Longitudinal Study of Pelvic Floor Characteristics Before, During, and After Pregnancy in Nulliparous Women

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Abbreviations
POP, pelvic organ prolapse; POP-Q, pelvic organ prolapse quantification

Objectives—To investigate the changes in the pelvic floor before, during, and after pregnancy in the same collective of nulliparous women.

Methods—In a prospective observational pilot study between April 2015 and June 2019 in nulliparous women with planned pregnancy, we used the pelvic organ prolapse quantification (POP-Q) system; a 2-dimensional (2D) sonography to investigate the bladder neck, cervix, and anorectal junction positions; and a 3D/4D sonography to measure the hiatus of the levator ani muscle (LH area) during Valsalva maneuver. Five visits were planned: 1 before, 3 during, and 1 visit after pregnancy.

Results—Twenty-four women participated in the study. We achieved a minimum of 2 visit measurements from 10 women who became pregnant. The LH area decreased during the first trimester and then increased until the third trimester. Postpartum, the LH area reached the prepregnancy state. We observed changes in the bladder neck mobility, bladder neck position, cervix, and anorectal junction from the first trimester. Postpartum, the bladder neck mobility was higher, and the position of the bladder neck and anorectal junction was lower than before pregnancy. We observed no remarkable changes in the POP-Q state during pregnancy.

Conclusion—This was the first study to investigate pelvic floor characteristics in the same collective before, during, and after pregnancy. We observed pelvic floor changes from the prepregnancy state to the first trimester to postpartum. The study results need to be confirmed in a larger study.

Key Words—2D and 3D/4D ultrasound; levator hiatus; pelvic floor; pregnancy; POP-Q

Pregnancy and childbirth are known to impact the pelvic floor anatomy and function and are recognized risk factors for the development of urogynecological symptoms in later life.[1,2] Stress urinary incontinence, pelvic organ prolapse (POP), and anal incontinence affect up to 30% of the adult female population and may negatively influence women's quality of life.[1,3–5] It is still a matter of debate as to what extent pelvic floor changes are caused by vaginal delivery and birth trauma and to what extent they can be attributed to pregnancy-specific changes.[6–8]

In the last 20 years, 2-dimensional (2D) and 3D/4D translabial/transperineal sonography has become increasingly important as a fast, noninvasive, and easy-to-learn diagnostic tool for evaluating the pelvic floor anatomy and function. In several

studies, transperineal sonography has been shown to be reproducible and at least equivalent to *magnetic resonance imaging*.[9,10] Since sonography is an established and safe diagnostic tool in pregnancy, it has been increasingly used for pelvic floor assessments in pregnant women. Previous studies examined the pelvic floor before and after delivery and correlated changes with the mode of delivery. Results showed that in about 13 to 36% of women, vaginal delivery can lead to pelvic floor injuries. Avulsion, ie, traumatic detachment of the levator ani muscle from the pubic bone, is particularly associated with forceps delivery and not seen after cesarean sections. Therefore, this specific trauma is likely to be directly connected to the mechanical strain of the pelvic floor during vaginal delivery.[11,12] However, pregnancy itself may contribute to the development of other perinatal changes of the pelvic floor, ie, increased bladder neck mobility, pelvic organ descent, and increase in the hiatal area of the levator ani (LH area). Studies investigating the changes of the pelvic floor during pregnancy showed that these changes already occur in the course of pregnancy. Most studies started their analysis in pregnancy and compared pelvic floor measurements between mid and late pregnancy and after delivery.[8,13–20] No study published till date has characterized the pelvic floor before, during, and after pregnancy in the same collective. In this study setting, the evaluation of pelvic floor changes directly related to pregnancy-specific hormonal and physiological changes may be best done during early pregnancy, at a time when the weight of the uterus and the increase in intra-abdominal pressure are not yet relevant.[21]

To evaluate this purpose, we conducted a prospective pilot study. The aim was to show changes in different pelvic parameters—prolapse stage using the pelvic organ prolapse quantification system (POP-Q system) and translabial 2D and 3D/4D sonography measurement—of the position of the bladder neck, cervix uteri, and anorectal junction and the LH area during Valsalva maneuver before, during, and after pregnancy in the same collective.

Materials and Methods

Nulliparous women were recruited between 2015 and 2017 in our endocrinology outpatient department. Follow-up was stopped in June 2019. Women visiting the endocrinology department typically present with either infertility and/or planned pregnancy. Inclusion criteria were as follows: no former pregnancy over 15 weeks of gestation, at least 18 years old, no history of preexisting pelvic floor disorders or treatment, and no contraindication in performing Valsalva maneuver (such as cardiac or pulmonary disease). Written informed consent was obtained from all women before starting the investigation. The study was approved by the local ethics committee of the Medical University of Graz (number 26–147 ex 13/14).

In total, 24 women agreed to participate in the study. Basic demographic data, including age, height, weight, and urogynecological history, such as urinary incontinence, symptoms of POP, and stool or defecation problems, were registered.

