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# Strength and Pelvic Health in Peripartum Runners: A Pilot Cohort Study

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# Strength and Pelvic Health in Peripartum Runners: A Pilot Cohort Study


## ABSTRACT

***CONTEXT:*** Peripartum women are running yet there is minimal evidence to understand if these runners experience changes in strength or pelvic floor health. Expert guidelines recommend strength training and rehabilitation while returning to running; however, changes in strength and pelvic floor symptoms have not been investigated in cohorts of pregnant and postpartum runners.

***OBJECTIVE:*** This pilot study aimed to assess hip strength and pelvic floor symptoms in cohorts of peripartum runners.

***DESIGN:*** Cohort study.

***SETTING:*** Laboratory data collection.

***PARTICIPANTS:*** Healthy runners who were trying to conceive, pregnant or postpartum and reported running at least once a week for ten minutes were eligible to participate.

***MAIN OUTCOME MEASURES:*** Four cohorts of participants (each trimester and postpartum) underwent hip strength testing with a dynamometer. All hip motions were measured. The pelvic floor disability index survey (PFDI-20) assessed participant's weekly prevalence and burden of pelvic floor symptoms. A general linear mixed model analysis was performed to compare the strength among the cohorts. Descriptive statistics of pelvic floor symptoms by cohort were performed.

***RESULTS:*** Eighteen runners were included in the study. Runners produced significantly less bilateral hip flexion strength in 2nd and 3rd trimester groups compared to strength values of nulliparous and 1st trimester group. Pelvic floor symptoms were frequently

reported by the different cohorts (62.5%–75%) and symptoms were moderately bothersome for multiple weeks from second trimester to postpartum.

***CONCLUSION:*** This pilot study identified only hip flexion strength significantly decreased in the second and third trimester in cohorts of perinatal runners. Over 50% of enrolled runners reported moderately burdensome pelvic health symptoms from second trimester through to postpartum. Health care providers should screen for pelvic health symptoms, measure hip strength, and monitor changes over time to keep perinatal runners active and refer to appropriate providers, especially if the symptoms limit participation in physical activity.

Total words: 299/300

***Key Words:*** runner, pregnant, postpartum, pelvic health, strength

**Key Points**

1. Current postpartum running guidelines are based on expert opinion. There are no known guidelines for running during pregnancy.
2. In this pilot cohort study, hip flexion decreased significantly from first to second and third trimesters. Over 50% of enrolled runners reported moderately burdensome pelvic health symptoms from the second trimester into postpartum.
3. When working with pregnant or postpartum runners, healthcare providers should prioritize screening for hip strength changes and pelvic floor symptoms to modify treatment plans and support continued running participation.

Women are participating in running during the peripartum period however, when postpartum, up to 84% report musculoskeletal pain and 32.7% report stress urinary incontinence (SUI).[1] While the reason for the pain and/or incontinence have been hypothesized as a result of changes throughout pregnancy (e.g., the growing uterus and its increasing weight)[2–4], or other factors such as adjustment of running gait,[5,6] decreased physical activity,[7,8] increased flexibility,[9] and decreased muscle strength,[5] studies in the peripartum running population investigating reasons for the pain and SUI are lacking. As a result, women may choose to be sedentary and the lack of participation in physical activity can negatively affect their health.[10,11]

Experts have proposed that strength impairments such as hip, pelvic floor and abdominal muscle weakness may be reasons for pain when running postpartum.[9] One study compared strength in postpartum runners to controls and found decreased hip strength (abduction and adduction).[7] To our knowledge, no studies have measured runners at the different time points through pregnancy and postpartum, leaving a gap in understanding how strength changes throughout peripartum in athletic populations.

When investigating risk factors for SUI in postpartum individuals who are returning to running, having SUI pre-pregnancy and during pregnancy were found to increase the odds of SUI postpartum.[1] SUI has also been associated with hip muscle weakness[1,12]; one study that looked at the odds of developing SUI postpartum reported that antenatal weight training did decrease the odds.[1]

With the significant gap in understanding strength changes in peripartum athletes, the purpose of the current study was to explore changes in hip muscle strength and self-reported pelvic floor symptoms in cohorts of runners during pre-

pregnancy/early, mid, and late pregnancy, and postpartum. We hypothesized that hip muscle strength would overall decrease from pregnancy to postpartum. We also hypothesized that pelvic floor symptom reports would increase in frequency from the second trimester through to postpartum. The knowledge gained can be used for targeted interventions to promote physical activity and rehabilitation practices as current recommendations are based on expert reports and not cohort studies. Additionally, the data can inform the development of targeted interventions and rehabilitation to promote the successful return to running postpartum.

