature index are shown in Figure 1a. Angles were defined as the included angle between two straight lines, thus making an angle closer to 180 degrees straighter. The sacrococcygeal angle is shown in Figure 1b. The sacral angle was excluded from this study as many scans did not include necessary sacral landmarks[13].

All of these measures were defined and measured in previous literature that intended to quantify the change in shape of the sacrum and coccyx that aimed to investigate and define normal adult sacrococcygeal morphometry and were as follows: Coccygeal curved and straight lengths were measured from the middle of the upper border of Co1 to the coccygeal tip; sacral curved and straight lengths were measured from the middle of the upper border of S1 to the middle of the of the inferior border of S5; sacrococcygeal curved and straight lengths were measured from S1 to the tip of the coccyx; sacrococcygeal angle was the included angle between the middle of the superior portion of S1, the middle of the superior portion of the Co1, and the tip of the coccyx (Figure 1b); and the coccygeal angle was the included angle between the line drawn through the middle of the superior and inferior edges of Co1 and the line drawn through the middle of the superior and inferior edges of the most inferior coccygeal vertebrae.

Statistical analyses were conducted in IBM SPSS Statistics v25 (IBM Corp., Armonk, NY USA) and consisted of a One-Way Independent MANCOVA followed by univariate ANOVAs with multiple comparisons and Benjamini-Hochberg (BH) corrections post-hoc[14]. The covariate was the age of the patient. In a BH correction, an allowable false discovery rate (the rate at which a null hypothesis is rejected incorrectly) is chosen (10% for this study). A critical value is calculated using the rank of the p-value from the MANCOVA analysis, the allowable false discovery rate, and the number of measurements. A p-value smaller than the critical value is considered significant. Those variables were then considered in a univariate analysis. Using the rank of the p-values instead of the numerical value of them means that a BH correction is a less conservative alternative to a Bonferroni correction. Measures with significant differences between groups were followed-up with additional multiple comparisons. Homogeneity of variances were tested, and independent samples were assumed.

Results

While there was a significant difference between the groups' ages (p=0.018), the MANCOVA analysis showed that the observed shape differences were due to the groups (p<0.001) and not due to age (p=0.711). Among parous women, the median parity was 2 and median time since last delivery was 2 years. Overall, it was observed, both visually and quantitatively, that the sacrum and coccyx were straighter in pregnant women (Table 1). This was reflected by significant differences between the three groups in the coccygeal curvature index (p=0.001), sacrococcygeal curvature index (p=0.002), and sacrococcygeal angle (p=0.016) (Table 1). All other measures failed to achieve significance.

Gravidity resulted in a 13.3% increase in the coccygeal curvature index (89.2 ± 10.0) compared to nulliparous women (78.7 ± 6.6, p=0.003). Parous women (80.0 ± 5.5) demonstrated a near return to nulliparous values with a significant decrease of 10.3% relative to the pregnant group (p=0.004; Figure 2a) and no difference from the nulliparous group. The additional analysis of subgroups of pregnant women demonstrated an interesting trend reflecting increased straightening with increased parity (Figure 2d). However, a similar trend was not observed in the parous subgroups, suggesting that most of the observed changes are limited to pregnancy.

The sacrococcygeal curvature index, which includes the combined curvature of the sacrum and coccyx, also demonstrated a significantly straighter (8%) sacrococcygeal shape for pregnant (79.2 ± 3.7) relative to nulliparous women (73.3 ± 5.8, p=0.016). For this metric, the parous group straddled the pregnant and nulliparous groups but, again, was not significantly different from either (Figure 2b).

Not surprisingly, differences for the sacrococcygeal angle followed those of the sacrococcygeal curvature index with the angle for the nulliparous group at 92.8° ± 10.9° versus 109.3° ± 9.4° for the pregnant group (p=0.002) and the parous group straddling both but not different from the nulliparous group (Figure 2c). Both metrics exhibited a similar trend as that shown for the coccygeal curvature index when evaluating the subgroups within the pregnant and parous groups individually (Figure 2e/f). It should be noted that none of the measures describing the shape of the sacrum alone were found to be significant (Table 1). Thus, it is likely that the significant metrics for the sacrum-coccyx are being driven by the rotation/elongation of the coccyx.