The participating women laid in supine to Fowler's position during the examination and sonographic assessment. A baseline clinical examination of the pelvic floor was performed using the International Continence Society POP-Q System.[22] In addition, we performed 2D sonography to investigate the position of the bladder neck, cervix uteri, and anorectal junction at rest and during Valsalva maneuver and a 3D/4D sonography to measure the LH area during Valsalva maneuver. The measurements were performed after voiding or with a nearly empty bladder. We used a wideband convex volume transducer (RAB4-8-D, 2–8 MHz) linked to a Voluson E6 ultrasound system (GE Healthcare, Zipf, Austria). The sonographic transducer was positioned between the labia minora in the vaginal introitus in the midsagittal plane with minimum pressure. A minimum angle of 70° was used. The anatomical structures of the pubic symphysis, bladder neck, urethra, vagina, cervix, and rectal ampulla were focused on 2D sonography. The positions of the bladder neck, cervix, and anorectal junction were measured using a horizontal reference line through the pubic symphysis at rest and on Valsalva maneuver. The distances from the symphysis pubis (right angle to the reference line through the pubic symphysis) of the bladder neck, cervix, and anorectal junction at rest and on Valsalva maneuver were recorded (Figure 1).[17,23,24]

To measure the LH area, we used a 3D/4D sonography. The LH area was derived from the 2D midsagittal plane and determined by the pubic symphysis and the rectal ampulla, as described by Dietz et al.[25] (Figure 2).

We started at rest and asked the participants to perform a proper Valsalva maneuver for at least 5 seconds. The picture was frozen at maximum Valsalva maneuver, and LH area measurement was performed. Data were stored digitally and printed. We also examined the levator ani muscle in tomographic recordings to identify levator detachment from the pelvic sidewall.[26] All measurements and examinations were performed by three investigators. Two investigators are gynecologists who specialize in sonographic techniques of the pelvic floor. The third investigator was trained by the other two investigators for a minimum of 20 examinations and was also a gynecologist with high experience in sonographic techniques.

The inexperienced examiner ICL (at the beginning of the study) was trained theoretically and practically by the experienced examiners GT and DG. The intraobserver repeatability determined by the intraoperator intraclass correlation coefficient comparing the first 10 measurements in V0 (2D and 3D/4D sonography) by ICL, GT, and DG for the positions of bladder neck, cervix and anorectal junction, and the LH was between 0.74 and 0.96.[27]

The participants were contacted regularly to inquire about the onset of pregnancy. There were a total of five visits planned: V0 before pregnancy, V1 at the first trimester of pregnancy until the 14th week of gestation, V2 at the second trimester between the 20th and 28th weeks of gestation, V3 at the third trimester between the 32nd and 39th week of gestation, and V4 at a minimum of 6 months and a maximum of 2 years postpartum.

The study data were collected in an Excel 2013 (Microsoft Corporation, Redmond, WA) spreadsheet. We used SPSS statistics 25 (IBM Corporation, Armonk, NY) to analyze the data. We performed descriptive statistics and used the Friedman test and

Figure 2. Three-dimensional sonographic measurement of the hiatus of levator ani muscle (white broken line) on Valsalva maneuver (**B**). The LH area was derived from the 2D midsagittal plane (**A**) and determined by the pubic symphysis (1) and the pubovisceral muscle just posterior to the rectal ampulla (2).
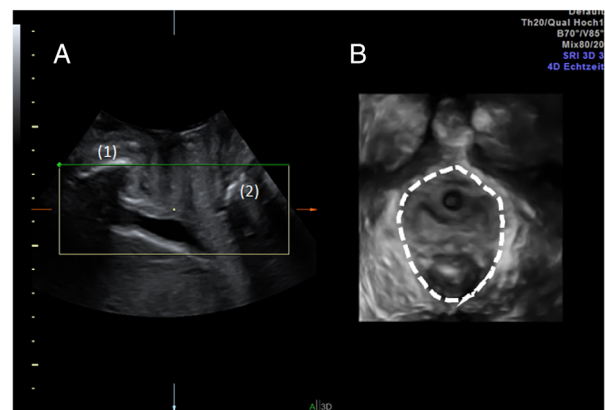

Figure 1. 2D sonographic measurement of bladder neck, cervix, and anorectal junction. Measurements were performed from a horizontal reference line (1) through the pubic symphysis: **A**, at rest and **B**, on Valsalva maneuver. Vertical distance: 2 bladder neck at rest, 3 cervix at rest, 4 anorectal junction at rest; 5 bladder neck on Valsalva maneuver, 6 cervix on Valsalva maneuver, and 7 anorectal junction on Valsalva maneuver.
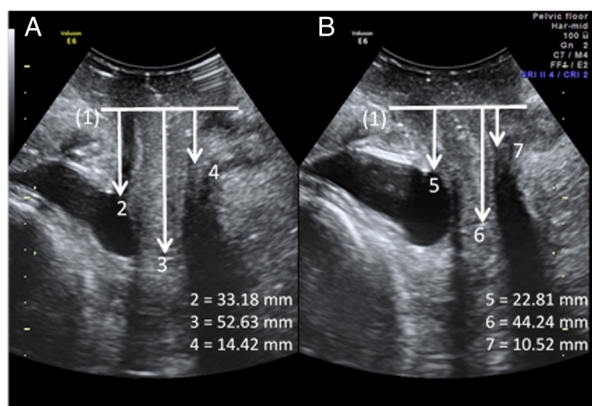
Table 1. Baseline Demographics and Delivery Data of the Pregnancy Group

