Accepted Manuscript

Type of manuscript: Regular Article

Article Title

Relationship between Hip External Rotator Strength and Pelvic Floor Muscle Function in Nulliparous Women

Authors

Satoko Nakano, PTR, Ph.D.[1,*], Wataru Nakano, PTR, Ph.D.[1], Michitaka Kato, PTR, Ph.D.[1], Hiroko Komai, MNs[2], Yasue Makino, PTR [3]

Affiliations and mailing address

1. Department of Shizuoka Physical Therapy, Faculty of Health Science, Tokoha University, 1-30 Mizuochi-cho, Aoi-ku, Shizuoka-city, Shizuoka 420-0831, Japan.

2. Ito Clinic, 2-2-21 Sakaemachi, Yaizu-city, Shizuoka 425-0027, Japan.

3. Department of Rehabilitation, Shizuoka City Shizuoka Hospital, 10-93 Otemachi, Shizuoka-city, Shizuoka 420-0853, Japan.

Corresponding Author: Satoko Nakano

Department of Shizuoka Physical Therapy, Faculty of Health Science, Tokoha University, 1-30 Mizuochi-cho, Aoi-ku, Shizuoka-city, Shizuoka 420-0831, Japan.

Tel: +81-54-297-3200

Fax: +81-54-297-3243

E-mail: s-nakano@sz.tokoha-u.ac.jp

Number of tables and figures

Tables: 3, Figures: 2

Running Title: Hip External Rotator Strength and Pelvic Floor Muscle Function

ABSTRACT

Objectives: Strengthening of the hip external rotator muscles may improve pelvic floor muscle function. In this study, we examined the relationship between hip external rotator strength and pelvic floor muscle function in nulliparous women.

Methods: This cross-sectional study included 59 women aged ≥18 years who had never given birth. Pelvic floor muscle function was measured using transabdominal ultrasound. Muscle strength during hip flexion, abduction, and external rotation, and handgrip strength were also measured. Multiple regression analysis was performed to examine the association between pelvic floor muscle function and hip external rotator strength.

Results: Fifty-five participants (average age: 20.3 years) were included in the final analysis. A single correlation was observed between pelvic floor muscle and hip flexor strength (r=0.334, p=0.013), hip abductors (r=0.203, p=0.038), and hip external rotators (r=0.413, p<0.001). Conversely, no relationship was observed between pelvic floor muscle function and handgrip strength (r=−0.124, p=0.369). Multiple regression analysis revealed an independent association between pelvic floor muscle and hip external rotator muscle strength (β=0.605, p=0.032). However, no association was observed between pelvic floor muscle function and hip flexor (β=0.086, p=0.545), abductor (β=−0.052, p=0.902), and handgrip strength (β=−0.012, p=0.101).

Conclusions: Hip external rotator muscle strength was associated with pelvic floor muscle function independently of hip flexor and abductor, and handgrip strength in nulliparous women. The findings suggest that hip external rotator strength may be related to pelvic floor muscle function in nulliparous women.

Key Words: pelvic floor muscle, hip external rotator muscle, nulliparous women

表題名：

未産婦における股関節外旋筋力と骨盤底筋力との関係

著者名：

中野 聡子, PTR, Ph.D.[1]*, 中野 渉, PTR, Ph.D.[1,] , 加藤 倫卓, PTR, Ph.D.[1], 駒井 裕子 MNs [2], 牧野 泰枝, PTR [3]

所属機関：

1. 常葉大学 健康科学部 静岡理学療法学科

2. 伊東クリニック

3. 静岡市立静岡病院　リハビリテーション科

抄録

目的：股関節外旋筋の強化は骨盤底筋機能を改善する可能性がある。本研究では、未産婦における股関節外旋筋と骨盤底機能の関係を調査した。

方法：この横断的研究には、出産経験のない 18 歳以上の女性 59 名が参加した。骨盤底筋の筋力は経腹超音波を用いて測定した。また、股関節屈曲筋、外転筋、外旋筋の筋力および握力も測定した。骨盤底筋と股関節外旋筋の筋力との関連性を検討するため、重回帰分析を実施した。

結果：最終分析には55名の被験者（平均年齢20.3歳）が含まれた。骨盤底筋の筋力と股関節屈曲筋力（$r=0.334$、$p=0.013$）、外転筋力（$r=0.203$、$p=0.038$）、および外旋筋力（$r=0.413$、$p<0.001$）の間に単相関が認められた。一方で、骨盤底筋の筋力と握力との間には相関関係は認められなかった（$r=-0.124$、$p=0.369$）。重回帰分析の結果、骨盤底筋の筋力と股関節外旋筋の筋力との間に独立した関連が示された（$\beta=0.605$、$p=0.032$）。一方、骨盤底筋の筋力と股関節屈曲筋（$\beta=0.086$、$p=0.545$）、外転筋（$\beta=-0.052$、$p=0.902$）、および握力（$\beta=-0.012$、$p=0.101$）との間には関連は認められなかった。

結論：未産婦において、股関節外旋筋の筋力は骨盤底筋の筋力と関連していた。この結果は、股関節外旋筋の筋力が未産婦の骨盤底筋機能と関連している可能性を示唆している。股関節外旋筋の強化が腹圧性尿失禁の改善に効果があるかどうかを確定するためには、さらなる研究が必要である。

Introduction

Urinary incontinence (UI) significantly reduces quality of life (QOL)[1] and represents an important issue affecting individuals of all ages. In particular, the prevalence of UI in women after childbirth is approximately 26%[2], emphasizing the importance of maintaining pelvic floor function from a young age.