Discussion

Main Findings

The midsagittal sacrum-coccyx measures differed across nulliparous, pregnant, and parous groups with the sacrum-coccyx assuming a straighter shape during pregnancy as the coccyx rotates posteriorly about the sacrococcygeal joint. Although not significantly different from the nulliparous group, parous values tended to straddle the nulliparous and pregnant groups, suggesting that the sacrum-coccyx shape of some parous women does not completely return to the nulliparous range even years postpartum.

Interestingly the most significant statistic was the coccygeal curvature index, while the least significant was the coccygeal angle. At first glance, they appear to describe the same shape changes, but the curvature index is much more sensitive to subtle changes. Figure 3 demonstrates how the curved length (simplified as 2 lines) can remain the same while the coccygeal angle and straight length increase. The increase in the simplified straight length, and by extension the curvature index, (4.3%) is larger than the increase in angle (1.7%). This suggests that when evaluating coccyx shape the curvature index may highlight differences that the coccygeal angle would not capture.

Strengths and Limitations

The major limitation of this study was its retrospective nature and cross-sectional design. Due to the retrospective nature of this study some of the subjects were imaged in different positions. Nonpregnant patients were imaged in the supine position while pregnant patients were imaged in a lateral decubitus position (standard for pregnant patients). However, this difference in scanning position would result in less posterior motion for pregnant women because the effect of gravity would be minimized in those patients. Thus, any measurements in orientation change of the coccyx due to pregnancy were likely an underestimation.

Despite this design, which is subject to inter-patient variations in shape confounding the findings, significant straightening of the coccyx and sacrum-coccyx was observed. This suggests that shape changes in the coccyx are a measurable and meaningful remodeling event that occurs in pregnant women. A longitudinal study design may be able to determine if some of the observed statistically insignificant trends in this study are significant or simply explained by patient variation in the sacrum-coccyx shape.

Interpretation

We observed increased straightening of the coccyx within the pregnant subgroups that had previously delivered solely via CD. Thus, the potential confounding influence of vaginal birth-related injury was absent. This suggests that additional remodeling is achieved in subsequent pregnancies and that these shape differences are likely due to mechanical and hormonal changes of pregnancy alone, and not delivery. This is supported by previous work showing that subsequent pregnancies yielded an increased cellular and hormonal response[15]. While this result was not significant and may be better delineated with an increased sample size and longitudinal data in a future study, it nevertheless supports the major finding of this study: the coccyx is undergoing significant changes in shape during pregnancy either due to remodeling of the coccyx itself, the tissues attached to it, or both.

Though it has been previously noted that the coccyx moves during vaginal delivery due to direct interaction with the fetal head[7,16], this study found that the coccyx also moves in pregnancy by rotating posteriorly about the sacrum presumably in preparation for delivery. It is possible that this straightening reflects relaxation of the levator ani, anococcygeal raphe, and coccygeus (which all insert on this structure); remodeling of the connective tissues supporting the sacrococcygeal joint; or a combination of these events. Straightening of the sacrum-coccyx may be a maternal adaptation to lessen the severity of stretch induced injury that has been demonstrated in prior simulations of vaginal delivery and imaging studies following vaginal delivery[17,18]. The effects of the growing fetus resulting in increased intraabdominal pressure would likely exhibit a similar effect and could be an alternative contributing mechanism.

Previous studies describe levator ani defects in parous women and there was concern about such injuries impacting the results of this study[19–21]²¹(21).While some pregnant women in our study may have delivered abdominally after entering the second stage of labor, it is important to note that our pregnant group was vaginally nulliparous and CD in any stage of labor has been found to be protective of levator injury and the development of pelvic floor disorders[22,23]. Thus, the impact of levator damage was minimized. We did not observe any differences comparing nulliparous and parous women, which would suggest that either no injuries were present in our parous cohort or that the coccyx is not a good indicator of injury.

