Gait & Posture 70 (2019) 196–202

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Anthropometry, standing posture, and body center of mass changes up to 28 weeks postpartum in Caucasians in the United States

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ARTICLE INFO

Keywords:
Posture
Postpartum
Center of mass
Anthropometry
Gestational lordosis

ABSTRACT

Background: Anthropometric models are used when body center of mass motion is calculated for assessment of dynamic balance. It is currently unknown how body segments and posture change in the postpartum period. Therefore, this study was conducted to evaluate the longitudinal changes in anthropometry, center of mass, and standing posture postpartum.
Methods: Seventeen pregnant women were tested at nine different times: 16–20 weeks and 36–40 weeks gestation, and then in 4-week intervals from childbirth to 28 weeks postpartum. Anthropometry was measured and then participants conducted a static standing and static laying trial. Force plate data and motion capture data were used in combination with anthropometry to calculate the masses of individual segments and the body center of mass. Change over time was determined through a linear mixed model analysis.
Results: Anthropometric changes related to the abdomen or fluid retention during pregnancy immediately regress to early pregnancy levels following childbirth. However, other changes related to breast tissue and fat deposits persist postpartum. As such, masses of different segments affect an anthropometric model for center of mass calculation, and body center of mass changes in the lateral and anterior directions postpartum. Vertical body center of mass position was unaffected.
Significance: Increased postpartum breast mass may be the cause of persistent lordotic curvature changes in the lumbar spine. There is potential that this affects postpartum back pain. Future research should explore how body center of mass changes postpartum for individuals that do not breast feed, and thus may not have significant breast mass postpartum.

1. Background

Center of mass (COM) motion is sometimes used to assess balance in standing [1–3] and more commonly used in dynamic tasks [4,5]. One of the most common methods for identifying the COM is to calculate it from the weighted sum of body segments [6]. However, it is typical that a predefined anthropometric model is used to make this calculation, not considering the individual differences within the sample or in reference to the population used to originally create the anthropometric model. We have previously shown that different anthropometric models can significantly alter balance results [6]. Because of this, and the dearth of anthropometry related to pregnant body change, we created a methodology by which we can determine how torso COM changes during pregnancy [7]. This information allowed us to document dynamic balance changes during pregnancy [8]. However, it is still unknown how the body COM changes postpartum.

It is currently thought that the COM location changes during pregnancy mostly because of the mass change and reshaping of the trunk [9,10]. Women gain anywhere from 11 to 15.5 kg, or 5 points in body mass index (BMI), during pregnancy in a nonlinear fashion [11,12]. This weight gain can vary by race and nationality [11]. The average Caucasian newborn weighs 3.5 kg in the United States [13], acting as the major constituent to mass, but by calculation would only account for a little over 30% of the mass gains during pregnancy. Amniotic fluid volume is < 1 L near birth [14], and placental weight account for a little under 20% of mass, specifically added to the pelvis and abdomen [12]. Systemic increases in adiposity, extracellular fluid, and blood volume make up another 40% of mass increases during pregnancy [12]. Breast weight increases can account for the remaining mass increase during pregnancy.

Abbreviations: COM, center of mass; sd, standard deviation

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https://doi.org/10.1016/j.gaitpost.2019.03.009
Received 20 December 2018; Received in revised form 13 February 2019; Accepted 11 March 2019

Localization of the fetus obviously leads to substantially more weight gains in the pelvis and torso. Small weight gains are common throughout the body though, with significant weight gains in the thighs [7], representing the next heaviest segments after the torso and pelvis [15], respectively. Adipose weight throughout the body represents a significant change due to pregnancy that can persist even after giving birth, as it is typical that women weigh significantly more postpartum compared to pre-pregnancy [16]. Additionally, significant weight gains in the breasts are common in late pregnancy and persist for a varying amount of time postpartum with respect to breastfeeding habits [17].

In addition to mass changes during pregnancy, postural changes are thought to reposition the COM during pregnancy. As abdominal mass grows anteriorly, so too does the body COM [9]. Uncompensated, such a growth would put more onus on posterior muscles to maintain standing posture [18]. In response, it is typical for pregnant women to lean back [18] and develop greater lordotic curvature to reposition the upper body COM backward over the hip joint centers [9], through spine extension.

