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DEFORMITY

The Effect of Parity on Age-Related Degenerative Changes in Sagittal Balance

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Study Design. Retrospective cohort study.

Objective. Evaluate the effects of parity (number of births) on measures of sagittal posture in elderly women. The long-term objective of this study is to identify and mitigate factors contributing to age-related postural deformity in older adults.

Summary of Background Data. Adult spinal deformity is a prevalent condition that often requires costly surgical management. Females are disproportionately represented in spinal deformity surgical cases with up to 90% of patients being women. The potential contributions of pregnancy on postural degeneration have only begun to be acknowledged and require further study.

Methods. Two hundred eight women with standing lateral radiographs were selected from the TwinsUK register. Parity information was extracted from questionnaires. Sagittal balance measurements (thoracic kyphosis, lumbar lordosis [LL], pelvic incidence [PI]) were collected and PI-LL mismatch was calculated. One-way analysis of variance tests were done between three separate age categories for measures of sagittal balance and parity and stepwise multivariate regression was done for PI-LL.

Results. Both age and PI-LL mismatch significantly differed between parity categories. PI-LL was on average $7.0^\circ \pm 2.5^\circ$ greater in multiparous (3+ births) subjects than in nulliparous subjects ($P < 0.01$). Parity did not have an independent relationship with lumbar disc degeneration, lumbar bone mineral density, or any of the individual sagittal balance parameters ($P > 0.05$ for all), except for PI-LL. From a subanalysis of the effect of parity on sagittal alignment within twin pairs, we found that within pair differences in parity associate with within pair differences in thoracic kyphosis.

Conclusion. This study established correlations between measures of spinal curvature in older women and parity for the first time. Longitudinal research is required to establish a causative relationship.

Key words: females, lumbar lordosis, parity, pelvic incidence, postural degeneration, sex differences, spinal curvature, thoracic kyphosis.

Level of Evidence: 4

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Adult spinal deformity (ASD) is a prevalent condition that adversely affects up to 68% of older adults.[1] The hospital costs for surgical treatment of ASD in the United States averaged $120,394 per surgery in 2014.[2] With the population of adults older than 65 years projected to grow nearly 45% between 2013 and 2025, ASD will be a significant burden on healthcare costs.[3] Females represent the overwhelming majority of patients with ASD undergoing surgery. For example, in a recent study of 7075 adult scoliosis patients, 91.5% were women,[4] whereas in a study of reoperation rates in a cohort of patients with ASD 86% were women.[5] Although clinical studies show that women are overwhelmingly more at risk for ASD, the prevalence between sexes for specific spinal deformity conditions varies tremendously. For instance, in juveniles, the risk for idiopathic scoliosis has been shown to be as high as 17 times more prevalent in women compared to men.[6] Conversely, the difference between sexes in risk for adult degenerative scoliosis is less established, but has been shown to only be

one to two times more likely to occur in women compared to men.[7–9] In addition, hyperkyphosis is at least twice as likely to occur in women than in men.[10] The reason women are at greater risk for ASD is unclear and likely multifactorial. Understanding the underlying risk factors that may contribute to sex differences in ASD will clarify sex differences in the prevalence of ASD.

Potential factors contributing to ASD in women include ligamentous laxity,[11] lower bone mineral density (BMD),[12] intervertebral disc degeneration,[13] and intramuscular fat infiltration or degeneration of the dynamic stabilizing muscles of the spine.[14] Our recent work identified sex differences in lumbar lordosis (LL) that were evident in standing load bearing but not while supine in an asymptomatic population.[15] The degree of standing LL in the healthy female spine is 26% to 28% greater than that in the male spine.[16–18] Recent computational analyses have demonstrated sexual dimorphism in the pelvis, lumbar spine, and sacrum result in up to a twofold increase in range of motion in the sacroiliac joint and corresponding increases in stresses and loads in the female sacroiliac joint.[19] These may be factors contributing to sex differences in prevalence for ASD. However, the role of parous history in these observed differences and their contributions to measures of sagittal posture and degeneration has only begun to be explored.

Upright, bipedal posture brings a unique set of challenges to the female spine during pregnancy which we hypothesize could have long-term consequences on spinal structure. One recent study demonstrated that parity is positively associated with risk of degenerative spondylolisthesis.[20] The increased fetal load anterior to the spine demands adaptation of the pregnant mother's stature and places increased stress on the static and dynamic stabilizers of the spine. Significant increases in LL occur during pregnancy and load distributions in the lumbar spine adapt to have the zygapophyseal joints carry more than double their normal load.[21] This shift in load distribution may shield the intervertebral discs from damaging shear loading and but also modifies the demands on the posterior elements of the spine and spinal musculature. Although numerous studies have associated low back pain with pregnancy[22] and chronic postpartum back pain,[23] they have not extended those observations to characterize the effects of parity on sagittal balance or age-related postural degeneration.