Baseline demographics	Prepregnancy group N = 24	Pregnancy group N = 10
Age (years)	33.4 (3.6)	33.0 (3.2)
Ethnicity (n)		
Caucasian	23	10
Black	1	0
Body mass index (kg/m^2)	23.8 (5.0)	21.9 (2.9)
Delivery data		
Gestational age at birth (weeks)		37.3 (4.1)
Birth weight (g)		2795 (840)
Mode of delivery (n)		
Spontaneous		6
Caesarean section		3
Vacuum		1

Note: Data are shown in number or mean and standard deviation.

the Wilcoxon test to compare the data regarding the bladder neck, cervix, and anorectal junction positions at rest and on Valsalva maneuver and the LH areas. A level of $P < .05$ was defined as statistically significant.

We performed a power calculation using our data of the LH area measurements to evaluate the minimum size of the group to achieve significant results.

Results

We obtained complete prepregnancy measurements (V0) from 24 recruited women (prepregnancy group).

None of the women had urinary problems, symptoms of prolapse, or stool problems in V0. Most women had stage 0 POP-Q score in V0 or maximum stage 1 POP-Q score (1 woman). In total, 14 of the 24 women became pregnant. From 10 women, we could obtain a minimum of two measurements during and after pregnancy. These women were considered for further analysis (baseline demographics and delivery data of the prepregnancy and pregnancy groups are summarized in Table 1).
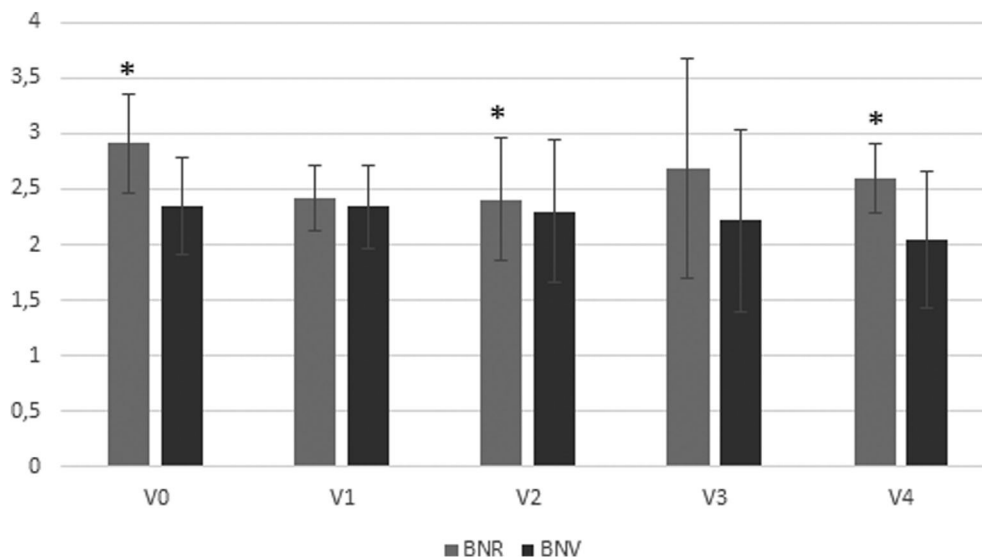
Data on POP-Q before, during, and after pregnancy are shown in Table 2. We observed no remarkable changes in the POP-Q state during pregnancy.

Table 2. POP-Q Score Before, During, and After Pregnancy

POP-Q Points	Prepregnancy V0	During pregnancy			Postpartum V4
		V1	V2	V3	
Ba	−2.58 (0.56)	−2.80(0.40)	−2.57 (0.49)	−2,67 (0.75)	−2.25 (0.82)
C	−7.74 (0.87)	−8 (0.00)	−7.75 (0.66)	−7.67 (0.75)	−8.13 (0.33)
Bp	−2.74 (0.41)	−2.80 (0.40)	−2.78(0.35)	−2.67 (0.74)	−2.00 (1.00)
GH	2.86 (0.43)	2.40 (0.49)	2.44 (0.49)	2.83 (0.37)	2.50 (0.50)
PB	2.69 (1.27)	2.80 (0.40)	2.61 (0.44)	2.75(0.38)	2.44 (0.58)

Notes: POP-Q variables. V0: prepregnancy, V1: pregnancy until 14th week of gestation, V2: pregnancy between 20th and 28th week of gestation, V3: pregnancy between 32nd and 39th week of gestation, V4: 3 months to 2 years postpartum.