## METHODS

### Study Design

This was a pilot cohort study with runners categorized into four groups: nulliparous and 1st trimester, 2nd trimester, 3rd trimester, and postpartum (3 to 11 months). Nulliparous and first trimester were considered as one cohort, as changes during pregnancy have been seen to be minimal during early pregnancy.[13–16] Data collection took place at XXX University in XXX. All eligible and consented runners participated in their normal training or workout routines. Participants' running routines were not altered in any way for this study. This research project was reviewed and approved by XXX (IRB number XXX) to ensure participants were informed of risks and benefits of participating in the study.

### Participants

Inclusion criteria: Individuals (aged 18–50 years old) who were pregnant or actively trying to conceive, and who were running at least one time a week for ten minutes at a time at study enrollment were eligible to participate. Participants were accepted into the

study when pregnant, no matter their trimester at enrollment, and assigned to the specific cohorts.

**Exclusion Criteria**

Participants were excluded if, at the start of the study, they reported: any pain, injury, or running related concerns that would prevent them from participating in running while trying to conceive, pregnant, or postpartum.

**Participant Recruitment**

Recruitment occurred from August 2022 through October 2024. Flyers were distributed around the university and surrounding communities, including local obstetrics and gynecology practices and pediatrician offices. Word-of-mouth was also used to recruit participants through physical therapists, running groups, and track and field listservs. Social media was also used to advertise the study on groups specific to peripartum runners. Prospective participants were sent an online baseline survey through Qualtrics to be screened for inclusion and exclusion criteria. Eligible participants were provided a study information sheet and a consent form, as the first part of the survey.

**Procedure**

To ensure consistency of the testing procedures and data collection, calibration and standardized training was performed. At each visit participants consented to the study and confirmed the absence of symptoms that would be contraindications for exercise (e.g., vaginal bleeding, abdominal pain, amniotic fluid leakage, dizziness, headache, chest pain, muscle weakness, difficulty with balance, calf pain or swelling) and vitals (blood pressure, heart rate, etc.) were taken for additional screening. Participants also confirmed that they had no pain during running.

## Strength Testing

A handheld dynamometer (Commander Echo model, JTECH Medical, Midvale, UT) was used with an external belt fixation to create a stationary measurement. Hip flexion, extension, abduction, adduction, external and internal rotation were measured (see appendix A for positioning).[17–19] The participants were instructed to perform a maximum isometric voluntary contraction (MVIC) for five seconds against the dynamometer, and three measures were collected on each limb with at least 10 seconds of rest.[17] If any MVIC trial was greater than 10%, up to two more trials were conducted.[17] Participants were monitored for pain and appropriate padding was used if needed (e.g. towel on shin for hip abduction). Forces were collected in kilograms and then divided by body weight at the time of visit.[20] Standard error of measurement as well as minimal clinical difference for this method of strength testing were referenced.[17] Due to the length of the study some participants were able to participate at multiple time points and were included in more than one cohort (Figure 1).

## Pelvic Floor Symptoms

Enrolled pregnant or postpartum participants completed a weekly online survey distributed through Qualtrics which collected the presence and burden of pelvic floor symptoms. Using a PFDI-20, the first question asked the participant, “Have you had any bowel, bladder or pelvic symptoms that have been bothersome to you in the past week?”, when the participant answered “Yes” to this question, additional questions were displayed to gather data on the type and burden of each pelvic floor symptom (modified to ask somewhat, moderately and quite a bit). Surveys were sent each Sunday, asking

the participant to consider the presence and burden of their symptoms over the last week. The survey closed each Tuesday to reduce recall bias.

**Statistical Analysis**

Since this was a pilot study, a priori sample size estimation was not performed. Given that some participants were included in multiple cohorts and that we had unequal number of participants in each cohort, a general linear mixed model analysis was performed to compare the strength among the four groups. A completer analysis approach was used to handle the missing data. Descriptive statistics of self-report pelvic floor symptoms by cohort were performed. SPSS 31.0 (IBM Inc. Armony, NY) was used to perform statistical analyses with an alpha of 0.05.

**RESULTS**

Eighteen pregnant runners (average age: 34.4 years ± 4.4) were enrolled in the study between January 2022 and December 2024 at varying timepoints. The sample size distribution for each of the four groups was as follows: Nulliparous and 1st trimester (n=5), 2nd trimester (n=10), 3rd trimester (n=10), and postpartum (n=11). In the nulliparous and 1st trimester group, 2 participants were nulliparous only, 2 participants were 1st trimester only and 1 came to both nulliparous and 1st trimester collections and the average strength numbers was used. Some participants were able to be part of more than one cohort due to the duration of the study, as data was collected over a span of 24 months (see Figure 1).

**Strength Testing**

The fixed effects model revealed a significant group main effect for right hip flexion strength (p=0.004) and left hip flexion strength (p=0.015). Bonferroni post hoc

tests showed that the right and left hip flexion strength of 2nd and 3rd trimester groups were significantly less than the corresponding strength values of nulliparous and 1st trimester group ($p < 0.05$; Table 1). No other significant differences were found.

**Longitudinal Data Trends**

In general, right and left hip flexion strength decreased from 1st trimester to 3rd trimester and then increased postpartum for most of the participants.