Previous research by our group evaluating midsagittal pelvic floor shape found that the levator plate was more posterior, or "relaxed", in pregnant women compared to nulliparous and parous women, coinciding with the posterior motion of the tip of the coccyx resulting in rotation about the sacrum noted in this study[24]. While it is not clear whether remodeling of the coccyx allows for the noted relaxation or vice versa, the combined implications are that these maternal changes are necessary and more favorable for vaginal delivery. Women that fail to remodel sufficiently may be at greater risk for a complicated delivery and/or maternal injury. Additionally, the failure to recover the pre-pregnancy shape of the coccyx could be an indication of injury either to the coccyx or the muscles that insert on it. While there are currently no clear indications of impaired levator muscle function in the women analyzed in this study, further research may provide indication of impaired levator function based on the shape and/or orientation of the coccyx. Finally, this work indicates that changes in the levator ani/plate may not be solely related to muscle injury. If changes in the coccyx persist long-term, this could alter the length-tension relationships and normal physiologic function of muscles that insert onto it and potentially compromise support to the pelvic organs. While much of these discussion points will require more evidence, this study highlights that the coccyx may be playing a more important role than has been previously considered.

These findings also have implications for computational models of vaginal delivery. We have shown that there is significant remodeling and motion of the coccyx about the sacrum during pregnancy[7]. If a model of vaginal delivery did not account for these changes (i.e. using nulliparous anatomy) then the geometry may not accurately predict outcomes of vaginal delivery. By not accounting for the remodeling of the coccyx or pelvic floor, that model is likely simulating a pelvis that is not fully prepared for vaginal delivery, meaning the coccyx and levator plate would need to move further posteriorly to reach the same final configuration as a simulated pregnant pelvis.

Conclusions

This study found that the coccyx is the main cause of variation in the combined maternal sacrum-coccyx shape as the coccyx is more posterior with respect to the sacrum and straighter in pregnant women. Considering the coccyx's importance as an insertion point for the pelvic floor muscles future studies may show that there is more adaptation of the female pelvic muscles and bony anatomy.

Disclosure of Interests

LM reports grants from Renovia Inc., outside the submitted work

MR has nothing to disclose

PM has nothing to disclose

GR has nothing to disclose

SA reports grants from Renovia Inc., outside the submitted work

Contribution of Authorship

LM made substantial contributions to the conception and design of the work and was the primary researcher with respect to analysis of the data. He also wrote and edited parts of all drafts of the manuscript and approves this version for publication.

MR, and SA made substantial contributions to the conception and design of the work and assisted in the analysis of data. They provided feedback and assisted on drafting the manuscript. They approve this manuscript for publication.

PM, and GR acquired the data used in this study. They provided feedback and assisted on drafting the manuscript. They approve this manuscript for publication.

Details of Ethics Approval

The collection of data for this study was either IRB approved (data collected at Magee-Womens Research Institute; IRB number PRO15060009, 6/27/2016) or IRB exempt (data collected at Northshore University HealthSystem; IRB exempt STUDY18110093, 12/14/2018)

Funding

This study was funded by the Swanson School of Engineering Undergraduate Summer Research Grant and NSF GRFP Grant #1747452.