Figure 3. Bladder neck position at rest (bladder neck position at rest (BNR) light gray) and Valsalva (bladder neck position at Valsalva (BNV) dark gray) in 2D sonography. Data are presented as mean (bar plots) with standard deviation (error bars) measurement in cm. V0: prepregnancy, V1: pregnancy until 14th week of gestation, V2: pregnancy between 20th and 28th week of gestation, V3: pregnancy between 32nd and 39th week of gestation, V4: 3 months to 2 years postpartum. Statistical analyses using the Friedman test for differences between V0/V1/V2/V3/V4 results in $P = .463$ at rest and $P = .331$ at Valsalva. *We observed for the position of the bladder neck at rest between V0 and V2 ($P = .025$) and V0 and V4 ($P = .043$) using the Wilcoxon test.

Changes in the bladder neck, cervix, and anorectal junction positions before, during, and after pregnancy are shown in Figures 3–5.

In contrast to the prepregnancy state, we found a decrease in the bladder neck mobility in the first and second trimesters and an increase in the third trimester. The bladder neck mobility postpartum reached nearly prepregnancy results, but at a lower level. There was an elevation of the cervix position during pregnancy at rest and on Valsalva, reaching a nearly prepregnancy state postpartum. The anorectal junction position was higher in the first trimester and deeper during gestation. Its position was lower postpartum than in the prepregnancy state.

The LH area measurements before, during, and after pregnancy are shown in Figure 6. There was a decrease in the LH area in the first trimester, which increased until the third trimester. The postpartum LH area reached a nearly prepregnancy state. After delivery, no women had a POP stage of more than 1, and there were no signs of levator avulsion. One woman had an occult lesion of the sphincter ani externus with minor stool problems after spontaneous delivery and a primary low grade tear of the perineum.

We used the Friedman test for statistical analyses between V0/V1/V2/V3/V4 for the position of the bladder neck, cervix, anorectal junction, and LH area. Because of the test proprieties and the low power of only 10 participants, we could observe statistically tendencies between visits but not significant results ($P > .05$). We used the Wilcoxon test to compare V0 versus V1/V2/V3/V4 for the position of the bladder neck, cervix, anorectal junction, and LH area. We

Figure 4. Cervix position at rest (cervix position at rest (CR) light gray) and Valsalva (cervix position at Valsalva (CV) dark gray) in 2D sonography. Data are presented as mean (bar plots) with standard deviation (error bars) measurement in cm. V0: prepregnancy, V1: pregnancy until 14th week of gestation, V2: pregnancy between 20th and 28th week of gestation, V3: pregnancy between 32nd and 39th week of gestation, V4: 3 months to 2 years postpartum. Statistical analyses using the Friedman test for differences between V0/V1/V2/V3/V4 results in $P = .699$ at rest and $P = .627$ at Valsalva. Using the Wilcoxon test also no significant results were achieved ($P > .05$).
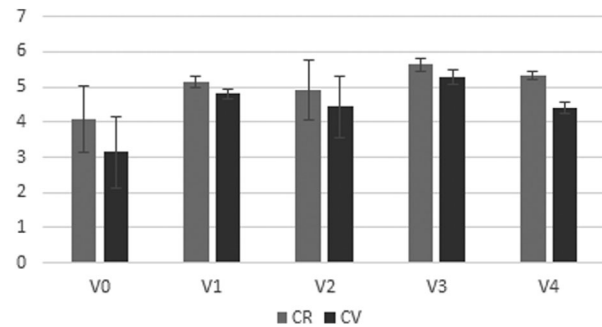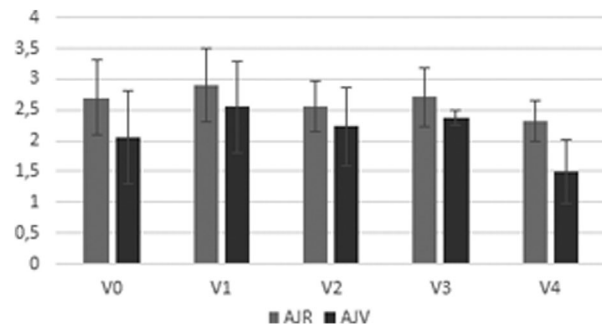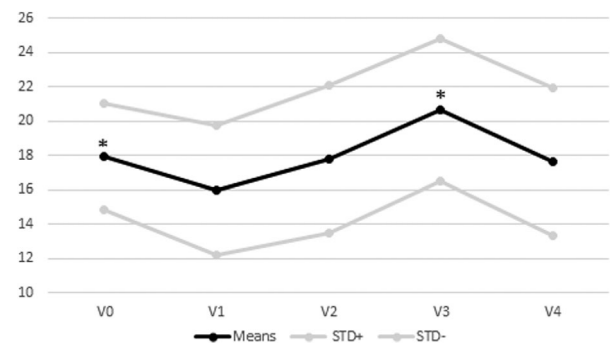
Figure 5. Position of anorectal junction at rest (position of anorectal junction at rest (AJR) light gray) and Valsalva (position of anorectal junction at Valsalva (AJV) dark gray) in 2D sonography. Data are presented as mean (bar plots) with standard deviation (error bars) measurement in cm. V0: prepregnancy, V1: pregnancy until 14th week of gestation, V2: pregnancy between 20th and 28th week of gestation, V3: pregnancy between 32nd and 39th week of gestation, V4: 3 months to 2 years postpartum. Statistical analyses using the Friedman test for differences between V0/V1/V2/V3/V4 results in $P = .772$ at rest and $P = .772$ at Valsalva. Using the Wilcoxon test also no significant results were achieved $P > .05$.