Insert Figure 2 near here

**Pelvic Floor Symptoms**

In total, 11 participants responded to the survey with the following count across each trimester: 1st trimester N=1, 2nd trimester N=8, third trimester N=8 and postpartum N=9. In the 1st trimester, a single participant responded “yes” to the survey question “In the past seven days do you have any pelvic symptoms to report” but had no significant symptoms to report.

During the second trimester, eight of 10 enrolled participants completed the weekly pelvic symptom surveys (Table 2). Five of the eight participants (62.5%) indicated they had pelvic floor symptoms to report at least once during the trimester. Three participants reported "moderately" bothersome symptoms, and one participant reported symptoms that were "quite a bit" bothersome during the second trimester. Notably, a different participant indicated having pelvic floor symptoms but did not select any of the specifics of how bothersome as when the participant answered “Yes” to the question “Have you had any bowel, bladder or pelvic symptoms that have been bothersome to you in the past week?”, additional questions were displayed to gather

data on the type and bother of each pelvic floor symptom per the PFDI-20 (i.e. somewhat, moderately and quite a bit) that the participant did not answer.

Overall, symptom severity tended to increase across the group from the beginning to the end of the trimester. The most frequently reported symptom was frequent urination.

Eight out of ten participants completed the weekly survey during the third trimester (Table 3). Six of these eight participants (75.0%) reported at least one pelvic symptom. Five of these six participants indicated their symptoms were “moderately” bothersome. Two of the six participants reported their symptoms were “quite a bit” bothersome. Overall, symptom reporting and severity tended to increase from the start to the end of the third trimester. The most frequently reported symptom during the second trimester with the highest amount of bother to participants was frequent urination, the same as the second trimester.

Nine of eleven participants completed the weekly pelvic symptom survey during postpartum (Table 4). During the postpartum period, eight of the eleven participants (72.7%) reported pelvic symptoms; the remaining three participants did not report any pelvic symptoms. Eight participants reported "moderately" bothersome symptoms. Six of these eight participants also reported symptoms that were "quite a bit" bothersome at different timepoints. Unlike the second and third trimester where symptoms progressively increased, postpartum symptom reporting varied considerably across individuals, with no consistent pattern in frequency or severity over time. The most burdensome symptom reported during the postpartum period was heaviness or dullness in the pelvic area.

## DISCUSSION

The purpose of this study was to investigate cohorts of runners during pregnancy and postpartum to understand changes in hip strength and pelvic floor symptoms during the peripartum lifespan stage. Overall, there were no significant differences in relative hip strength between the cohorts except for hip flexion strength. Pelvic floor symptoms were frequently reported by the different cohorts (62.5% - 75.0%) and symptoms were moderately bothersome for multiple weeks from second trimester to postpartum.

As this study is unique, and to our knowledge the first to measure strength at different time points of pregnancy and postpartum in runners, there are a few important takeaways. First, the only significant change in strength was a decrease in hip flexion strength from first to second and first to third trimester. This may be due to pregnancy related changes such as the growing uterus. As the fetus grows between second and third trimester, there may be an overall anterior tilt to the pelvis as the runner is accommodating for this growth[21], which may affect the strength of the hip flexors. Hip flexors play an important role in running, especially during the swing phase to contribute to maintaining stride length and cadence by accelerating the thigh after toe-off.[22,23] Hip flexors have also been postulated to play an important role in postural control and pelvic stability with weakness or tightness potentially leading to compensatory running patterns and elevated injury risk.[22] A recent Delphi study[5,24] recommended screening hip strength as the runner returns to running postpartum to identify any weakness and rehabilitate the runner as needed. Based on our preliminary results, we support the recommendation that clinicians should prioritize screening and monitoring changes in

hip strength as a runner continues running during pregnancy and when returning to running postpartum.

Second, other than hip flexion strength, there were no other statistically significant changes in hip strength (i.e., extension, abduction, adduction, external rotation or internal rotation). This finding may suggest that athletes that continue to stay active during pregnancy maintain hip strength during the peripartum period. We did not note a change in hip abduction strength as noted in one study;[7] however, this may be because we compared cohorts of runners during different phases of pregnancy compared to postpartum versus nulliparous controls reported in the study. It is important, therefore, to work with pregnant individuals who want to continue running during pregnancy and provide them with education and resources to continuing running and staying physically active. Exercise during pregnancy supports maternal and fetal health. Physical activity is a critical intervention to prevent maternal deconditioning and improve mental health outcomes.[25]

When investigating pelvic floor symptoms, 62.5% - 75% of runners each cohort reported at “moderately bothersome” symptoms. These symptoms ranged from "moderately” bothersome to “quite a bit. The second and third trimester shared the same most commonly reported symptom with the greatest burden, frequency of urination. This is not an unexpected finding given that this symptom is likely attributable to the weight and location of the growing fetus as pregnancy progresses.[26] In postpartum, the feeling of “heaviness or dullness” represented the symptom with the greatest frequency and burden reported by participants. Two participants in this study who were five months postpartum reported this symptom as “moderately” bothersome.