Pelvic floor muscle training is recognized as an effective method for preventing UI[3]. Specifically, in the case of postpartum UI, studies have reported that the preventive effect is greater when training is performed consistently before childbirth rather than starting after childbirth[4]. Moreover, the effectiveness of pelvic floor muscle training can be enhanced when combined with hip muscle strength training[5]. In older adults, a decrease in hip external rotation muscle strength has been observed in patients with lower urinary tract disorders, including UI[6]. Additionally, it has been reported that training the hip external rotation muscles can improve pelvic floor function[7]. These findings suggest that maintaining sufficient strength in the hip muscles may facilitate proper contraction of the pelvic floor muscles. However, the relationship between pelvic floor muscles and hip external rotators in nulliparous women remains unclear.

The aim of this study was to investigate the relationship between pelvic floor function and hip external rotator strength in nulliparous women.

Methods

Study participants

Fifty-nine nulliparous women aged ≥18 years, who had provided written informed consent after receiving a full explanation of the study objectives, were enrolled in this study. The exclusion criteria included a history of neurogenic bladder or chronic renal failure and an inability to achieve pelvic floor muscle contraction. The study design was approved by the ethics committee of Tokoha University (approval number 22-01). The study complied with the Declaration of Helsinki and the Japanese Ethical Guidelines for Medical and Health Research Involving Human Subjects.

Assessment of pelvic floor muscle function

Pelvic floor muscle function was evaluated by measuring the bladder base displacement using transabdominal ultrasound imaging[8)]. Bladder base displacement is related to vaginal pressure, an important component of pelvic floor muscle function[8)]. To measure this distance, transabdominal ultrasound was performed in M-mode using a 3.5–5 MHz convex probe (LOGIQ P6; GE HealthCare Japan, Inc. Tokyo, Japan) under two conditions: rest and pelvic floor contraction[8]. Participants urinated 1 h before the measurements were performed, drank 500 ml of water, and refrained from urinating until the measurements were completed. Measurements were performed in the supine resting position with the pelvis in a neutral tilt, the hip joints flexed at 45°, and the knee joints flexed at 90°. The ultrasound probe was placed 10 cm below the umbilicus, above the pubic symphysis, and inclined 15–30° towards the head to allow visualization of the bladder base. Bladder base displacement was measured in 0.1 mm increments using the measurement function of the ultrasound diagnostic imaging system, based on continuous M-mode ultrasound imaging of the bladder base. The displacement measured at rest and during contraction were compared to evaluate changes in bladder base movement (Figure1). For participants who had difficulty moving the bladder base towards the head, the instructions were adjusted to facilitate movement and compensatory movements other than those of the pelvic floor muscles were corrected[9,10]. Each participant underwent five measurements, and the maximum bladder base displacement was recorded as the final value. Ren Fig1.

Bladder base displacement measurements were performed by two examiners with knowledge of the anatomy of the pelvic floor region and ultrasound image reading skills. Both examiners received prior training to standardize imaging procedures, and all measurements in this study were performed according to a standardized protocol. Intra-rater reliability was evaluated by using intraclass correlation coefficient (ICC) (1,1) based on the five measurements performed by each examiner on the same subject. Inter-rater reliability was assessed by calculating the ICC (2,1) using the mean of five measurements performed on the same participant by each examiner.

Assessment of muscle strength

A μ-tus F–1 hand-held dynamometer (Anima Co. LTD., Tokyo, Japan) was used to assess hip muscle strength[6,11)]. Isometric make tests were used, incorporating a strap to facilitate fixed resistance and minimize the effect of assessor strength on measurements[6,12)]. Hip flexor strength was measured with the participant in the sitting position, with the hip at 90°flexion and neutral hip rotation. Hip abductor strength was measured in the side-lying position with pillows supporting the test hip at neutral abduction, rotation, and flexion/extension. Hip external rotator strength was measured in the sitting position with the hip at 90°flexion and neutral hip rotation. For each muscle group, participants performed a maximal isometric contraction sustained for 3 seconds. Two trials were conducted, and the greater of the two values was used for analysis. Prior to testing, participants were provided with standardized instructions and familiarization trials to minimize compensatory movements. If any compensatory motion was observed during testing, the trial was interrupted and repeated.

As an indicator of whole-body muscle strength, handgrip strength was measured twice using a digital hand dynamometer (TKK5401; Takei Scientific Instruments Co. Ltd., Niigata, Japan), and the maximum value (kg) was recorded.