Figure 6. Hiatus of the levator (LH area) on Valsalva maneuver before, during, and after pregnancy. Measurements are in cm^2 and standard deviation. V0: prepregnancy, V1: pregnancy until 14th week of gestation, V2: pregnancy between 20th and 28th week of gestation, V3: pregnancy between 32nd and 39th week of gestation, V4: 3 month to 2 years postpartum. Statistical analyses using the Friedman test for differences between V0/V1/V2/V3/V4 results in $P = .231$. *We observed statistical significant results between V0 and V3 for the LH area ($P = .018$) using the Wilcoxon test.

observed statistical significant results between V0 and V3 for the LH area (P = .18) and for the position of bladder neck at rest between V0 and V2 (P = .025) and V0 and V4 (P = .043). Regarding the position of the cervix and the anorectal junction, no significant results were observed (P > .05).

Discussion

In this first pilot study, we measured the pelvic floor before, during, and after pregnancy. We observed changes in the LH area on Valsalva maneuver from the first trimester onward. There was a decrease in the LH area in the first trimester compared with the prepregnancy state. The LH area increased as the pregnancy progressed until the third trimester. Postpartum, the LH area reached the prepregnancy state.

Compared with the prepregnancy state, we observed changes in the bladder neck mobility and the bladder neck, cervix, and anorectal junction positions from the first trimester. Postpartum, the bladder neck mobility was higher, and the position of the bladder neck and anorectal junction was lower than before pregnancy.

We found no remarkable changes in the POP-Q state during and after pregnancy.

Our study fulfils the purpose of a pilot study, and our results (even if they were not significant) indicate that it is worth investigating the pelvic floor before, during, and after pregnancy in the same collective in larger prospective studies. Only our study design can truly evaluate pregnancy-induced modifications of the pelvic floor. Introducing additional investigating parameters, laboratory values, and measurements should be considered, but in the same study setting.

The main limitation of our study was the small group size. We performed a post hoc power calculation to evaluate the right size of the study group, which would lead to significant results regarding LH area changes. Considering the fertility rate and dropout rate, we will need about 100 nulliparous women willing to become pregnant in a future study.

Another limitation of our investigation was the missing visits of some women and the missing measurements of the LH area at rest and on pelvic floor muscle contraction. Even if some studies show that the LH area on Valsalva maneuver may be the most important LH area for characterizing levator ani muscle and function, the LH area at rest and that during contraction are basic measurements and should be investigated together.[6,8,14,17,25,28,29]

Even if we are dealing only with infertility women, a comparison with previous studies including nulliparous women showed similar results regarding pelvic floor parameters.[25,30,31] Nevertheless, in a larger study, a control group should be considered or the recruitment of women desiring to get pregnant should be through advertising and general practitioners to achieve, healthy "women with no infertility problems."[32]

Anyhow there are only few studies that evaluated the pelvic floor in the first trimester, and there is no study until yet that investigated the pelvic floor *before* and during pregnancy in the same collective.

Hiatus Area of Musculus Levator Ani Before, During, and After Pregnancy

Our measurements in the first trimester are similar to the measurements of other Caucasian collectives in the first trimester but differ from those of other ethnicities.[13,14,17] Especially regarding the LH area, it is known that there are differences in this area according to ethnicity and population. Therefore, the investigation of the same collective before and during pregnancy seems to be important.[28,30,33] Changes in the pelvic floor in the first trimester had to be directly affected by hormonal and physiological pregnancy-specific changes. We know, especially from animal studies, that maternal tissues, such as the vagina and pelvic floor, change during gestation to attempt successful vaginal delivery.[34] Previous literature showed that changes in the pelvic floor are related to the birth mode or the successful attempt of a vaginal birth.[8,29,35–37] A study by Oliphant et al. investigating maternal adaptation in preparation for parturition in humans showed that the vagina elastase activity, especially in the first trimester, is significantly associated with successful vaginal delivery.[38] Therefore, pelvic floor changes have to start very early and are recognizable in the first trimester. A delayed onset or insufficient modeling of the pelvic floor and vagina could lead to poor preparation for vaginal delivery with a higher rate of cesarean section, need for instrumented vaginal deliveries, and higher risk of pelvic floor injuries.