While the specific symptom of “heaviness or dullness” is not well documented in the literature, other postpartum pelvic floor symptoms, such as dyspareunia, have been noted as persisting for up to twelve months post-delivery.[27,28]

This subset of healthy, active pregnant runners represents a population that, to our knowledge, has not yet been investigated at different trimesters. Our rates of pelvic floor symptom incidence were similar to those reported by Brown et al,[29] who documented a prevalence of 63.2% of urinary incontinence in late pregnancy in the general population. Clinicians working with pregnant or postpartum runners should screen patients for pelvic floor dysfunction and refer to a pelvic health provider if necessary. There is evidence to support the effectiveness of pelvic floor physical therapy to decrease the burden of symptoms and improve quality of life.[30–34]. It is imperative to keep pregnant people active and healthy, as burdensome symptoms have been seen as a reason some athletes may stop engaging in sport and exercise.

This study also supports an important call to action; pregnant athletes should be screened and referred to an appropriate provider if symptoms are present. As the presence of pelvic symptoms was as high as 75% in this study during the third trimester, screening and monitoring pregnant women who are active during pregnancy should be part of routine obstetrics management. Pregnant women often have increased care during this time, with up to weekly check ins to monitor the fetus and growth, and it is important for the supervising health care provider to ask about the mother’s level of physical activity and symptom prevalence. Previous studies have documented that pregnant people report decreased physical activity levels and increased sedentary behaviors due to “pregnancy related changes”.[35] Pelvic floor health

and incontinence symptoms may be one such symptom limiting activity. Previous research has established that while urinary incontinence is a highly prevalent symptom postpartum, few ask for help due to embarrassment and/or stigma around the condition.[36] Referrals to a pelvic health care provider during pregnancy can positively impact the mother's continued participation in physical activity while reducing the risk of incontinence in the future.[34]

**LIMITATIONS**

This study had several limitations. First, a small number of runners who were pregnant and in their first trimester of pregnancy enrolled in the study. We attempted to use a rolling enrollment to increase participant numbers however, some cohorts remained small (first trimester N=5). Due to small numbers, and therefore low power, it could be that findings were false positive. Second, in-person follow-up during postpartum was difficult for the participants to navigate due to balancing the needs of a newborn, childcare, and return to work schedule. These challenges were not lessened with the option for on-site childcare and participant incentive gift cards that were advertised and offered to participants. Several participants canceled due to inability to find the time to attend, lack of adequate childcare and/or sickness of the child which mirrors common burdens to physical activity reported in this population. Third, strength measurements did not involve taking into account moment arms (femur length) which could affect the amount of torque or moment produced at the hip joint. A mixed model analysis of our data revealed that there were no significant differences in height (P=0.621) and weight (P=0.189) among the four cohorts. Since the height was not significantly different among the cohorts, we can assume that the proportional moment arms of the femur would also be similar

among the cohorts thereby making the average force comparison appropriate.[37–40] A final limitation of this study is the generalizability of the results. The population in this study represents a specific subset of pregnant people who were running before, during, and after pregnancy. Compared to most women in the United States who are pregnant and not physically active, this population is unique and uncommon, thereby limiting the applicability of these results.

## CONCLUSION

This pilot study identified that hip flexion strength significantly decreased in the second and third trimester in cohorts of perinatal runners. A second notable finding was that over 50% of enrolled runners reported moderately burdensome pelvic health symptoms from second trimester through to postpartum. Health care providers should screen for pelvic health symptoms, measure hip strength, and monitor changes over time to keep perinatal runners active. If weakness or pelvic health symptoms exist it is important to refer to appropriate providers, especially if the symptoms are limiting participation in physical activity.

## REFERENCES


1. Moore IS, James ML, Brockwell E, Perkins J, Jones AL, Donnelly GM. Multidisciplinary, biopsychosocial factors contributing to return to running and running related stress urinary incontinence in postpartum women. *Br J Sports Med*. 2021;55(22):1286-1292. doi:10.1136/bjsports-2021-104168
2. Al-Sayegh NA, Salem M, Dashti LF, Al-Sharrah S, Kalakh S, Al-Rashidi R. Pregnancy-related lumbopelvic pain: prevalence, risk factors, and profile in Kuwait. *Pain Med*. 2012;13(8):1081-1087. doi:10.1111/j.1526-4637.2012.01424.x