Through this retrospective cohort analysis we aimed to test the hypothesis that parity affects measures of sagittal posture in elderly women. Understanding how parity affects spinal curvature may improve our understanding of disease mechanisms, identify an at-risk population, and inform clinical management that may include proactive postpartum rehabilitation of spinal muscles to reduce age-related postural degeneration.

MATERIALS AND METHODS

Sample

This was a retrospective cohort study. A sample of 208 women from the general population was obtained from the TwinsUK register. This sample includes both monozygotic and dizygotic twins from the TwinsUK (http://www.twinsuk.ac.uk) register of King's College. The inclusion criteria were twin participants without spine fracture, trauma, or spine surgery at the time of enrollment. Twins from this registry have been shown to be comparable to the age-matched general population for a broad variety of medical and behavioral traits.[24]

Imaging Data

Sagittal balance measurements (thoracic kyphosis [TK], pelvic incidence [PI]; Figure 1) were collected from standing lateral radiographs of the spine using SpineView software. The difference between PI and LL (PI-LL) is predictive of malalignment[25] and was calculated for each subject. These data were previously used for a heritability study on sagittal alignment and collection methods are further described within that source.[26]

Twins that comprise this radiographic study were included in prior magnetic resonance imaging and Dual X-ray Absorptiometry studies,[27,28] from which Pfirrmann grades for lumbar disc degeneration (LDD) and lumbar BMD values were determined.

Parity Data

Parity for subjects within this sample was separately extracted from questionnaires in the comprehensive TwinUK database. Parity, the number of prior births, was determined based on agreement between subject-reported number of births and any potential information regarding the subject's biological children.

Statistical Analyses

One-way analysis of variance tests were done between three parity categories (to better distribute sample size between groups) to measure whether there were independent differences between covariables and parity categories. Regression analyses were done to test the directions of the relationships between parity and sagittal balance measurements with twin pairs adjusted as a repeated measure. Regression analyses included (1) univariate regression analyses for each dependent variable (TK, LL, PI, PI-LL, LDD, BMD, age, and BMI) with parity and (2) backward stepwise multivariate linear regression of each sagittal balance measurement (TK, LL, and PI) with parity while including all other variables as potential covariates (listed in Table 1). Lastly, a stepwise multivariate regression was done for PI-LL with LL and PI excluded as they were included covariates. Variables were tested for normality and collinearity. β-Coefficients are reported for parity and represent the degree change in sagittal balance measures per additional birth. All analyses included robust standard error estimation and adjusted for twins by clustering twin pairs. Lastly, we tested for within twin pair differences in sagittal alignment and parity using *t* tests comparing both nulliparous and nulliparous-multiparous twin pairs, as well as, linear regression between within twin pair differences for sagittal alignment and parity.[29]