It is currently unknown if pregnancy-related segment anthropometry changes persist postpartum. Persistent changes may result in significant changes to the body COM location. The goal of this study was to explore if changes that occur during pregnancy (internal and external anthropometry, pelvic posture, and body COM) persist over any period of time postpartum. This information is essential as we explore balance changes, balance perturbations (e.g. child carrying and divided attention), and clinical outcomes to back pain common during postpartum.

2. Methods

Seventeen pregnant women participated in this study. All participants were Caucasian and United States citizens. The eligibility criteria were as follows: (1) aged 18–45 years at the start of pregnancy; (2) normal-risk pregnancy; (3) no lower-extremity injury; and (4) no neurological conditions that affect normal balance. The present study received approval from the Washington State University Institutional Review Board for human subject research. The first testing was conducted at 16–20 weeks gestation, second at 36–40 weeks gestation, and then at 4-week intervals after birth to 7-months postpartum. The first monthly testing postpartum occurred an average of 19.4 (sd = 6.5) days after birth.

2.1. Experimental procedures

The following procedures were repeated at each testing. Each testing started with the (re)signing of the informed consent form and a screening for exclusion criteria. Participants wore a tank top, shorts, low-cut socks, and their personal walking shoes. Participants had body anthropometry measured to allow for volume calculations of thirteen body segments [7,15]. Segment lengths and cross-sectional areas were used to calculate participant- and testing-specific segment masses from assumed segment densities. Measurements related to thickness (Fig. 1) were further used as dependent variables to evaluate change over time. The measurements at the first testing were always conducted by the lead author. Measurements were taken by a research assistant with oversight of the lead author at subsequent testings. Measurements were input into an Excel (Microsoft Corp., Redmond, USA) worksheet that highlighted any value outside of 5% of the running average of the measure for that person. If outside of 5%, the measurement was retaken. If still outside 5%, the research team conferred on the accuracy of the measure.

In order to account for the position of thirteen body segments (Fig. 2), participants had 54 reflective markers adhered to body landmarks following previously described marker set [7,8]. We used a 10-camera motion capture system (MotionAnalysis Corp., Santa Rosa, USA) to track marker positions at 100 Hz. The first trial was quiet

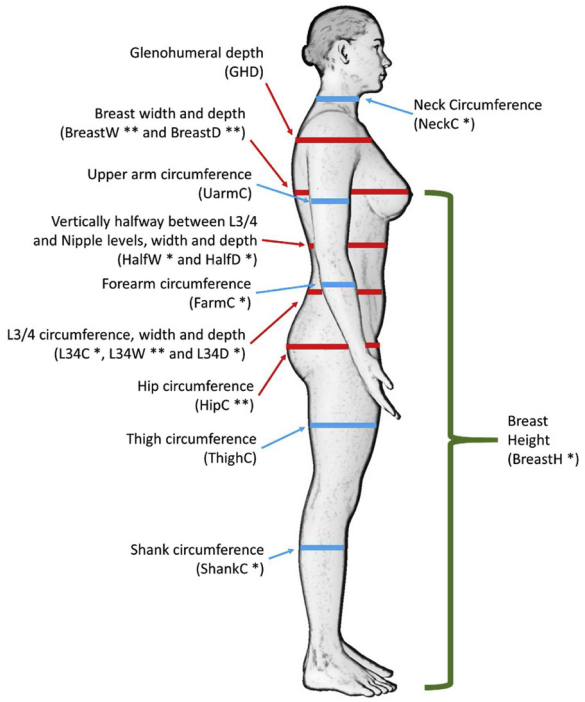

Fig. 1. Cross-sectional measurements used as dependent variables of external anthropometry. Red lines represent trunk (torso and pelvis) related measurements. Blue lines represent extremity related measurements. All measurements were first normalized as a percent of body height before being used as dependent variables. Discussed in the results, * had a change during pregnancy and immediate return postpartum, ** has a persistent change during postpartum. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

standing in anatomical position for 10 s on a force plate (Kistler Inc., Amherst, USA) collecting at 1000 Hz. We then used the real marker locations during quiet standing to create similar virtual markers for all posterior markers. All posterior markers were then removed and the second trial of quiet laying in anatomical position for 10 s on a backboard spanning two force plates was performed.

Hip joint centers were tracked with ASIS and sacral markers following a previously validated methodology [19]. The top of the pelvis segment was at that L3-4 joint center, represented by a point halfway between the L4 spinous process and a point that represents the theoretical umbilicus when not pregnant. This umbilicus location was determined following a previously validated methodology using ASIS and sacral markers [20].