Other clinical parameters

Information on age, height, weight, and medical history was collected using questionnaires. The International Consultation on Incontinence questionnaire-short form (ICIQ-SF) was used to assess UI [13)].

Statistical analysis

To exclude the effect of body weight, all hip muscle strength measurements were analyzed relative to bodyweight and expressed as ratios. For ordinal scales, the Shapiro–Wilk test was used to assess the normality of each variable. After confirmation of normality, Pearson's correlation analysis was performed to examine the relationship between pelvic floor function and lower limb muscle strength. Multiple regression analysis was used to identify factors associated with pelvic floor muscle function. Statistical significance was set at $p < .05$. Statistical analyses were performed using

SPSS 28.0 for Windows (IBM Corp., Armonk, NY, USA).

Results

The participant characteristics are presented in Table 1. Four of the 59 participants were excluded from the analysis because of their inability to move their bladder base towards their head[9,10]. Thus, 55 participants (average age: 20.3 years) were included in the analysis. Ren Table1.

The intra-examiner reliability of pelvic floor elevation distance measurement demonstrated very high consistency, with ICC (1,1) = 0.90 and 0.94 for subjects A and B, respectively. Inter-examiner reliability was evaluated using ICC (2,1) and showed ICC = 0.94, confirming excellent agreement between examiners.

Correlations with bladder base displacement are shown in Figure 2 and Table 2. Bladder base displacement correlated significantly with hip flexor strength ($r=0.334$, $p=0.013$), hip abductor strength ($r=0.203$, $p=0.038$), and hip external rotator strength ($r=0.413$, $p<0.001$). In addition, the hip flexor, abductor, and external rotator strengths were significantly correlated with each other (Table 2). In contrast, the correlation between handgrip and hip muscle strength was weak; a significant correlation was only observed between handgrip and hip abductor strength. No relationship was observed between handgrip strength and bladder base displacement. Ren Fig2, Table2.

Multiple regression analysis showed that hip external rotator strength was independently associated with bladder base displacement (β=0.605, p=0.032), regardless of hip flexor and abductor strength (Table 3). In contrast, no association was observed between pelvic floor muscle function and hip flexor (β=0.086, p=0.545), abductor (β=−0.052, p=0.902), and handgrip strength (β=−0.012, p=0.101). No multicollinearity was observed among the independent variables included in the model. Ren Table3.

Discussion

We examined the relationship between pelvic floor muscle function and hip muscle strength in nulliparous women. Our results showed that hip external rotator strength was related to pelvic floor muscle function independently of hip flexor and abductor, and handgrip strength. In contrast, hip flexor, hip abductor, and handgrip strengths were not independently associated with pelvic floor muscle function.

Although several previous studies have reported an association between hip external rotator strength and UI, a direct relationship between hip external rotator and pelvic floor muscle function, which is assumed to be the underlying mechanism, has not been established. In nulliparous women aged 18–35 years and in participants aged 55 years and older, hip strength training focusing on the hip external rotators reportedly improves pelvic floor muscle function as measured using vaginal pressure[7,14)]. We have also shown that hip external rotator strength is associated with pelvic floor muscle function independently of hip flexor and abductor strengths. Because hip external rotator strength correlates with hip flexor (r=0.690) and hip abductor strength (r=0.644), these effects should be considered. The pelvic floor muscles originate at the arch of the anal eminence tendon, to which the internal obturator muscles and external rotators of the hip joint are connected[15,16)]. In addition, the contraction of the piriformis muscle is related to the contraction of the pelvic floor muscles[17)]. Therefore, the hip external rotator muscle is thought to play an important role in the function of the pelvic floor muscles. Our results showed that strengthening the hip external rotator muscles may contribute to pelvic floor muscle function in nulliparous women.

Despite reports that active straight leg raising improves pelvic floor muscle function[18,19)], this study found no independent relationship between hip flexor muscle strength and pelvic floor muscle function. This finding suggests that the effect of active straight leg raising and lowering on pelvic floor muscle function may be mediated more by the transversus abdominis and rectus abdominis muscles rather than the hip flexors. In this study, hip flexor muscle strength was measured in a sitting position, which likely had minimal impact on pelvic floor muscle function. Therefore, different results might have been obtained if hip flexor muscle strength had been assessed during active straight leg raising and lowering.

Hip abductor strength is reportedly associated with lower urinary tract symptoms[6)] and nocturia[20)]. These findings are mainly based on studies in older adults, and lower urinary tract symptoms and nocturia are affected not only by pelvic floor muscle weakness but also by mobility, similar to functional UI. Therefore, the association between lower urinary tract symptoms and nocturia, and hip abductor strength in older adults may be due to a lack of mobility rather than pelvic floor muscle weakness. The main muscle involved in hip abduction is the gluteus medius, which is located on the outer side of the pelvis and has no direct connection to the pelvic floor muscles[21)]. In this study, although a correlation was found between pelvic floor muscle function and abductor muscle strength, this relationship disappeared in the multivariate analysis. Therefore, in women who have not given birth, strengthening the abductor muscles may not necessarily improve pelvic floor muscle function.