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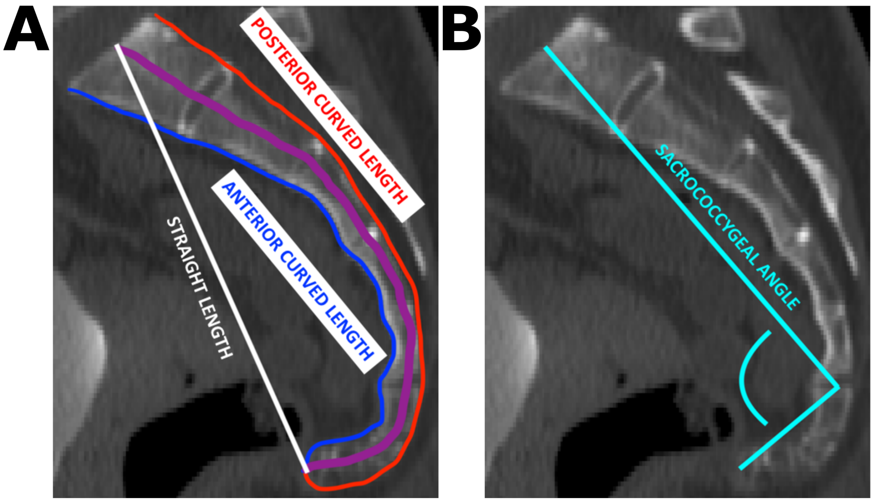
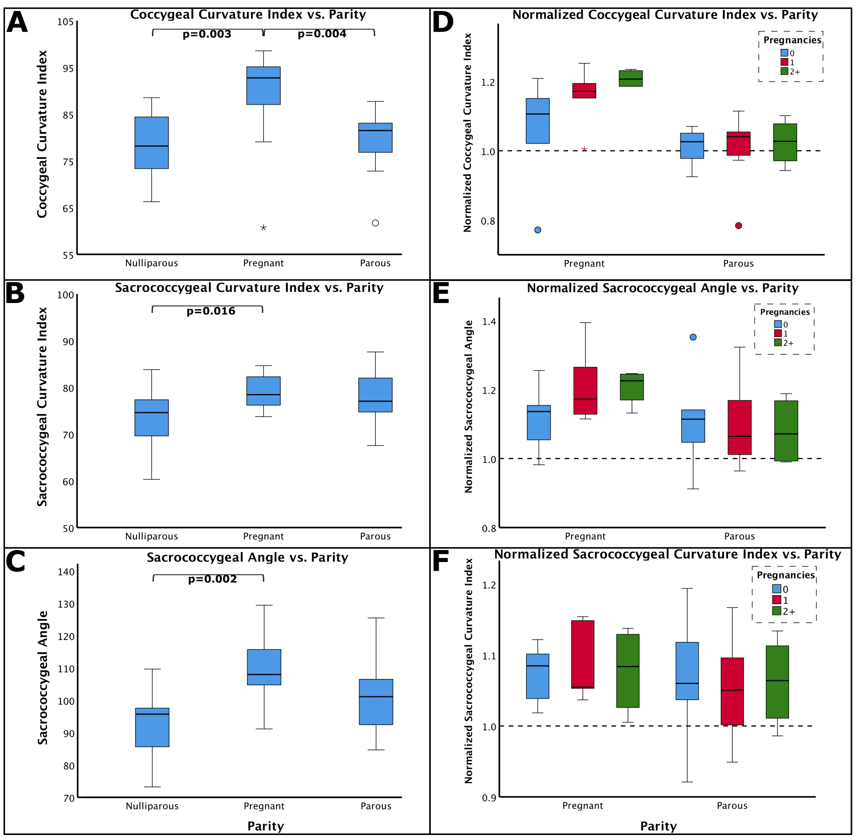
Tables