2.2. Data processing procedures

Marker and force plate data were filtered with a 4th order low-pass Butterworth filter at a 6 Hz cutoff frequency. Segment mass and COM location information for all segments except the torso were derived from anthropometry measures following previously validated method [15]. We have previously described a methodology to calculate the three dimensional location of the torso COM given the force plate center of pressure and weighted sum of all other segment COMs [7]. The torso COM in the anterior direction perpendicular to the long axis was calculated from the average position of the force plate center of pressure during quiet standing. The torso COM in the lateral and long axis directions were calculated from the average center of pressure during quiet laying.

Three-dimensional hip angles were calculated following ISB standards [21]. Lumbar flexion angle was calculated as the sagittal plane projection angle between the T12, L2, L4, and S2 markers (Fig. 3).

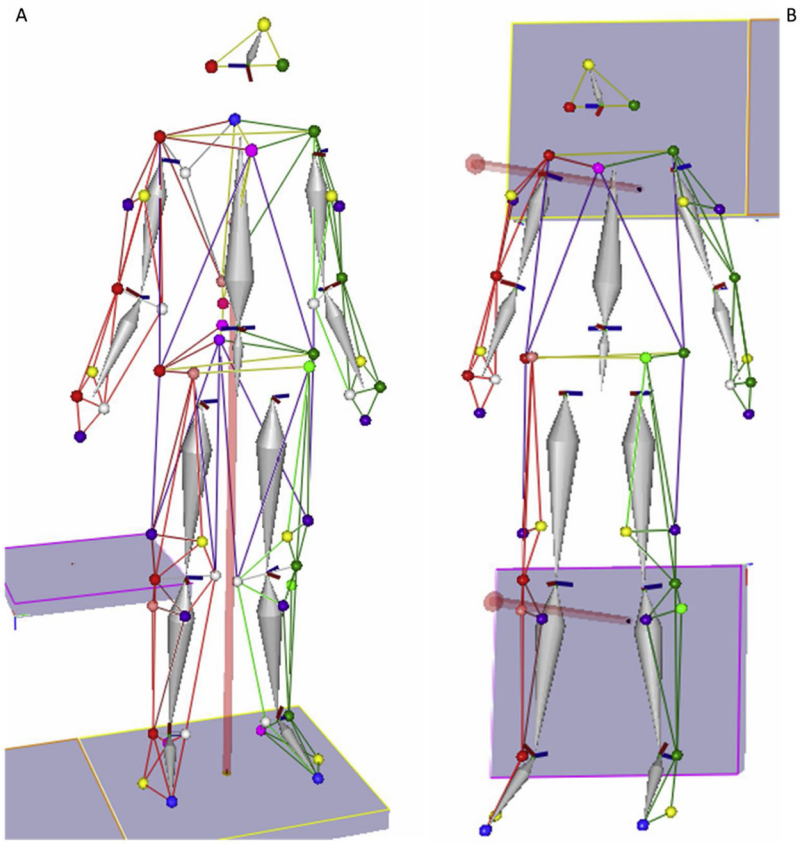

Fig. 2. (A) Quiet standing trial. (B) Quiet laying trial.

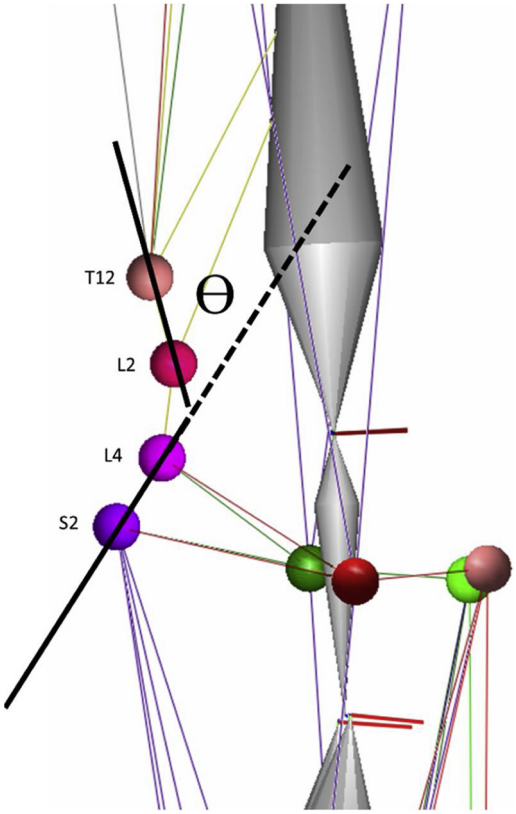

Fig. 3. Sagittal plane projection angle for calculated lumbar extension angle (Θ).