In this study, no association was observed between handgrip strength, as a measure of total-body strength, and pelvic floor muscle function. In older populations, there is an association between sarcopenia and UI [22,23], as well as between handgrip strength and both stress urinary incontinence (SUI) [24] and pelvic floor muscle function[25]. These findings suggest that whole-body muscle strengthening exercises may improve pelvic floor muscle function and UI in older individuals. However, there have been reports on the lack of association between handgrip strength and pelvic floor muscle function in younger populations. A cross-sectional study of postpartum women with a mean age of 29.8 years reported that pelvic floor muscle function was not associated with handgrip strength[26]. In addition, whole-body exercise has been reported to increase handgrip strength but not pelvic floor muscle function in nulliparous women with a mean age of 24.3 years[27]. Consistent with these findings, our results suggest that targeted pelvic floor muscle strengthening, rather than whole-body muscle strength or exercise, is required to maximize pelvic floor muscle function in nulliparous women.

Strengthening the external rotators of the hip joint to facilitate pelvic floor muscle movement may effectively improve pelvic floor function. Pelvic floor muscle training reportedly strengthens the pelvic floor muscles and improves the blood flow and elasticity of the external genital tissues, enhancing the contraction-relaxation function of the pelvic floor muscles[28]. As the internal obturator muscles, which are the external rotators of the hip joint, share nutrient vessels with the pelvic floor muscles[29], active engagement of the internal obturator muscles may enhance blood flow to the pelvic floor muscles, thereby improving their function. Indeed, studies have shown that training the hip external rotators alone, without specific pelvic floor muscle training, improves pelvic floor muscle function in older women[7]. The current study revealed a relationship between hip external rotator muscle and pelvic floor muscle function, suggesting that training the hip external rotators may be related to pelvic floor muscle function in nulliparous women.

In this study, hip external rotator muscle strength was measured isometrically from a neutral seated position, with the hips and knees flexed at 90 degrees and the lower legs hanging freely. This position was selected for its ease and consistency of measurement; however, it is possible that individual anatomical differences, such as femoral anteversion, may have influenced the resting length and mechanical advantage of the external rotators in this posture[30]. A greater degree of femoral anteversion can reduce external rotation range of motion and alter the initial muscle tension, which may in turn affect the ability of the muscles to generate force. Although we did not assess femoral anteversion in the present study, none of the participants reported symptoms such as hip pain or abnormal gait that would suggest significant torsional deformities. Nonetheless, unrecognized variations in femoral anteversion may have influenced the results. Future studies should consider evaluating femoral torsion to more precisely interpret the relationship between hip muscle strength and pelvic floor muscle function.

This study had several limitations. First, its cross-sectional design limited our ability to establish causal relationships between hip external rotator and pelvic floor muscle function. Longitudinal studies are required to better explain the temporal nature of these associations. Second, pelvic floor muscle function was assessed using transabdominal ultrasound. Although vaginal pressure is considered the gold standard for measuring pelvic floor muscle function[4)], transabdominal ultrasound has demonstrated reliability and validity[8,31,32)]. Transabdominal ultrasound may be appropriate for evaluating women who have not given birth and do not exhibit symptoms of UI. Third, pelvic floor muscle function in this study was evaluated solely based on bladder base displacement. Although bladder base displacement is one factor that mainly reflects the strength of the pelvic floor muscles, factors such as endurance and voluntary control of the pelvic floor muscles may also contribute to pelvic floor muscle function. Controlling for these factors may lead to a better understanding of the association between hip external rotator muscle strength and pelvic floor function.

Fourth, we excluded four participants from the primary analysis because no bladder base displacement could be detected on ultrasound. When all 59 participants were included in the analysis, the associations between variables became slightly weaker. However, the key finding that hip external rotator muscle strength was independently associated with bladder base displacement remained unchanged. Therefore, the main conclusions of the study were robust. Nevertheless, it should be noted that the present findings are applicable only to individuals in whom bladder base movement could be clearly visualized on ultrasound. This limitation must be considered when interpreting the generalizability of the results.

Conclusion

Hip external rotator strength was associated with pelvic floor muscle function independently of hip flexor and abductor, and handgrip strength in nulliparous women. The findings suggest that hip external rotator strength may be related to pelvic floor muscle function in nulliparous women. Further research is needed to determine whether strengthening hip external rotator can improve SUI.

Funding

This study was supported by Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (Grant No. 22K11190) of the Japanese Ministry of Education, Culture, Sports, Science, and Technology.

Conflict of interest

There are no conflicts of interest to declare.

Author Contributions

Experiment conception and design: SN and WN. Experiment implementation: YK and YM. Data analysis: SN and WN. Paper composition: SN. Analyzing and writing advisory: WN, MK, YK and YM. All authors approved the final version of the manuscript.