3. Wang X, Mao M, Xie F, et al. Urinary incontinence developmental trajectories and risk predictors: a prospective study from pregnancy to 4 years after childbirth. *BMC Public Health*. 2025;25(1):3433. doi:10.1186/s12889-025-24742-5
4. Orvieto R, Achiron A, Ben-Rafael Z, Gelernter I, Achiron R. Low-back pain of pregnancy. *Acta Obstet Gynecol Scand*. 1994;73(3):209-214. doi:10.3109/00016349409023441
5. Christopher SM, Donnelly G, Brockwell E, et al. Clinical and exercise professional opinion of return-to-running readiness after childbirth: an international Delphi study and consensus statement. *Br J Sports Med*. 2024;58(6):299-312. doi:10.1136/bjsports-2023-107489
6. Donnelly GM, Coltman CE, Straker R, von Lieres Und Wilkau H, Brantner CL, Moore IS. Pelvic compression garments alter running biomechanics, perceived support, and fear of symptoms in postpartum women with pelvic floor dysfunction: preliminary observations from an exploratory, randomised, repeated-measures crossover design. *Front Sports Act Living*. 2025;7(1691794):1691794. doi:10.3389/fspor.2025.1691794
7. Christopher SM, Bauer L, Maylone R, et al. Biomechanical and Musculoskeletal Differences Between Postpartum Runners and Nulliparous Controls. *J Womens Health Phys Therap*. 2022;46(1):11. doi:10.1097/JWH.0000000000000226
8. Edie R, Lacewell A, Streisel C, et al. Barriers to exercise in postpartum women: A mixed-methods systematic review. *J Womens Health Phys Therap*. 2021;45(2):83-92. doi:10.1097/jwh.0000000000000201
9. Christopher SM, Garcia AN, Snodgrass SJ, Cook C. Common musculoskeletal

impairments in postpartum runners: an international Delphi study. *Arch Physiother*. 2020;10:19. doi:10.1186/s40945-020-00090-y

10. Christopher SM, Cook CE, Snodgrass SJ. What are the biopsychosocial risk factors associated with pain in postpartum runners? Development of a clinical decision tool. *PLoS One*. 2021;16(8):e0255383. doi:10.1371/journal.pone.0255383
11. Evenson KR, Mottola MF, Owe KM, Rousham EK, Brown WJ. Summary of international guidelines for physical activity after pregnancy. *Obstet Gynecol Surv*. 2014;69(7):407-414. doi:10.1097/OGX.0000000000000077
12. Foster SN, Spitznagle TM, Tuttle LJ, et al. Hip and Pelvic Floor Muscle Strength in Women with and without Urgency and Frequency Predominant Lower Urinary Tract Symptoms. *J Womens Health Phys Therap*. 2021;45(3):126-134. doi:10.1097/jwh.0000000000000209
13. Butler EE, Colón I, Druzin ML, Rose J. Postural equilibrium during pregnancy: Decreased stability with an increased reliance on visual cues. *Am J Obstet Gynecol*. 2006;195(4):1104-1108. doi:10.1016/j.ajog.2006.06.015
14. Inanir A, Cakmak B, Hisim Y, Demirturk F. Evaluation of postural equilibrium and fall risk during pregnancy. *Gait Posture*. 2014;39(4):1122-1125. doi:10.1016/j.gaitpost.2014.01.013
15. Oliveira LF, Vieira TMM, Macedo AR, Simpson DM, Nadal J. Postural sway changes during pregnancy: a descriptive study using stabilometry. *Eur J Obstet Gynecol Reprod Biol*. 2009;147(1):25-28. doi:10.1016/j.ejogrb.2009.06.027
16. Conder R, Zamani R, Akrami M. The biomechanics of pregnancy: A systematic review. *J Funct Morphol Kinesiol*. 2019;4(4):72. doi:10.3390/jfmk4040072

17. Thorborg K, Bandholm T, Hölmich P. Hip- and knee-strength assessments using a hand-held dynamometer with external belt-fixation are inter-tester reliable. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(3):550-555. doi:10.1007/s00167-012-2115-2
18. Luedke LE, Heiderscheit BC, Williams DSB, Rauh MJ. Association of isometric strength of hip and knee muscles with injury risk in high school cross country runners. *Int J Sports Phys Ther*. 2015;10(6):868-876. https://www.ncbi.nlm.nih.gov/pubmed/26618066
19. Daniels W, Hislop HJ, Montgomery J. *Daniels and Worthingham's Muscle Testing: Techniques of Manual Examination*. (Saunders WB, ed.).; 1995.
20. Jaric S, Radosavljevic-Jaric S, Johansson H. Muscle force and muscle torque in humans require different methods when adjusting for differences in body size. *Eur J Appl Physiol*. 2002;87(3):304-307. doi:10.1007/s00421-002-0638-9
21. Mccrory JL, Chambers AJ, Daftary A, Redfern MS. The pregnant "waddle": An evaluation of torso kinematics in pregnancy. *J Biomech*. 2014;47:2964-2968. doi:10.1016/j.jbiomech.2014.07.00
22. Ferber R, MacDonald S. *Running Mechanics and Gait Analysis*. Human Kinetics; 2014. doi:10.5040/9781718209732
23. Novacheck TF. The biomechanics of running. *Gait Posture*. 1998;7(1):77-95. doi:10.1016/s0966-6362(97)00038-6
24. Deering RE, Donnelly GM, Brockwell E, Bo K, Davenport MH, De Vivo M. Clinical and Exercise Professional Opinion on Designing a Postpartum Return-to-Running Training Program: An International Delphi Study and Consensus Statement. *British*

*Journal of Sports Medicine*. Published online 2023.