2.3. Statistical analysis

We conducted all statistical analyses in SPSS v24 (IBM Corp., Armonk, USA). To evaluate change in anthropometry (both internal like center of mass, and external like segment circumferences) over time, we conducted a linear mixed model analyses. Time was a repeated measure in this analysis. To evaluate change in body COM and standing posture, we conducted linear mixed model analyses with time and body mass index (BMI) as independent variables. Participants were split into two BMI groups, ≥ (7 high-BMI) and < (10 low-BMI) 25 kg/m^2, measured at the first testing. In a separate analysis (because of the sample size) we split the sample into two group based on birth history (primigravida vs. multigravida). If the main effect of time was statistically significant, we then conducted pairwise comparisons between time points with *Bonferroni* corrections for multiple comparisons (alpha = 0.05).

3. Results

Table 1 displays the participants' demographics at the start of the study. All participants had normal-risk singleton pregnancies with deliveries at 38–42 weeks gestation. All participants breastfed or pumped milk after the birth of the child, except one individual stopped before

Table 1
Participant demographics.

	Low-BMI group	High-BMI group	Total Average	Total sd
Age (years)	27.80	30.57	28.94	4.02
Mass (kg)	68.59	79.70	71.58	9.83
Height (cm)	171.79	166.80	169.74	7.76
BMI (kg/m^2)	22.28	28.66	24.91	3.64

Notes: Average demographics of all 17 participants at the first testing. sd = standard deviation.

the end of testing. Eleven of the participants were primigravida, while six had previously birthed up to four children.

3.1. External anthropometry

Fig. 1 defines the abbreviations used in this section. All external anthropometric dependent variables were normalized by body height. There were three different trends in external anthropometry change over time. GHD ($P = 0.268$), UarmC ($P = 0.676$), and ThighC ($P = 0.245$) did not have any statistically significant change over time of pregnancy or postpartum.

BreastH ($P < 0.001$), HalfW ($P < 0.001$), HalfD ($P < 0.001$), L34D ($P < 0.001$), NeckC ($P = 0.029$), L34C ($P < 0.001$), ShankC ($P < 0.001$), and FarmC ($P = 0.016$) increased significantly during pregnancy, but then reduced to first pregnancy testing levels immediately after birth. These are denoted by a single asterisk in Fig. 1.

Most pertinent to this study, some external anthropometric variables changed significantly during pregnancy, and remained significantly different from the first pregnancy testing levels for some period of time into postpartum testing. These were BMI ($P < 0.001$), BreastW ($P < 0.001$), BreastD ($P < 0.001$), L34W ($P < 0.001$), and HipC ($P < 0.001$). All of these, except BMI, are denoted by double asterisks in Fig. 1. BMI and BreastW significantly increased during pregnancy, and remained significantly greater until the 8–12 week postpartum testing compared to the first pregnancy testing. HipC and L34W remained significantly greater until the 12–16 week postpartum testing compared to the first pregnancy testing. BreastD remained significantly greater until the 20–24 week postpartum testing compared to the first pregnancy testing.

3.2. Center of mass

All body segments had a significant change in mass relative to total body mass except for the thighs (Table 2). Head, torso, upper arm, forearm, shank, and feet mass changes corresponded with pregnancy, changing during pregnancy and then returning to first-testing levels after pregnancy. Pelvis mass had a significant main effect ($P = 0.020$), but there were no discernable pairwise differences between specific time points. The fact that thigh mass percentage did not have a significant change during testing shows that it is related more to body mass than pregnancy, which was shown in the last section (BMI) to not correspond directly with pregnancy.

Torso COM shifted significantly from right to left between pregnancy and 20–24 weeks postpartum ($P = 0.008$) (Table 3). There was a trend for torso COM drop during pregnancy and the rise again after birth, but this was not statistically significant ($P = 0.066$). There was a significant anterior shift in torso COM during pregnancy, and an immediate return to its first-testing posterior position after birth ($P < 0.001$).