REFERENCES

1) Homma Y, Yamaguchi O, and Hayashi K. 2006. Neurogenic Bladder Society Committee. Epidemiologic survey of lower urinary tract symptoms in Japan. *Urology.* 68(3):560–4. doi: 10.1016/j.urology.2006.03.035.

2) Dai S, Chen H, Luo T. Prevalence and factors of urinary incontinence among postpartum: systematic review and meta-analysis. 2023. *BMC Pregnancy Childbirth.* 23(1):761. doi: nih.gov/37898733/

3) Dumoulin C, Cacciari LP, and Hay-Smith EJC. 2018. Pelvic floor muscle training versus no treatment, or inactive control treatments, for urinary incontinence in women. *Cochrane Database Syst Rev* 10: CD005654. doi: 10.1002/14651858.CD005654.pub4.

4) Woodley SJ, Lawrenson P, Boyle R, Cody JD, Mørkved S, Kernohan A, and Hay-Smith EJC. 2020. Pelvic floor muscle training for preventing and treating urinary and faecal incontinence in antenatal and postnatal women. *Cochrane Database Syst Rev* 5: CD007471. doi: 10.1002/14651858.CD007471.pub4.

5) Marques SAA, Silveira SRB da, Pássaro AC, Haddad JM, Baracat EC, and Ferreira EAG. 2020. Effect of pelvic floor and hip muscle strengthening in the treatment of stress urinary incontinence: A randomized clinical trial. *J Manipulative Physiol*

Ther 43: 247–256. doi: 10.1016/j.jmpt.2019.01.007.

6) Foster SN, Spitznagle TM, Tuttle LJ, Sutcliffe S, Steger-May K, Lowder JL, Meister MR, Ghetti C, Wang J, Mueller MJ, and Harris-Hayes M. 2021. Hip and pelvic floor muscle strength in women with and without urgency and frequency predominant lower urinary tract symptoms. *J Womens Health Phys Therap* 45: 126–134. doi: 10.1097/jwh.0000000000000209.

7) Tuttle LJ, Autry T, Kemp C, Lassaga-Bishop M, Mettenleiter M, Shetter H, Shetter H, and Zukowski J. 2020. Hip exercises improve intravaginal squeeze pressure in older women. *Physiother Theory Pract* 36: 1340–1347. doi: 10.1080/09593985.2019.1571142.

8) Whittaker JL, Thompson JA, Teyhen DS, and Hodges P. 2007. Rehabilitative ultrasound imaging of pelvic floor muscle function. *J Orthop Sports Phys Ther* 37: 487–498. doi: 10.2519/jospt.2007.2548.

9) Yoshida M, Murayama R, Hotta K, Higuchi Y, and Sanada H. 2017. Differences in motor learning of pelvic floor muscle contraction between women with and without stress urinary incontinence: Evaluation by transabdominal ultrasonography. *Neurourol Urodyn* 36: 98–103. doi: 10.1002/nau.22867.

10) Vermandel A, De Wachter S, Beyltjens T, D'Hondt D, Jacquemyn Y, and Wyndaele

JJ. 2015. Pelvic floor awareness and the positive effect of verbal instructions in 958 women early postdelivery. *Int Urogynecol J* 26: 223–228. doi: 10.1007/s00192-014-2483-x.

11) Stratford PW and Balsor BE. 1994. A comparison of make and break tests using a hand-held dynamometer and the Kin-Com. *J Orthop Sports Phys Ther* 19: 28–32. doi: 10.2519/jospt.1994.19.1.28.

12) Katoh M, Hiiragi Y, and Uchida M. 2011. Validity of isometric muscle strength measurements of the lower limbs using a hand-held dynamometer and belt: A comparison with an isokinetic dynamometer. *J Phys Therapy Sci* 23: 553–557. doi: 10.1589/jpts.23.553.

13) Gotoh M, Homma Y, Funahashi Y, Matsukawa Y, and Kato M. 2009. Psychometric validation of the Japanese version of the International Consultation on Incontinence Questionnaire-Short Form. *Int J Urol* 16: 303–306. doi: 10.1111/j.1442-2042.2008.02237.x.

14) Tuttle LJ, DeLozier ER, Harter KA, Johnson SA, Plotts CN, and Swartz JL. 2016. The role of the obturator internus muscle in pelvic floor function. *J Womens Pelvic Health Phys Ther* 40: 15. doi: 10.1097/JWH.0000000000000003.

15) Muro S, Nimura A, Ibara T, Chikazawa K, Nakazawa M, and Akita K. 2023.

Anatomical basis for contribution of hip joint motion by the obturator internus to defaecation/urinary functions by the levator ani via the obturator fascia. *J Anat* 242: 657–665. doi: 10.1111/joa.13810.

16) Muro S and Akita K. 2023. Pelvic floor and perineal muscles: A dynamic coordination between skeletal and smooth muscles on pelvic floor stabilization. *Anat Sci Int* 98: 407–425. doi: 10.1007/s12565-023-00717-7.