25. Redondo-Delgado P, Blanco-Giménez P, López-Ortiz S, García-Chico C, Vicente-Mampel J, Maroto-Izquierdo S. Effects of strength training on quality of life in pregnant women: A systematic review. *Acta Obstet Gynecol Scand*. 2025;104(7):1231-1243. doi:10.1111/aogs.15122
26. Minami R, Kobayashi K, Miyatake M, et al. Urinary function changes during pregnancy assessed by frequency volume charts in a prospective longitudinal study. *Sci Rep*. 2025;15(1):24710. doi:10.1038/s41598-025-10128-5
27. Banaei M, Kariman N, Ozgoli G, et al. Prevalence of postpartum dyspareunia: A systematic review and meta-analysis. *Int J Gynaecol Obstet*. 2021;153(1):14-24. doi:10.1002/ijgo.13523
28. de Amorim AC, Roque LC, Ito LM, de Oliveira Murer PG, Sartori MGF, GPAP Study Group. Symptoms of pelvic floor dysfunctions during pregnancy and postpartum. *BMC Pregnancy Childbirth*. 2025;25(1):742. doi:10.1186/s12884-024-07071-0
29. Brown SJ, Donath S, MacArthur C, McDonald EA, Krastev AH. Urinary incontinence in nulliparous women before and during pregnancy: prevalence, incidence, and associated risk factors. *Int Urogynecol J*. 2010;21(2):193-202. doi:10.1007/s00192-009-1011-x
30. Coyne KS, Wein AJ, Tubaro A, et al. The burden of lower urinary tract symptoms: evaluating the effect of LUTS on health-related quality of life, anxiety and depression: EpiLUTS. *BJU Int*. 2009;103 Suppl 3(s3):4-11. doi:10.1111/j.1464-410X.2009.08371.x
31. Hunskaar S, Vinsnes A. The quality of life in women with urinary incontinence as

measured by the sickness impact profile. *J Am Geriatr Soc*. 1991;39(4):378-382. doi:10.1111/j.1532-5415.1991.tb02903.x

32. Sut K, Balkanli Kaplan H. Effect of pelvic floor muscle exercise on pelvic floor muscle activity and voiding functions during pregnancy and the postpartum period. *Neurourology and urodynamics*. 2016;35(3):417-422.
33. Zhang D, Bo K, Montejo R, et al. Influence of pelvic floor muscle training alone or as part of a general physical activity program during pregnancy on urinary incontinence, episiotomy and third- or fourth-degree perineal tear: Systematic review and meta-analysis of randomized clinical trials. *Acta Obstet Gynecol Scand*. 2024;103(6):1015-1027. doi:10.1111/aogs.14744
34. Johannessen HH, Frøshaug BE, Lysåker PJG, et al. Regular antenatal exercise including pelvic floor muscle training reduces urinary incontinence 3 months postpartum-Follow up of a randomized controlled trial. *Acta Obstet Gynecol Scand*. 2021;100(2):294-301. doi:10.1111/aogs.14010
35. Downs DS, Chasan-Taber L, Evenson KR, Leiferman J, Yeo S. Physical activity and pregnancy: Past and present evidence and future recommendations. *Res Q Exerc Sport*. 2012;83(4):485-502. doi:10.5641/027013612804582669
36. Koomson G, Mgolozeli SE, Mshunqane N. Prevalence of urinary incontinence in postpartum women and physiotherapy interventions applied: An integrative review. *Int J Gynaecol Obstet*. 2025;168(3):965-977. doi:10.1002/ijgo.15950
37. Hauser R, Smoliński J, Gos T. The estimation of stature on the basis of measurements of the femur. *Forensic Sci Int*. 2005;147(2-3):185-190. doi:10.1016/j.forsciint.2004.09.070

38. Paley D, Sutaria S, Pinsky D, Roberts D, Robbins C. Is human height based on a Lucas sequence relationship between the foot height, tibial length, femur length and upper body length? *J Anat*. 2024;244(5):861-872. doi:10.1111/joa.14002
39. Shella R, Parinduri AG. Determination of Height Based on Estimated Femur Length in Medan City. *Estimated Femur Length in Medan City Buletin Farmatera*. 2025;10(3):239-247.
40. Duyar I, Pelin C. Body height estimation based on tibia length in different stature groups. *Am J Phys Anthropol*. 2003;122(1):23-27. doi:10.1002/ajpa.10257

**Figure 1. Illustration of participant enrollment and lab-based data collection across the cohort study. Each green box indicates when manual muscle data was collected for each participant.**