Body COM change did not correspond with torso COM changes. There was no significant change in body COM vertical position over time ($P = 0.538$). However, there was a significant difference between low-BMI and high-BMI groups ($p < 0.001$), where low-BMI individuals had a body COM position 1.5% higher than high-BMI individuals. The ML and AP positions of the body COM did correspond with torso COM changes. The ML position of the body COM significantly changed over time, but not until 20–24 weeks postpartum ($P = 0.013$). The AP position of the body COM was significantly further anterior just before birth compared to all other time points ($P < 0.001$).

3.3. Standing posture

Table 2 indicates postural changes over time. Standing posture around the hips changed by 8.3° greater hip flexion during pregnancy ($P = 0.139$), but this was statistically insignificant compared to the more than 11.5° increase in hip extension that occurred between the time just before birth and 4–8 weeks postpartum and thereafter ($P < 0.007$). On the other hand, lumbar extension angle increased by 8° from first testing until 4–8 weeks postpartum, after which it plateaued through the course of testing in this study ($P = 0.015$). While

Table 2
Segment masses as a percentage of body mass.

	Weeks gestation		Weeks postpartum						
	16–20	36–40	0–4	4–8	8–12	12–16	16–20	20–24	24–28
Head*	7.63	6.74	7.01	7.32	7.64	7.26	7.58	7.57	7.83
sd	0.98	0.78	1.07	1.10	0.93	0.75	1.10	1.04	0.93
Torso*	27.87	29.80	28.46	28.37	28.56	28.04	27.97	27.64	28.32
sd	1.43	1.91	2.59	1.69	1.73	1.62	1.88	1.36	1.35
Pelvis*	18.16	18.21	18.09	18.21	17.84	18.00	17.85	18.04	17.68
sd	0.82	0.76	0.90	1.10	0.93	0.74	0.98	1.01	0.55
R. Uarm*	2.85	2.56	2.81	2.78	2.77	2.89	2.84	2.81	2.87
sd	0.26	0.34	0.27	0.30	0.32	0.29	0.28	0.31	0.38
L. Uarm*	2.90	2.60	2.94	2.74	2.79	3.06	2.86	2.84	2.87
sd	0.32	0.34	0.29	0.31	0.35	0.46	0.25	0.29	0.41
R. Farm*	2.43	2.34	2.49	2.41	2.49	2.45	2.48	2.45	2.47
sd	0.17	0.20	0.28	0.20	0.22	0.18	0.19	0.26	0.19
L. Farm*	2.31	2.24	2.42	2.34	2.35	2.42	2.38	2.39	2.40
sd	0.21	0.22	0.27	0.24	0.23	0.23	0.19	0.25	0.18
R. Thigh	11.41	11.42	11.39	11.37	11.25	11.41	11.33	11.42	11.20
sd	0.51	0.44	0.54	0.48	0.40	0.35	0.55	0.43	0.26
L. Thigh	11.36	11.43	11.38	11.37	11.23	11.42	11.35	11.38	11.21
sd	0.48	0.46	0.51	0.48	0.39	0.35	0.47	0.44	0.28
R. Shank*	4.80	4.67	4.82	4.82	4.83	4.81	4.93	4.95	4.85
sd	0.26	0.31	0.42	0.30	0.39	0.35	0.33	0.24	0.31
L. Shank*	4.75	4.65	4.77	4.80	4.74	4.77	4.89	4.93	4.79
sd	0.24	0.30	0.44	0.23	0.35	0.34	0.32	0.19	0.31
R. Foot*	1.76	1.66	1.71	1.73	1.75	1.74	1.78	1.79	1.76
sd	0.13	0.09	0.14	0.13	0.10	0.13	0.14	0.17	0.12
L. Foot*	1.76	1.67	1.71	1.73	1.76	1.75	1.77	1.77	1.76
sd	0.12	0.09	0.12	0.13	0.12	0.14	0.14	0.16	0.12

Notes: sd = standard deviation. R = right. L = left. Uarm = upper arm. Farm = forearm.
* Statistically significant change over time ($P \leq 0.05$).

Table 3
Torso and Body COM positions and standing posture variables.