17) Wang Z, Zhu Y, Han D, Huang Q, Maruyama H, and Onoda K. 2022. Effect of hip external rotator muscle contraction on pelvic floor muscle function and the piriformis. *Int Urogynecol J* 33: 2833–2839. doi: 10.1007/s00192-021-05046-9.

18) Mens JMA, Vleeming A, Snijders CJ, Koes BW, and Stam HJ. 2002. Validity of the active straight leg raise test for measuring disease severity in patients with posterior pelvic pain after pregnancy. *Spine* 27: 196–200. doi: 10.1097/00007632-200201150-00015.

19) Mens JMA, Vleeming A, Snijders CJ, Koes BW, and Stam HJ. 2001. Reliability and validity of the active straight leg raise test in posterior pelvic pain since pregnancy. *Spine* 26: 1167–1171. doi: 10.1097/00007632-200105150-00015.

20) Tabara Y, Ikezoe T, Matsumoto T, Murase K, Setoh K, Funada S, Kawaguchi T, Nagashima S, Kosugi S, Hirai T, Nakayama T, Wakamura T, Chin K, Ichihashi N,

Tsuboyama T, andMatsuda F. 2019. Association of weak hip abduction strength with nocturia in older women: The Nagahama study. *Geriatr Gerontol Int* 19: 1010–1016. doi: 10.1111/ggi.13761.

21) Ashton-Miller JA and DeLancey JOL. 2007. Functional anatomy of the female pelvic floor. *Ann N Y Acad Sci* 1101: 266–296. doi: 10.1196/annals.1389.034.

22) Suskind AM, Cawthon PM, Nakagawa S, Subak LL, Reinders I, Satterfield S, Cummings S, Cauley JA, Harris T, and Huang AJ; Health ABC Study. 2017. Urinary incontinence in older women: The role of body composition and muscle strength: From the Health, Aging, and Body Composition Study. *J Am Geriatr Soc* 65: 42–50. doi: 10.1111/jgs.14545.

23) Silva RRL, Coutinho JFV, Vasconcelos CTM, Vasconcelos Neto JA, Barbosa RGB, Marques MB, Saboia DM, and C Maia Jet. 2021. Prevalence of sarcopenia in older women with pelvic floor dysfunction. *Eur J Obstet Gynecol Reprod Biol* 263: 159–163. doi: 10.1016/j.ejogrb.2021.06.037.

24) Zhang N, Mao W, Sun S, Zhang G, Shi N, Yao C, Liu N, Chen S, Gao W, Zhang L, Chen M, and Zou X. 2023. Association between grip strength and stress urinary incontinence of NHANES 2011-2014. *BMC Womens Health* 23: 521. doi: 10.1186/s12905-023-02628-1.

25) Soytas R, Soytas M, Danacioglu YO, Citgez S, Yavuzer H, Can G, Onal B, and Doventas A. 2021. Relationship between the types of urinary incontinence, handgrip strength, and pelvic floor muscle strength in adult women. *Neurourol Urodyn* 40: 1532–1538. doi: 10.1002/nau.24699.

26) Moss W, Shaw JM, Yang M, Sheng X, Hitchcock R, Niederauer S, Packer D, and Nygaard IE. 2020. The association between pelvic floor muscle force and general strength and fitness in postpartum women. *Female Pelvic Med Reconstr Surg* 26: 351–357. doi: 10.1097/SPV.0000000000000718.

27) Middlekauff ML, Egger MJ, Nygaard IE, and Shaw JM. 2016. The impact of acute and chronic strenuous exercise on pelvic floor muscle strength and support in nulliparous healthy women. *Am J Obstet Gynecol* 215: 316.e1–316.e7. doi: 10.1016/j.ajog.2016.02.031.

28) Mercier J, Morin M, Tang A, Reichetzer B, Lemieux M-C, Samir K, Samir K, Zaki D, Gougeon F, and Dumoulin C. 2020. Pelvic floor muscle training: Mechanisms of action for the improvement of genitourinary syndrome of menopause. *Climacteric* 23: 468–473. doi: 10.1080/13697137.2020.1724942.

29) Netter FH. Netter Atlas of Human Anatomy: Classic Regional Approach: Paperback + EBook (Netter Basic Science) 8th Edition. Media Alternatives,

Incorporated; 2022. 712 p.

30) Cibulka MT. 2004. Determination and significance of femoral neck anteversion. *Phys Ther.* 84(6):550–558. doi: 10.1093/ptj/84.6.550.

31) Moser H, Luginbuehl H, Baeyens J-P, and Radlinger L. 2019. Reliability and validity of pelvic floor muscle displacement measurements during voluntary contractions. *Int Urogynecol J* 30: 2093–2100. doi: 10.1007/s00192-019-03932-x.

32) Okamoto M, Murayama R, Haruna M, Matsuzaki M, Kozuma S, Nakata M, and Murashima S. 2010. Evaluation of pelvic floor function by transabdominal ultrasound in postpartum women. *J Med Ultrason* 37: 187–193. doi: 10.1007/s10396-010-0271-x.

Figure legends

Figure 1. Ultrasound image

Method for Measuring Bladder Base Displacement Using Ultrasound Imaging.