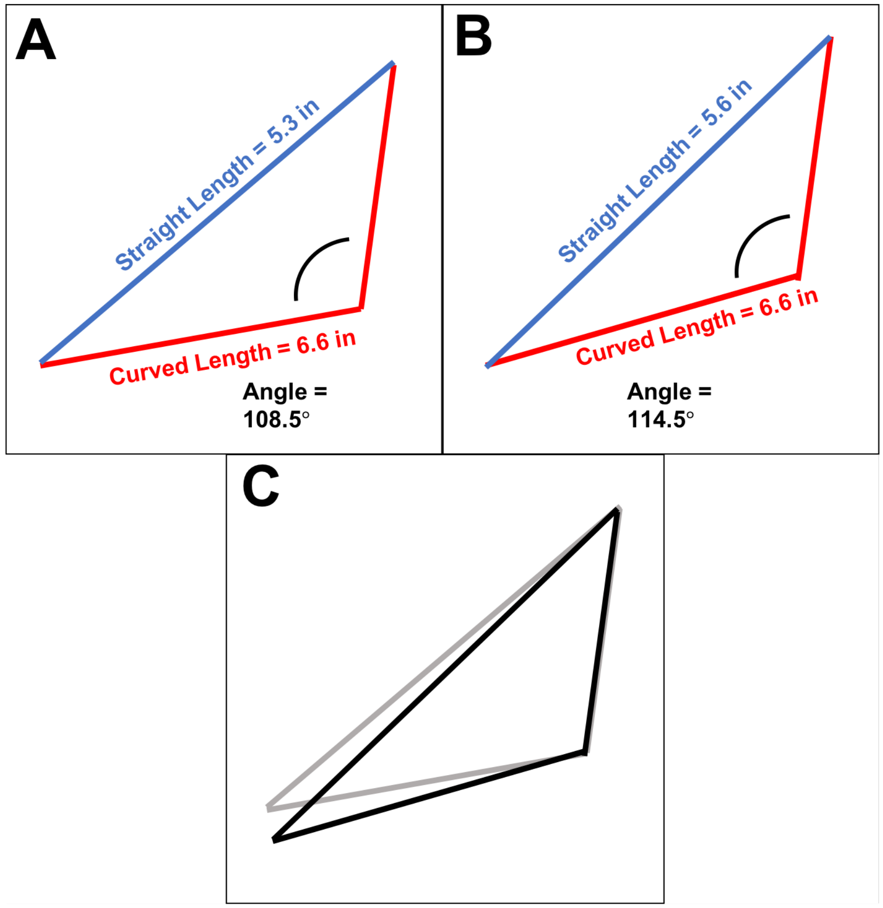
Table 1. Table of measures, averages, standard deviations, p-values, and BH critical values

Measure	**Nulliparous (Mean ± std)**	**Pregnant (Mean ± std)**	**Parous (Mean ± std)**	**ANOVA p-value**	**BH CV**
Coccygeal Curvature Index	78.7 ± 6.6	89.2 ± 10.0	80.0 ± 5.5	0.001*	0.007
Sacrococcygeal Angle (°)	92.8 ± 10.9	109.3 ± 9.4	101.9 ± 11.0	0.002*	0.017
Sacrococcygeal Curvature Index	73.3 ± 5.8	79.2 ± 3.7	77.6 ± 5.4	0.016*	0.025
Coccygeal Straight Length (cm)	3.2 ± 0.5	3.7 ± 0.8	3.2 ± 0.5	0.046	0.033
Sacral Curvature Index	90.7 ± 6.6	89.2 ± 3.6	92.6 ± 4.6	0.120	0.042
Sacrococcygeal Straight Length (cm)	11.4 ± 1.2	12.3 ± 0.9	11.9 ± 1.2	0.212	0.050
Sacral Straight Length (cm)	10.8 ± 0.8	10.5 ± 1.0	10.7 ± 0.9	0.586	0.058
Sacral Curved Length (cm)	12.0 ± 0.8	11.8 ± 0.9	11.7 ± 0.8	0.618	0.067
Sacrococcygeal Curved Length (cm)	15.6 ± 1.0	15.5 ± 1.4	15.4 ± 1.1	0.735	0.075
Coccygeal Vertebrae	3.5 ± 0.7	3.4 ± 0.5	3.5 ± 0.6	0.760	0.073
Coccygeal Curved Length (cm)	4.1 ± 0.6	4.2 ± 0.8	4.1 ± 0.6	0.832	0.092
Coccygeal Angle (°)	126.3 ± 17.2	132.4 ± 21.9	133.9 ± 14.5	0.920	0.100

* Denotes statistical significance






A
Straight Length = 5.3 in
Curved Length = 6.6 in
Angle = 108.5°
B
Straight Length = 5.6 in
Curved Length = 6.6 in
Angle = 114.5°
C