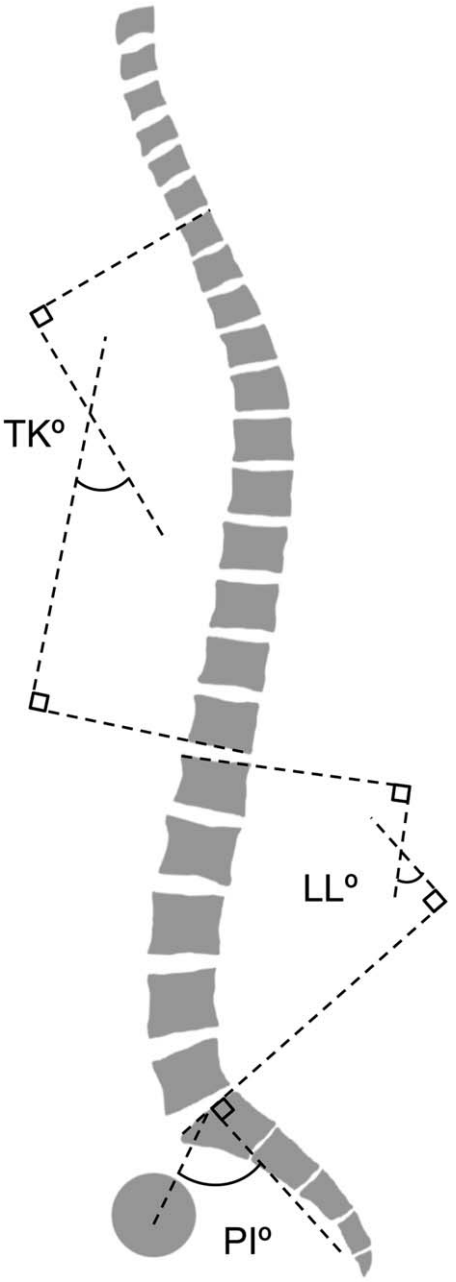

Figure 1. Schematic of spinal alignment measurements. Thoracic kyphosis was defined as the Cobb angle between the cranial T2 and caudal T12 endplates. Lumbar lordosis (LL) was defined as the Cobb angle between the cranial L1 and cranial S1 endplates. Pelvic incidence was defined as the angle between two lines: (1) a line perpendicular to the plane formed by the S1 cranial endplate and located at the endplate mid-point and (2) a line between the mid-point of the S1 cranial endplate and mid-point of a line connecting the central points of both acetabula. LL indicates lumbar lordosis; PI, pelvic incidence; TK, thoracic kyphosis.

RESULTS

Parity data were available for 208 women (64.4 ± 7.5 years) and ranged from 0 to 5 births (0: n = 37 [18%]; 1: n = 13 [6%]; 2: n = 91 [44%]; 3: n = 54 [26%]; 4: n = 9 [4%]; 5: n = 3 [1%]). The average number of births per person was 1.97.

Bivariate Analyses

One-way analysis of variance was performed to test for differences in dependent variable measurements between three parity categories (0 births: n = 37; 1–2 births: n = 104; 3+ births: 66) and found that only age and PI-LL significantly differed between parity categories (Table 1). PI-LL was on average 7.0° ± 2.5° greater in multiparous (3+ births) subjects than in nulliparous subjects ($P < 0.01$).

We then performed bivariate linear regression analyses between parity (as a discrete variable) and all other variables. Parity found to be positively associated with PI-LL mismatch ($\beta = 2.2°$, $P < 0.01$) did not have an independent relationship with LDD, lumbar BMD, or any of the individual sagittal balance parameters ($P > 0.05$ for all), except for PI-LL. PI-LL was positively associated with parity independently ($\beta = 2.2°$, $P < 0.01$). Additional regression analyses were also conducted with only age adjusted as a covariate and the results between parity and LDD, BMD, and sagittal balance parameters remained the same.

Multivariate Analyses

From backwards stepwise multivariate regression analyses (Table 2), parity associated with an increase in TK ($\beta = 2.09°$, $P = 0.01$), a decrease in LL ($\beta = -2.19°$, $P < 0.001$), and an increase in PI ($\beta = 2.53°$, $P < 0.001$; Table 1). For PI-LL, a backwards stepwise multivariate regression (without PI and LL included due to collinearity), parity associated with an increase in PI-LL ($\beta = 2.15°$, $P < 0.001$).

Within Twin Pair Effects

Within our dataset, there were 41 monozygotic twin pairs and 55 dizygotic twin pairs. After comparing within pair differences between pairs in which both sisters were nulliparous (n = 7) and pairs in which one sister was nulliparous and one was multiparous (3+ births) (n = 8), we found that within-pair differences in TK were significantly greater in the latter group (both nulliparous: 4.6° ± 6.3°, nulliparous-multiparous: 11.1° ± 6.4°, $P = 0.03$). Regression analyses comparing within twin pair differences in alignment and parity similarly show a positive relationship between differences in TK and parity among the monozygotic twin pairs ($\beta = 3.65$, $P < 0.01$). Outside of TK, within twin pair differences for the other sagittal alignment measures did not differ between both nulliparous and nulliparous-multiparous pairs.