	Weeks gestation		Weeks postpartum						
	16–20	36–40	0–4	4–8	8–12	12–16	16–20	20–24	24–28
Torso ML[a*]	2.72	2.54	0.75	0.73	1.69	0.28	0.11	−1.69	1.13
sd	3.18	3.19	4.66	3.18	4.29	2.51	2.79	2.59	3.08
Torso Long[b]	42.48	40.47	42.48	42.59	43.52	43.00	42.92	42.72	43.31
sd	2.85	2.92	2.48	3.74	4.05	3.82	3.72	3.09	4.07
Torso APc [c*]	−4.99	7.80	−12.05	−8.22	−7.35	−3.42	−6.34	−6.95	−6.22
sd	8.72	10.05	26.99	8.59	8.97	10.99	6.06	9.18	11.28
Body ML[d*]	1.53	3.71	1.31	−0.20	−0.27	−2.27	−1.47	−6.87	−1.29
sd	6.53	8.04	8.73	8.87	7.28	6.29	6.43	6.16	8.03
Body SI[e]	55.43	54.99	55.07	55.22	55.59	55.46	55.29	55.15	55.70
sd	1.05	1.21	1.32	1.54	1.45	1.13	1.14	1.05	0.94
Body AP[f*]	50.04	41.49	49.34	49.94	50.53	49.37	51.61	50.88	50.62
sd	7.01	8.37	5.13	6.72	6.91	8.57	4.58	7.36	6.94
Hip ext[g*]	11.10	2.83	10.21	14.06	14.53	11.14	13.72	14.21	15.13
sd	6.47	6.61	11.94	8.80	4.07	9.18	10.74	9.86	9.19
Hip add[h]	−2.37	−1.50	−1.24	−1.45	−2.36	−2.48	−2.52	−2.34	−2.48
sd	1.07	1.84	2.02	2.10	1.52	1.55	1.62	2.11	1.16
Hip ER[i]	−4.31	−1.77	−2.35	−3.02	−2.70	−3.48	−0.79	−1.89	−4.05
sd	6.88	7.33	4.48	6.05	5.76	6.22	6.68	5.67	7.25
Lumbar θ[*]	32.43	35.72	34.38	40.57	39.24	40.27	39.76	39.89	41.76
sd	8.45	9.87	10.14	10.25	9.48	9.79	8.85	7.14	6.82

Notes: sd = standard deviation.
[a] Lateral position as a percentage of torso long axis length (right is positive).
[b] Long axis position as a percentage of torso long axis length from L3-4 joint center to C7-T1 joint center.
[c] Perpendicular to plane of ML and Long as a percentage of torso long axis length (forward is positive).
[d] Millimeters from midline between right and left ASIS markers (right is positive).
[e] As a percentage of body height from ground.
[f] As a percentage of the posterior pelvic depth from midline ASIS to S2 marker.
[g] Hip extension angle.
[h] Hip adduction angle.
[i] Hip external rotation angle.
[*] Statistically significant change over time ($P \leq 0.05$).

not a significant change over time, the only difference we found between primigravida and multigravida women in this study was that women with previous birth history stood with almost 5° hip external rotation ($P = 0.048$).

4. Discussion

The goal of this study was to determine which physical characteristics of the pregnant body persist into the postpartum period compared to those that immediately revert following pregnancy. This research is significant toward further balance research and understanding the long-term effects of full-term pregnancy as postpartum women reintegrate into their pre-pregnancy daily activities.

External anthropometry (other than trunk width at the L3-4 level) of the abdomen are obviously most related to pregnancy and giving birth. L3-4 width remains significantly larger up to three months postpartum, indicating its relationship to fat accumulation, which has been shown to significantly increase in Korean women in the first month postpartum [22]. Likewise, pelvic dimensions remain larger for several months postpartum and thigh mass essentially remains proportional to total body mass throughout the study. As this study examined only breast-feeding women, breast dimensions of lactating women also remained larger for several months postpartum. It is unlikely that distal limb circumference increases during pregnancy are related to fat accumulation, as fat would take more time to lose following birth than what was observed in this study. Instead, it is more likely that distal limb circumferences are more related to intra- and extracellular water accumulation during pregnancy [23], which immediately decline postpartum [22].