**Figure 2. Trend lines for R and L hip flexion strength for each participant included in the study.**

**Table 1. Hip Joint Strength (Kg) Normalized by Weight (In Kg) At Each Time Point**

| Group | Statistic | Hip flexion | | Hip abduction | | Hip adduction | | Hip extension | | Hip external rotation | | Hip internal rotation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right | Left |
| Nulliparous+1st Trimester | Mean | 0.36 | 0.35 | 0.23 | 0.23 | 0.18 | 0.19 | 0.30 | 0.29 | 0.17 | 0.16 | 0.19 | 0.21 |
| | SD | 0.08 | 0.10 | 0.06 | 0.06 | 0.09 | 0.11 | 0.09 | 0.11 | 0.02 | 0.03 | 0.03 | 0.07 |
| 2nd trimester | Mean | **0.28[a]** | **0.26[b]** | 0.20 | 0.20 | 0.15 | 0.15 | 0.27 | 0.26 | 0.17 | 0.15 | 0.23 | 0.20 |
| | SD | 0.05 | 0.03 | 0.05 | 0.05 | 0.03 | 0.04 | 0.05 | 0.05 | 0.04 | 0.04 | 0.09 | 0.06 |
| 3rd trimester | Mean | **0.25[c]** | **0.26[d]** | 0.22 | 0.22 | 0.16 | 0.14 | 0.28 | 0.29 | 0.15 | 0.15 | 0.19 | 0.20 |
| | SD | 0.04 | 0.04 | 0.04 | 0.06 | 0.04 | 0.03 | 0.10 | 0.10 | 0.03 | 0.04 | 0.07 | 0.05 |
| Postpartum | Mean | 0.31 | 0.29 | 0.22 | 0.22 | 0.17 | 0.17 | 0.28 | 0.29 | 0.17 | 0.18 | 0.25 | 0.23 |
| | SD | 0.06 | 0.06 | 0.04 | 0.04 | 0.05 | 0.04 | 0.06 | 0.07 | 0.04 | 0.05 | 0.08 | 0.08 |

[a] *significant difference with corresponding value from Nulliparous+1st trimester group (P=0.048);*
[b] *significant difference with corresponding value from Nulliparous+1st trimester group (P=0.029);*
[c] *significant difference with corresponding value from Nulliparous+1st trimester group (P=0.004);*
[d] *significant difference with corresponding value from Nulliparous+1st trimester group (P=0.018)*



**Table 2. Summary of Weekly Pelvic Floor Symptom Reporting During Second Trimester**

| Symptom Characteristic | (n) | (%) | Total Weeks Reported | Notes/Range |
|---|---|---|---|---|
| Section 1: Survey Completion | | | | |
| Enrolled participants | 10 | 100.0 | — | — |
| Participants who completed weekly surveys | 8 | 80.0 | — | — |
| Participants who did not complete surveys | 2 | 20.0 | — | — |
| | | | | |
| Section 2: Symptom Presence | | | | |
| Participants reporting ANY pelvic floor symptoms | 5 | 62.5 | — | — |
| Participants reporting NO symptoms | 3 | 37.5 | — | — |
| | | | | |
| Section 3: Symptom Severity | | | | |
| "Moderately" bothersome | 4 | 80.0 | 7 | Range: 1-6 weeks per participant |
| "Quite a bit" bothersome | 1 | 20.0 | 1 | Single week only |

*Notes: n = number of participants; % = percentage of participants who completed surveys (n=8) unless otherwise specified; — indicates not applicable*

*Percentages calculated as proportion of n=8 participants who completed weekly surveys during second trimester*

**Table 3. Summary of Weekly Pelvic Floor Symptom Reporting During Third Trimester**

| Symptom Characteristic | (n) | (%) | Total Weeks Reported | Notes/Range |
|---|---|---|---|---|
| Section 1: Survey Completion | | | | |
| Enrolled participants | 10 | 100.0 | — | — |
| Participants who completed weekly surveys | 8 | 80.0 | — | — |
| Participants who did not complete surveys | 2 | 20.0 | — | — |
| | | | | |
| Section 2: Symptom Presence | | | | |
| Participants reporting ANY pelvic floor symptoms | 6 | 75.0 | — | — |
| Participants reporting NO symptoms | 2 | 25.0 | — | — |
| | | | | |
| Section 3: Symptom Severity | | | | |
| "Moderately" bothersome | 5 | 62.5 | 14 | Range: 1-6 weeks per participant |
| "Quite a bit" bothersome | 2 | 25.0 | 7 | One participant: 6 weeks; one participant: 1 week |

*Notes: n = number of participants; % = percentage of participants who completed surveys (n=8) unless otherwise specified; — indicates not applicable*

*Percentages calculated as proportion of n=8 participants who completed weekly surveys during third trimester. Most frequently reported symptom with highest bother: Frequent urination (consistent with second trimester)*