DISCUSSION

In this study we have shown that parity correlates with spinal posture in middle-aged and elderly women. This analysis demonstrates that parity is positively associated with deterioration of sagittal balance parameters. Interestingly, these data show associated changes in spinopelvic alignment with increased TK, decreased LL, and increased PI as parity increases (Figure 2). In particular, this highlights the effect of parity on the "mismatch" between PI and LL which is a well described predictor and clinical measurement

TABLE 1. Demographic and Spinal Curvature Information for the Study Participants

	Parity (Births)			
	0 (n = 37)	1–2 (n = 104)	3+ (n = 66)	*P*
Age (yr)	62.1 (9.2)	64.1 (6.6)	66.1 (7.2)	<0.05
BMI (kg/m^2)	25.1 (4.3)	25.7 (3.2)	25.7 (3.8)	n.s.
Lumbar degeneration (avg Pfirrmann)	2.3 (1.0)	2.5 (0.7)	2.6 (0.7)	n.s.
Lumbar BMD (g/cm^2)	1.0 (0.2)	1.0 (0.1)	1.0 (0.2)	n.s.
Thoracic kyphosis (°)	41.6 (16.2)	43.1 (12.5)	44.0 (12.8)	n.s.
Lumbar lordosis (°)	54.6 (15.4)	54.2 (14.0)	52.6 (12.7)	n.s.
Pelvic incidence (°)	51.3 (15.6)	51.2 (13.9)	55.6 (14.4)	n.s.
PI-LL (°)	−3.2 (11.9)	−2.49 (11.4)	3.8 (12.4)	<0.01

P values are provided for univariate analyses comparing the effect of parity group on each observed parameter.
BMD indicates bone mineral density; LL, lumbar lordosis; n.s., not significant; PI, pelvic incidence.

of spinal malalignment.[30] In addition to known risk factors such as reduced BMD and increased LDD, we have identified parity as a separate contributing factor to increased TK, decreased LL, and increased PI.

From a subanalysis of the effect of parity on sagittal alignment within twin pairs, we found that within pair differences in parity associate with within pair differences in TK. One potential reason that an effect was only observed for TK may be due to the relatively strong genetic component predicting TK in women. Prior work on this cohort explored the genetic underpinnings on spinal alignment and found TK to have the strongest genetic association between twin pairs.[26]

The mechanism behind parity as a potential risk factor for degenerative changes in spinal alignment is unknown. Pregnancy is biomechanically burdensome, creating unique loading demands on the spine that could have long-term consequences for spine health. Pregnancy creates a period of heighted spinal loading and changes in abdominal muscle positioning[31] followed by sudden unloading that may distort the relationship between active and passive stabilizing components of the lumbar spine—resulting in instability and pain. Recent work in astronauts showed that sudden changes in spinal loading exposure has significant implications in disc health, pain, and posture[32]; it is possible that similar sudden shifts in spinal loading occur in women postpartum creating a mismatch in active and passive stabilizing elements. Over time and left uncorrected this imbalance can lead to postural degeneration.

Previous studies showed the degree of LL correlated with extensor muscle volume[33] and extensor muscle strength,[34] whereas decreased extensor muscle volume correlated with back pain.[33,35–37] Although the value of postpartum exercise for rehabilitating pelvic floor and abdominal muscles has been well studied for back pain,[38–40] incontinence,[41,42] and pelvic girdle pain,[38,43,44] there has been little work on the longer-term consequences of parity on spinal posture or the importance of rehabilitating spinal muscles postpartum. The only study we found directly assessing the impact of parity on spinal health established that parity correlated with the prevalence of spondylolisthesis in women during aging.[20] Clearly more work is needed to explore the short-

TABLE 2. Results From Multivariate Regression Analysis for Thoracic Kyphosis, Lumbar Lordosis, and Pelvic Incidence With Parity and Additional Covariates

	TK (°) ($r^2 = 0.45$)			LL (°) ($r^2 = 0.64$)			PI (°) ($r^2 = 0.50$)		
	β	RSE	*P*	β	RSE	*P*	β	RSE	*P*
Parity (births)	2.09	0.80	0.01	−2.19	0.61	<0.001	2.53	0.68	<0.001
Age (yr)	0.40	0.13	0.002						
BMI (kg/m^2)									
Thoracic kyphosis (°)	—	—	—	0.43	0.05	<0.001	0.34	0.06	<0.001
Lumbar lordosis (°)	0.74	0.09	<0.001	—	—	—	0.85	0.06	<0.001
Pelvic incidence (°)	−0.39	0.08	<0.001	0.57	0.05	<0.001	—	—	—
Lumbar degeneration (avg Pfirrmann)				−2.9	0.78	<0.001			
Lumbar BMD (g/cm^2)									

All of the variables on the left were included in the backward stepwise regression and those that associated with dependent variable were retained in the resulting multivariate model.
BMD indicates bone mineral density; LL, lumbar lordosis; PI, pelvic incidence; RSE, relative squared error; TK, thoracic kyphosis.