The changes in the LH area during pregnancy conform to former studies with rising measurements until the third trimester. After birth, we observed the

recovery of the LH area to the prepregnancy state. In addition, this conforms to previously published data if it takes into account the following: small group size, mixed birth mode (vaginal delivery and cesarean section), the pelvic floor having time to recover with the postpartum examination performed within a minimum of 3 months after delivery, and no women having postpartum major pelvic floor trauma or POP.[13,14,17,19,39]

The Bladder Neck, Cervix, and Anorectal Junction Positions Before, During, and After Pregnancy

Compared with the prepregnancy state, we observed changes in the bladder neck, cervix, and anorectal junction positions from the first trimester onward. Chan et al. investigated the same parameters in more than 400 women who were pregnant and postpartum, depending on the delivery mode. There was significant descent of the bladder neck, cervix, and anorectal junction during pregnancy. One year after pregnancy, the pelvic organs remained more mobile and deeper regardless of the mode of delivery compared with first trimester measurements.[17,40] Another study led to similar results.[41] For the bladder neck and anorectal junction mobility and position, our results conform to previous literature. The observed differences in the cervix during and after pregnancy (elevation or stable state) in our study could be due to the small group size and the difficulty in obtaining the correct measurements of the cervix in pregnant women. Nevertheless, 1 study focusing on POP-Q scores during pregnancy showed a cranial shift of the vaginal POP-Q points from mid to late pregnancy.[42]

Changes of the Mobility of Bladder Neck, Cervix, and Anorectal Junction

The mobility of bladder neck, cervix, and anorectal junction was less in the first and second trimester, increased, especially for the bladder neck, in the third trimester, and reached prepregnancy state (or higher values for the anorectal junction) postpartum. Similar results were observed by previous literature.[17,40] Even if not significant, it is interesting that the mobility of all parameters was lowest in the first trimester. There are no comparable data in literature, so this observation should receive special attention in larger studies.

POP-Q Score Before, During, and After Pregnancy

Our findings conform with other studies that also observed no significant changes of POP-Q score during pregnancy and about 1 year after pregnancy.[7,43] Other studies showed a significant increase in the POP-Q stage until the third trimester.[42,44] Nevertheless, one study showed a cranial shift of the vaginal POP-Q points from mid to late pregnancy.[42] The different results of the POP-Q score show that this investigation method may not be the perfect method for examining pregnant women. Pregnancy is connected to young age, and a higher POP stage is not to be expected in these women, especially in nulliparous women. Other measurements, such as 2D and especially 3D/4D sonography, are more sensitive to functional and anatomical changes and injuries of the pelvic floor. The POP-Q system should be used for the classification of women with real prolapse (POP-Q stage ≥2). Even if this collective is small, approximately 0 to 10% of nulliparous pregnant women, these women may especially benefit from pelvic floor exercise and birth mode evaluation.[42]

Conclusion

The results of our pilot study indicate that pregnancy-specific changes in the pelvic floor start immediately on the first trimester. Only the investigation of the same collective before, during, and after pregnancy can evaluate the pregnancy-induced changes in the pelvic floor in contrast to the delivery-induced changes. The investigation of the pelvic floor using 2D and 3D/4D sonographic measurements accompanied by a short clinical investigation, with evaluation of the prolapse stage, should become basic evaluation methods during pregnancy. Further investigations on hormone levels, metabolism, circulation, and questionnaires regarding pelvic floor disorders and sexuality are also important to understand the effect of pregnancy on the pelvic floor from the first trimester onward.

We hope that our pilot study can inspire other study groups to initiate larger studies. Of course, you need good preparation and adequate financial and logistical resources, but if our results will be confirmed in larger studies, then they suggest that the pregnancy-induced changes of the pelvic floor starts

very early in pregnancy. Some studies indicated that an insufficient adaptation of the pelvic floor during pregnancy may lead to increased length of labor, higher rate of traumatic injuries of the levator ani muscle, and higher rate of caesarean section.[8,35,45] So if women with such insufficient adaptation of the pelvic floor can be identified in first trimester using ultrasound methods, this can have consequences for targeted counseling including training of the pelvic floor, weight control, hormonal substitution, and other life style changes, which may improve the adaptation of the pelvic floor. Recurring examination of the pelvic floor during pregnancy and taking into consideration other risk factors, which can lead to a traumatic vaginal delivery, can help identify these women who will really benefit of an elective caesarean section.

References

1. Nygaard I, Barber MD, Burgio KL, et al. Prevalence of symptomatic pelvic floor disorders in US women. *JAMA* 2008; 300: 1311–1316.

2. Mant J, Painter R, Vessey M. Epidemiology of genital prolapse: observations from the Oxford family planning association study. *Br J Obstet Gynaecol* 1997; 104:579–585.

3. Lowder JL, Ghetti C, Nikolajski C, Oliphant SS, Zyczynski HM. Body image perceptions in women with pelvic organ prolapse: a qualitative study. *Am J Obstet Gynecol* 2011; 204:441 e441–441 e445.