**Table 4. Summary of Weekly Pelvic Floor Symptom Reporting During Postpartum**

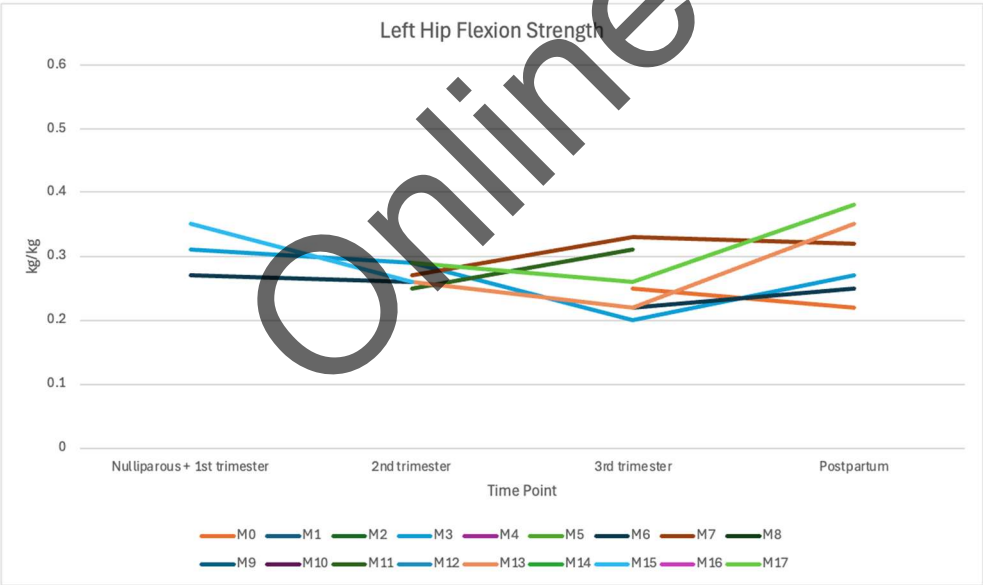
| Symptom Characteristic | (n) | (%) | Total Weeks Reported | Notes/Range |
|---|---|---|---|---|
| Section 1: Survey Completion | | | | |
| Enrolled participants | 11 | 100.0 | — | — |
| Participants who completed weekly surveys | 9 | 81.8 | — | — |
| Participants who did not complete surveys | 2 | 18.2 | — | — |
| | | | | |
| Section 2: Symptom Presence | | | | |
| Participants reporting ANY pelvic floor symptoms | 8 | 72.7 | — | — |
| Participants reporting NO symptoms | 3 | 27.3 | — | — |
| | | | | |
| Section 3: Symptom Severity | | | | |
| "Moderately" bothersome | 8 | 88.9 | 23 | One participant: 8 weeks; two participants: 4 weeks each; five participants: 1-2 weeks each |
| "Quite a bit" bothersome | 6 | 66.7 | 3 | Six participants at different timepoints |

*Notes: n = number of participants; % = percentage of participants who completed surveys (n=9) unless otherwise specified; — indicates not applicable*
*Percentages calculated as proportion of n=9 participants who completed weekly surveys during postpartum period. Most burdensome symptom: "Do you...usually experience heaviness or dullness in the pelvic area?"*

| Participant # | Nulliparous+1st Trimester | 2nd trimester | 3rd trimester | Postpartum |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
| 10 | | | | |
| 11 | | | | |
| 12 | | | | |
| 13 | | | | |
| 14 | | | | |
| 15 | | | | |
| 16 | | | | |
| 17 | | | | |
| 18 | | | | |

Figure 2

Title: Trend lines for R and L hip flexion strength for each participant included in the study.


M= participant number

Appendix A

Hip Flexion

- Participant: sits edge of table, strap/HHD goes around mid-femur
- Strap: strap/HHD goes around mid-femur
- Instruction: Lift knee up into the strap

Hip Abduction

- Participant: Side lying with top leg straight, bottom leg bent out of way
- Strap: strap/ HHD are around distal lower leg so hip is in 45 deg of abduction
- Instruction: Lift leg up and slightly back
- **Leg should be in slight extension and pelvis rotated forward**

Hip Adduction

- Participant: Side lying with bottom leg straight and top leg bent up and out of the way
- Strap: Around distal lower leg, adjusted so the hip is in 25 deg of add
- Instruction: Lift leg up and into strap

R Hip External Rotation

- Participant: sitting edge of table with towel roll under distal femur
- Strap: medical surface of distal lower leg adjusted so hip is in neutral rotation

- Instruction: pull the foot in towards the other foot (probably will need to show them)
- *watch for hip lifting off the table*

L Hip Internal Rotation

- Participant: sitting same as ER with towel roll under distal femur
- Strap: lateral surface of distal lower leg adjusted so hip is in neutral rotation
- Instruction: pull your foot out (probably will also need to show them)
- Watch for substitutions

Hip Extension

- Participant: standing, leaning over table propped up on elbows with tesing limb bent
- Strap: around distal femur adjusted so hip is in 45 deg of ext

- Instruction: push your leg back