Bladder base displacement was assessed using continuous M-mode ultrasound imaging of the bladder base, both at rest and during contraction.

Figure 2. Correlation coefficients of bladder base displacement

Scatter plots showing the relationships between bladder base displacement and the following variables: A. Handgrip strength, B. Hip flexor strength, C. Hip abductor strength, and D. Hip external rotator strength. All hip muscle strength measurements are presented as a ratio to body weight.

Fig.1 Ultrasound image

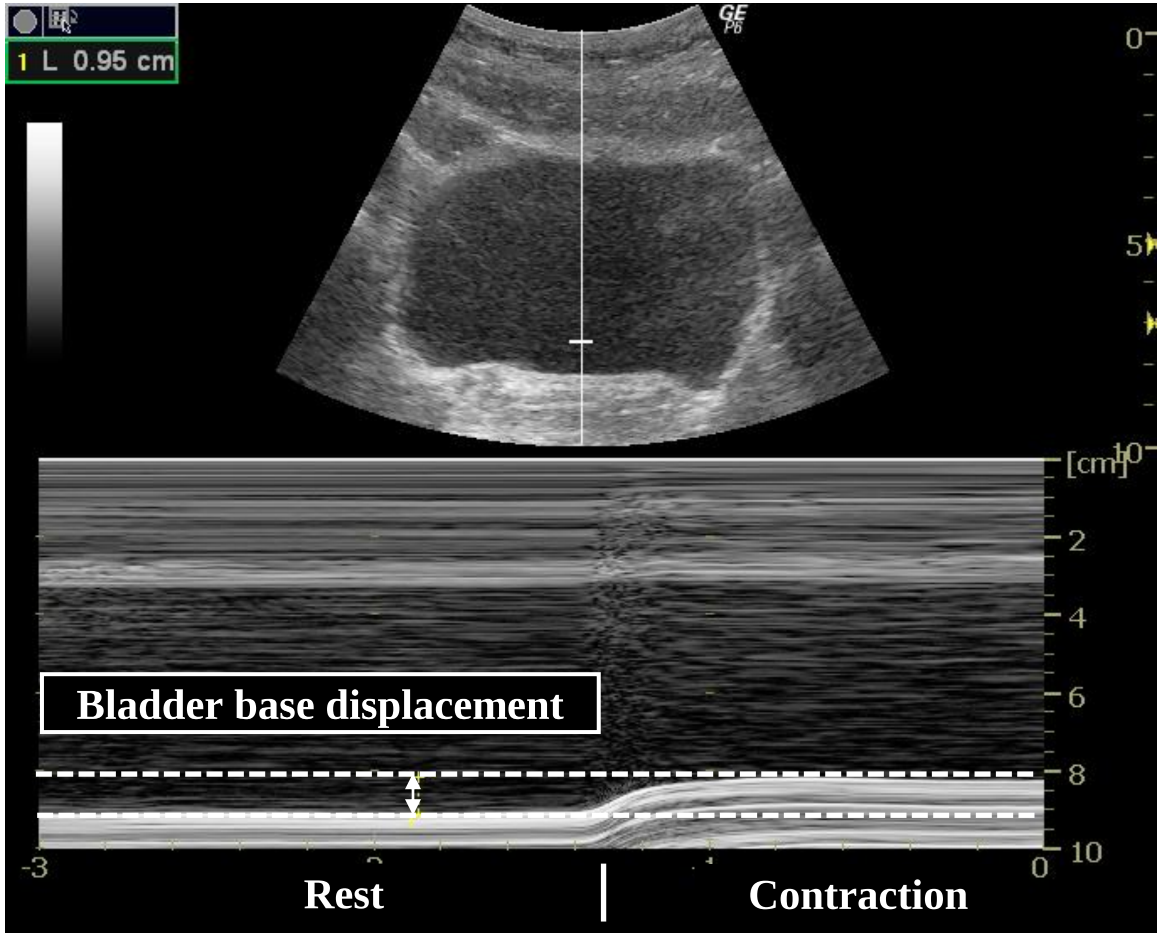
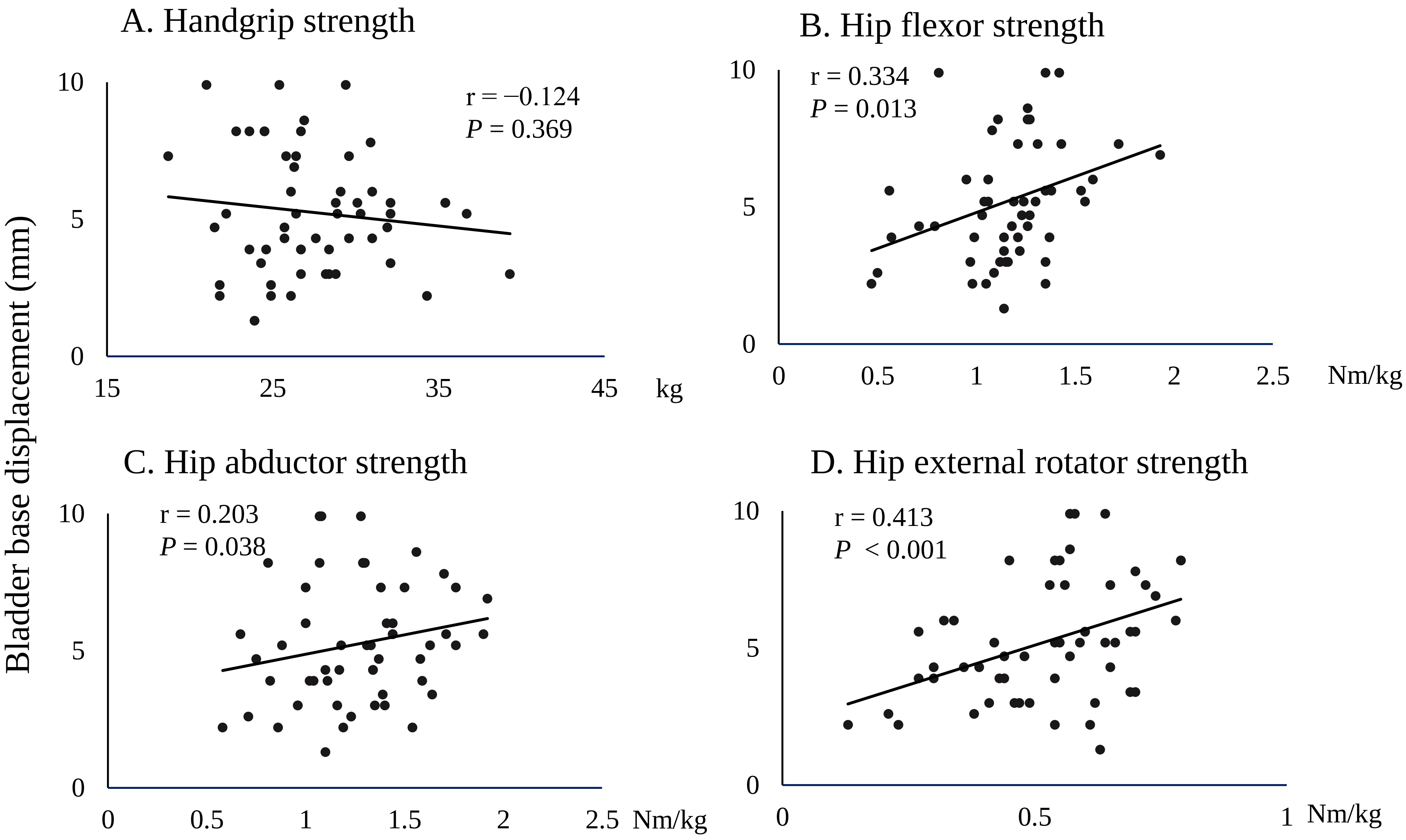