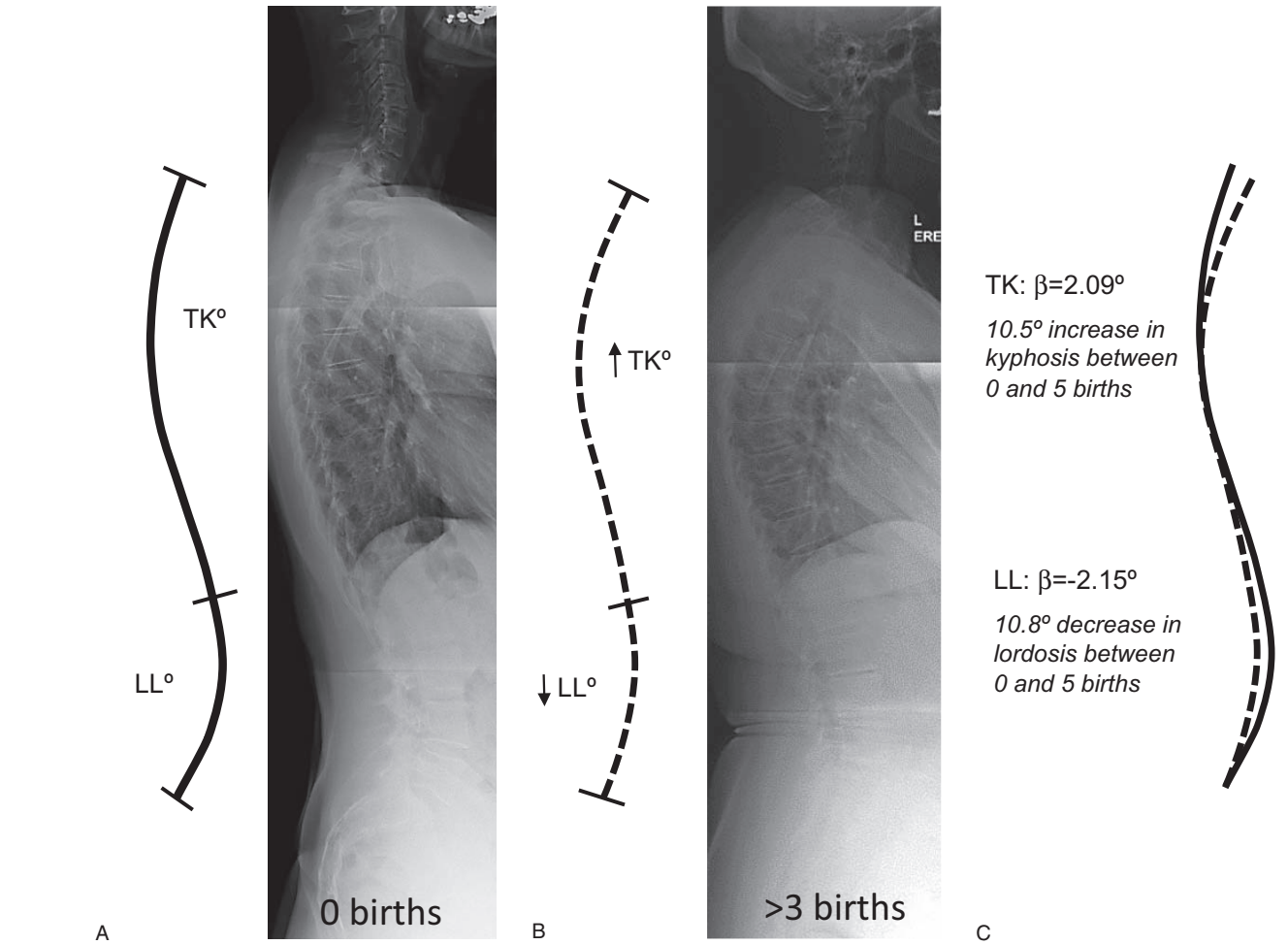

Figure 2. Schematic of parity-related differences in thoracic kyphosis and lumbar lordosis from regression analyses. A and B have radiographs of example female subjects with zero births and more than three births. Both are near the average PI-LL difference for those separate parity groups. In addition, A and B have schematics of sagittal alignment, that are then overlapped for comparison in C, showing differences between β coefficients for TK and LL ranging from the minimum (0) to the maximum (5) number of births in our analysis. LL indicates lumbar lordosis; TK, thoracic kyphosis.

and long-term consequences of child bearing on spinal posture and identify opportunities for intervention that may reduce age-related postural degeneration in women.