4. Barlow DH, Samsioe G, van Geelen JM. A study of European womens' experience of the problems of urogenital ageing and its management. *Maturitas* 1997; 27:239–247.

5. Rortveit G, Brown JS, Thom DH, Van Den Eeden SK, Creasman JM, Subak LL. Symptomatic pelvic organ prolapse: prevalence and risk factors in a population-based, racially diverse cohort. *Obstet Gynecol* 2007; 109:1396–1403.

6. de Araujo CC, Coelho SA, Stahlschmidt P, Juliato CRT. Does vaginal delivery cause more damage to the pelvic floor than cesarean section as determined by 3D ultrasound evaluation? A systematic review. *Int Urogynecol J* 2018; 29:639–645.

7. Rogers RG, Ninivaggio C, Gallagher K, Borders AN, Qualls C, Leeman LM. Pelvic floor symptoms and quality of life changes during first pregnancy: a prospective cohort study. *Int Urogynecol J* 2017; 28:1701–1707.

8. Siafarikas F, Staer-Jensen J, Hilde G, Bo K, Ellstrom Engh M. The levator ani muscle during pregnancy and major levator ani muscle defects diagnosed postpartum: a three- and four-dimensional transperineal ultrasound study. *BJOG: Int J Obstet Gynaecol* 2015; 122:1083–1091.

9. Dietz HP. Pelvic floor ultrasound: a review. *Am J Obstet Gynecol* 2010; 202:321–334.

10. Notten KJ, Kluivers KB, Futterer JJ, et al. Translabial three-dimensional ultrasonography compared with magnetic resonance imaging in detecting levator ani defects. *Obstet Gynecol* 2014; 124: 1190–1197.

11. Schwertner-Tiepelmann N, Thakar R, Sultan AH, Tunn R. Obstetric levator ani muscle injuries: current status. *Ultrasound Obstet Gynecol* 2012; 39:372–383.

12. Trutnovsky G, Kamisan Atan I, Martin A, Dietz HP. Delivery mode and pelvic organ prolapse: a retrospective observational study. *BJOG: Int J Obstet Gynaecol* 2016; 123:1551–1556.

13. Sanozidis A, Mikos T, Assimakopoulos E, et al. Changes in levator hiatus dimensions during pregnancy and after delivery in nulliparas: a prospective cohort study using 3D transperineal ultrasound. *J Matern Fetal Neonatal Med* 2018; 31:1505–1512.

14. van Veelen GA, Schweitzer KJ, van der Vaart CH. Ultrasound imaging of the pelvic floor: changes in anatomy during and after first pregnancy. *Ultrasound Obstet Gynecol* 2014; 44:476–480.

15. Staer-Jensen J, Siafarikas F, Hilde G, Benth JS, Bo K, Engh ME. Postpartum recovery of levator hiatus and bladder neck mobility in relation to pregnancy. *Obstet Gynecol* 2015; 125:531–539.

16. Liu F, Xu L, Ying T, Tao J, Hu B. Three-dimensional ultrasound appearance of pelvic floor in nulliparous women and postpartum women one week after their first delivery. *Int J Med Sci* 2014; 11:234–239.

17. Chan SS, Cheung RY, Yiu KW, Lee LL, Chung TK. Pelvic floor biometry in Chinese primiparous women 1 year after delivery: a prospective observational study. *Ultrasound Obstet Gynecol* 2014; 43:466–474.

18. Chan SS, Choy KW, Yiu KW, Cheung RY, Leung TY. Pelvic floor disorders related to pregnancy: a prospective observational study. *Hong Kong Med J* 2017; 23:42–46.

19. Staer-Jensen J, Siafarikas F, Hilde G, Bo K, Engh ME. Ultrasonographic evaluation of pelvic organ support during pregnancy. *Obstet Gynecol* 2013; 122:329–336.

20. Blomquist JL, Munoz A, Carroll M, Handa VL. Association of delivery mode with pelvic floor disorders after childbirth. *JAMA* 2018; 320:2438–2447.

21. Staelens AS, Van Cauwelaert S, Tomsin K, Mesens T, Malbrain ML, Gyselaers W. Intra-abdominal pressure measurements in term pregnancy and postpartum: an observational study. *PLoS One* 2014; 9:e104782.

22. Bump RC, Mattiasson A, Bo K, et al. The standardization of terminology of female pelvic organ prolapse and pelvic floor dysfunction. *Am J Obstet Gynecol* 1996; 175:10–17.

23. Dixit P, Shek KL, Dietz HP. How common is pelvic floor muscle atrophy after vaginal childbirth? *Ultrasound Obstet Gynecol* 2014; 43:83–88.

24. Dietz HP, Haylen BT, Broome J. Ultrasound in the quantification of female pelvic organ prolapse. *Ultrasound Obstet Gynecol* 2001; 18:511–514.