Fig.2 Correlation coefficient of bladder base displacement



Tables

Table 1. Participant characteristics

	Total (n=55)
Age, years	20.3 ± 1.4
Height, m	1.59 ± 0.6
Weight, kg	53.1 ± 6.7
BMI, kg/m^2	20.9 ± 2.1
Bladder base displacement, mm	5.2 ± 2.2
ICIQ-SF score, points	0.4 ± 1.2
Urinary incontinence	
Yes, n (%)	5 (9.0)
Handgrip strength, kg	27.5 ± 4.2
Hip flexor strength, Nm/kg	1.17 ± 0.28
Hip abductor strength, Nm/kg	1.26 ± 0.32
Hip external rotator strength, Nm/kg	0.52 ± 0.16

Mean ± standard deviation, number (%), BMI: Body Mass Index, ICIQ-SF: International Consultation on Incontinence Questionnaire - Short Form

Table 2. Correlation coefficients of bladder base displacement

	Bladder base displacement	Handgrip strength	Hip flexor strength	Hip abductor strength	Hip external rotator strength
Bladder base displacement	1	−0.124	0.334*	0.203*	0.413**
Handgrip strength	−0.124	1	0.147	0.331*	0.241
Hip flexor strength	0.334*	0.147	1	0.611**	0.690**
Hip abductor strength	0.203*	0.331*	0.611**	1	0.644**
Hip external rotator strength	0.413**	0.241	0.690**	0.644**	1

Pearson's correlation. **p<0.01, *p <0.05

Table 3. Multiple regression analyses of bladder base displacement

	Crude			Adjusted			
	ß	95% CI	*p*-value	ß	95% CI	*p*-value	VIF
Handgrip strength				−0.012	−0.026, 0.002	0.101	1.14
Hip flexor strength				0.086	−0.198, 0.371	0.545	2.11
Hip abductor strength				−0.052	−0.298, 0.194	0.902	2.01
Hip external rotator strength	0.570	0.224, 0.916	0.002	0.605	0.089, 1.122	0.032	2.26

CI: confidence interval, VIF: variance inflation factor