Considering that the abdomen grows during pregnancy this study found that torso COM trends downward during pregnancy, but not a significant amount, likely due to the concurrent increase in breast tissue. This is in contrast to our own previous study on a separate sample [7]. Even though there were significant mass changes throughout body segments, body COM had no significant vertical change during pregnancy or postpartum, in line with one other historic study [24]. However, given that segment masses change, it might be the case that tasks requiring postural changes away from static standing, like sit-to-stand, result in significant COM change over time of pregnancy or postpartum.

We've also previously described that COM position is not laterally symmetric, but instead varies by person and gestation [7,8]. Interestingly, we observed this trend through postpartum as well. We asked all participants to stand with equal weight on each foot when determining this lateral COM position. However, even if they weren't, our method of combining force plate and motion capture data [7] should account for asymmetric stance, and if it didn't we would expect lateral COM trends to be more random. Instead, we believe that a combination of shifting abdominal organs that persist up to a year postpartum [25] and differences in muscle fat/water content related to limb dominance in females [26] continues to result in a shifting body center of mass laterally after pregnancy. There were no other COM changes specific to the postpartum period, even in regards to high-BMI vs. low-BMI women. We suspected that mass distribution difference between these two groups might lead to different change through postpartum. This suggests that there are similar weight gains and losses through pregnancy and postpartum regardless of first-testing BMI. Our sample did not have any obese (BMI $\geq 30\,kg/m^2$) or underweight (BMI $< 18.5\,kg/m^2$) individuals, so we cannot comment on the effects of extreme BMIs.

As torso and body COMs return to their original locations posterior in the postpartum body, so too does standing hip extension posture. Hip flexion during gestation accommodates greater gestational lordosis that moves the pregnant COM over the hip joint centers. We found in this study that gestational lordosis [27,28] does not stop at birth, but

instead, grows through postpartum. We assume this is to accommodate postpartum breast weight, however, the curvature increase may also be a product of joint laxity, due to pregnancy related hormonal changes, that has been shown to persist at least 5–6 weeks postpartum [29]. Greater lumbar curvature should result in more shear force in the thoracolumbar spine [9]. Shear thoracolumbar force is suggested to place more load on the facets and the annulus fibrosis [30], and as such may be a source for postpartum back pain [31]. Postpartum back pain is a common source of physical impairment following childbirth, leading to increased use of sick leave when returning to work [32], and is even suggested to be a source of postpartum depression [33]. However, increased curvature is also suggested to be a long-term degenerative protective mechanism at the lumbopelvic area [34].

4.1. Limitations

Our findings can only be generalized to Caucasian United States nationals. Difference based on race, age and body height are possible, and so we suggest further study is this area. We did not collect information on type of delivery (cesarean vs. vaginal), but we do not expect that this information would significantly affect anthropometry, COM or standing posture postpartum beyond a couple weeks.

This study cannot state whether our sample or individuals returned to pre-pregnancy levels since our first testing occurred only as early as 16 weeks of pregnancy. By 16–20 weeks of pregnancy, the average weight gain is 2–4 kg [35]. We have previously shown that most of this weight gain between 8 and 20 weeks is in the pelvis, and that the torso center of mass has already started shifting down and forward in this part of pregnancy [7].

Our sample had only six multigravida women. Postpartum weight gain, compared to pre-pregnancy, is common [22]. Therefore, we assume that multigravida women would have less change between the first and last testing periods merely due to them previously being pregnant. However, it should be noted that many social, economic, and physiological factors confound our study of primigravida vs. multigravida postpartum anthropometry changes, and we believe that a much larger sample is needed for future study.

4.2. Conclusions

Our findings suggest that anthropometric changes related to the abdomen or fluid retention during pregnancy immediately regress after childbirth. However, other changes related to breast tissue and fat deposits persist postpartum. As such, masses of different segments affect an anthropometric model for center of mass calculation, and body center of mass changes in the lateral and anterior directions postpartum, but not vertical position in the body. Increased postpartum breast mass and/or persistent joint laxity may be the cause of persistent lordotic curvature changes in the lumbar spine postpartum. Future research should explore how body center of mass changes postpartum for individuals that do not breast feed, and thus may not have significant breast mass postpartum.

Conflict of interest

The authors declare no conflict of interest.

Funding

This research was funded by a WSU New Faculty Seed grant and a College of Education Faculty award.

Acknowledgments

Special thanks to our local OBGYN clinics and students in the EPP lab for their help in recruiting, and thanks to the many undergraduate students in the GPB lab for data processing help.

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