Furthermore, the effect of parity on pelvic ligamentous laxity may also impact postpartum sagittal alignment. Pregnancy has been shown to affect the ability to stabilize the pelvis and that this affect continued up to 8 weeks postpartum.[45] Specifically, the unconscious coactivation of the transverse abdominis (TrA) and internal oblique muscles with the pelvic floor muscles which is present in nulliparous women is compromised in pregnant and postpartum women.[46] Coactivation of the TrA is important for stabilizing the sacroiliac joint[47] and compromised TrA activation may lead to increased sacroiliac joint laxity, which may be a contributing factor to the establishment of PI, LL mismatch in aging women. The difference between PI and LL (''PI-LL mismatch'') is characteristic of sagittal imbalance. The PI-LL mismatch threshold that correlates with an Oswestry Disability Index score of 40 is 11°.[25] PI-LL between 10° and 20° is classified as moderate, whereas greater than 20° is ''marked.''[25] Historically, PI was been assumed to be a fixed measure[48]; however, the change of PI-LL with parity may indicate a compound effect of increased loading plus ligamentous laxity on the sacroiliac joint during pregnancy that has permanent structural implications. Targeted exercises that promote independent contraction of the TrA have shown beneficial effects in reducing pain and disability in patients with chronic low back pain[49] and may have potential for decreasing age-related postural degeneration in multiparous women.

It is worth noting that our study is not longitudinal and therefore we did not directly observe PI changing. Although it is possible that the association between higher number of births and greater PI could suggest that higher PI could be a factor that enables greater parity, we argue that ligamentous laxity and biomechanical demand on the sacrum associated with pregnancy and birth can alter PI. A longitudinal study needs to be done to clarify if PI is indeed constant with age, life-history, and debilitating spinal conditions that alter postural loading.

Some limitations to this study must be acknowledged. Although parity is reported for the study subjects, the age of

first birth was not available. Age at first birth (<20 years) has been shown to have a range of adverse health outcomes; however, separating the specific effects of age at first birth from pre-existing socioeconomic and health disadvantages has been challenging.[50] Age at first birth may have further specific effects on spinal posture that we could not elucidate in this study. Parity was not shown to correlate with either BMD or LDD, whereas parity did have an effect on TK and LL. It is not clear whether parity affected vertebral body or disc morphology (or both) to affect spinal curvature. The questionnaires for this study did not include information on vaginal or caesarian births. The surgical disruption of abdominal muscles during a caesarian section may have a greater effect on postural stability; however that could not be distinguished in this population and will require further research. There have been several studies showing hysterectomy increases the risk of low back pain in women and that effect continues as women age.[51] In addition, this study excluded those with a history of spinal fracture or surgery—this may bias the sample population in this case as those with higher parity may have already experienced spinal fracture or surgery. In comparing the birth history of our study population with studies of other elderly populations we had a greater proportion of nulliparous subjects (18%) than in other studies (9%).[50] Lastly, we did not have information regarding history of low back pain or lifestyle factors that could impact age-related changes in spinal alignment.

The women in our study population may have a lower birth rate than their national peers. The average birth rate of our study population (1.97) was lower than that from UK fertility cohort data for women born between 1940 and 1955 who had birthrates of 2.02 and 2.36 live births. This motivates further research that includes symptomatic individuals and those with a history of spinal fracture and surgery. Given our current observations, we expect the influence of parity on sagittal balance in a symptomatic population may be stronger.

Although women are disproportionately represented in clinical cohorts of patients with ASD[4,5] and pregnancy has demonstrated effects on spinal posture[21] there has been limited exploration of the effects of parity on age-related postural degeneration. This study established correlations between measures of spinal curvature in older women and parity for the first time. Having an identified cohort of patients at increased risk for age-related postural degeneration provides an ideal opportunity to assess the potential effectiveness of preventative treatment strategies to reduce the health and economic burden of age-related postural deformity.

➢ Key Points

- ❑ Pregnancy is known to affect spinal structures but parity has not been considered in spinal deformity research.
- ❑ Parity associates with increased TK, decreased LL, and increased PI.
- ❑ Within twin pairs, differences in parity associated with differences in TK.
- ❑ Parity correlates with a mismatch between PI and LL—a clinical metric linked to postural deformity and used as a basis for surgical correction.
- ❑ Pregnancy may be a contributing risk factor for higher risk of age-related ASD in women.

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