25. Dietz HP, Shek C, Clarke B. Biometry of the pubovisceral muscle and levator hiatus by three-dimensional pelvic floor ultrasound. *Ultrasound Obstet Gynecol* 2005; 25:580–585.

26. Dietz HP, Shek KL. Tomographic ultrasound imaging of the pelvic floor: which levels matter most? *Ultrasound Obstet Gynecol* 2009; 33:698–703.

27. Siafarikas F, Staer-Jensen J, Braekken IH, Bo K, Engh ME. Learning process for performing and analyzing 3D/4D transperineal ultrasound imaging and interobserver reliability study. *Ultrasound Obstet Gynecol* 2013; 41:312–317.

28. Gao Y, Zhao Z, Yang Y, Zhang M, Wu J, Miao Y. Diagnostic value of pelvic floor ultrasonography for diagnosis of pelvic organ prolapse: a systematic review. *Int Urogynecol J* 2020;31:15–33.

29. Shek KL, Kruger J, Dietz HP. The effect of pregnancy on hiatal dimensions and urethral mobility: an observational study. *Int Urogynecol J* 2012; 23:1561–1567.

30. Cheung RY, Shek KL, Chan SS, Chung TK, Dietz HP. Pelvic floor muscle biometry and pelvic organ mobility in east Asian and Caucasian nulliparae. *Ultrasound Obstet Gynecol* 2015; 45:599–604.

31. Swenson CW, Masteling M, DeLancey JO, Nandikanti L, Schmidt P, Chen L. Aging effects on pelvic floor support: a pilot study comparing young versus older nulliparous women. *Int Urogynecol J* 2020; 31:535–543.

32. Zielinski R, Ackerson K, Misiunas RB, Miller JM. Feasibility of a longitudinal study of women anticipating first pregnancy and assessed by multiple pelvic exams: recruitment and retention challenges. *Contemp Clin Trials* 2010; 31:544–548.

33. Abdool Z, Dietz HP, Lindeque BG. Ethnic differences in the levator hiatus and pelvic organ descent: a prospective observational study. *Ultrasound Obstet Gynecol* 2017; 50:242–246.

34. Ulrich D, Edwards SL, Su K, et al. Influence of reproductive status on tissue composition and biomechanical properties of ovine vagina. *PLoS One* 2014; 9:e93172.

35. Lanzarone V, Dietz HP. Three-dimensional ultrasound imaging of the levator hiatus in late pregnancy and associations with delivery outcomes. *Aust N Z J Obstet Gynaecol* 2007; 47:176–180.

36. Dietz HP, Moore KH, Steensma AB. Antenatal pelvic organ mobility is associated with delivery mode. *Aust N Z J Obstet Gynaecol* 2003; 43:70–74.

37. Svabik K, Shek KL, Dietz HP. How much does the levator hiatus have to stretch during childbirth? *BJOG: Int J Obstet Gynaecol* 2009; 116:1657–1662.

38. Oliphant SS, Nygaard IE, Zong W, Canavan TP, Moalli PA. Maternal adaptations in preparation for parturition predict uncomplicated spontaneous delivery outcome. *Am J Obstet Gynecol* 2014; 211:630 e631–630 e637.

39. Toozs-Hobson P, Balmforth J, Cardozo L, Khullar V, Athanasiou S. The effect of mode of delivery on pelvic floor functional anatomy. *Int Urogynecol J Pelvic Floor Dysfunct* 2008; 19: 407–416.

40. Chan SS, Cheung RY, Yiu KW, Lee LL, Leung TY, Chung TK. Pelvic floor biometry during a first singleton pregnancy and the relationship with symptoms of pelvic floor disorders: a prospective observational study. *BJOG: Int J Obstet Gynaecol* 2014; 121: 121–129.

41. Wijma J, Weis Potters AE, van der Mark TW, Tinga DJ, Aarnoudse JG. Displacement and recovery of the vesical neck position during pregnancy and after childbirth. *Neurourol Urodyn* 2007; 26:372–376.

42. Reimers C, Staer-Jensen J, Siafarikas F, Saltyte-Benth J, Bo K, Ellstrom Engh M. Change in pelvic organ support during pregnancy and the first year postpartum: a longitudinal study. *BJOG: Int J Obstet Gynaecol* 2016; 123:821–829.

43. Elenskaia K, Thakar R, Sultan AH, Scheer I, Onwude J. Pelvic organ support, symptoms and quality of life during pregnancy: a prospective study. *Int Urogynecol J* 2013; 24: 1085–1090.

44. O'Boyle AL, O'Boyle JD, Ricks RE, Patience TH, Calhoun B, Davis G. The natural history of pelvic organ support in pregnancy. *Int Urogynecol J Pelvic Floor Dysfunct* 2003; 14:46–49.discussion 49.

45. Reimers C, Siafarikas F, Staer-Jensen J, Smastuen MC, Bo K, Ellstrom Engh M. Risk factors for anatomic pelvic organ prolapse at 6 weeks postpartum: a prospective observational study. *Int Urogynecol J* 2019; 30:477–482.