SCIENTIFIC RESEARCH ARTICLE

Relationship between Perceived Leg Length Discrepancy at One Month and Preoperative Hip Abductor Muscle Elasticity in Patients after Total Hip Arthroplasty

Kodai KINOSHITA, PT, M.S.1, Kazushi KIMURA, PhD2, Shigenori MIYAMOTO, PT, PhD2, Yuichi TAKATA, PT, PhD2, Yuji KODAMA, PT, MS1, Akira IEIRI, PT, PhD1, Kazuhiro ISHIDA, PT, PhD1, Masahiro INOUE, MD, PhD3, Satomi ABE, MD3, Takashi MIKAMI, MD3 and Taiki KANNO, MD, PhD3

1) Department of Rehabilitation, Wajokai Eniwa Hospital, Japan
2) Graduate School of Rehabilitation Science, Hokkaido Bunkyo University, Japan
3) Department of Orthopedic Surgery, Wajokai Eniwa Hospital, Japan

ABSTRACT. Objective: Preoperative factors related to perceived leg length discrepancy (PLLD) after total hip arthroplasty (THA) are not well studied. This study aimed to examine the preoperative factors, including hip abductor modulus, related to PLLD one month after THA. Methods: The study included 73 patients diagnosed with osteoarthritis secondary to developmental dysplasia of the hip and a posterior approach to surgery. Multiple logistic regression analysis was performed using the presence or absence of PLLD as the dependent variable and preoperative hip abductor’s modulus of elasticity, pain, hip abduction range of motion, hip abductor muscle strength and pelvic obliquity as the independent variable. Additionally, receiver operating characteristic curves were used for the extracted variables for calculating the cutoffs, sensitivity, specificity and area under the curve (AUC) to determine the presence or absence of PLLD. The significance level was set at p<0.05. Results: The hip abductor modulus (odds ratio=1.13; 95% confidence interval=1.06-1.21; p<0.001) was selected as a preoperative factor. The cutoff value to determine the presence or absence of a PLLD was 16.32 kPa. The sensitivity and specificity were 81.8% and 72.5%, respectively, and the AUC was 0.8137. Conclusion: The hip abductor muscle elastic modulus affected PLLD one month after THA. If the preoperative hip abductor elastic modulus is higher than the cutoff value, it may affect the appearance of PLLD at one month postoperatively.

Key words: Total hip arthroplasty, Perceived leg length discrepancy, Preoperative factors, Shear-wave elastography

Total hip arthroplasty (THA) is one of the orthopedic treatments for osteoarthritis (OA), and the procedure has been reported to provide excellent pain relief and improve patients’ range of motion (ROM) and walking ability1). However, we frequently encounter cases wherein patients complain about a subjective leg length discrepancy, which is more significant than the leg length discrepancy seen on radiographic images (structural leg length discrepancy) after the surgery. Perceived leg length discrepancy (PLLD) is generally defined as the leg length discrepancy that the patient is aware of and is also referred to as functional leg length discrepancy2,3). However, because these two terms are almost synonymous, PLLD is used throughout this paper.

Hofmann et al.4) reported that the leg length difference after THA is the main reason for postoperative lawsuits. Pakpianpairoj et al.5) reported that postoperative EuroQol 5 Dimension (EQ-5D) decreases in patients with leg length differences. The EQ-5D evaluates 5 dimensions of questions, including mobility, self-care, usual activities, pain/
discomfort and anxiety/depression. EQ-5D is a standardized instrument for use as a measure of health outcome. Nakanowatari et al. reported that PLLD is an important postoperative condition and decreases the patient’s health-related quality of life. Furthermore, as a functional problem, PLLD after THA is associated with low back pain, decreased ability to walk, and decreased functional improvement. In a previous report, Holtzman et al. reported that patients with severe preoperative pain, reduced ability to walk, and who perform activities of daily living (ADL) had reduced postoperative function. Regarding the effects of preoperative physical therapy, Wang et al. reported a slight decrease in pain and a significant effect on Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), stair climbing, toilet use and chair start date at 6–8 and 12 weeks. As reported by Moyer et al., a recent meta-analysis evaluating the effects of preoperative rehabilitation showed improvements in pain, function and hospital stay length. Furthermore, preoperative rehabilitation was reported to affect pain reduction, quality of life and overall satisfaction at one year postoperation. On the contrary, Fujita et al. reported that physical functions such as pain and ROM significantly improved up to six weeks after THA. We believe that preoperative rehabilitation plays an essential role in improving various functions in the early postoperative period.

The ROM of hip adduction pelvic obliquity and lateral mobility of the lumbar vertebrae are factors reported to affect PLLD. Chi et al. stated that shortening of the hip abductor muscles occurs with the displacement of the femoral head. Jasty et al. reported that the degree of hip abductor stretch due to surgical leg extension and increased femoral offset length affects PLLD after THA. However, despite these reports, we could not find any study that objectively evaluated and examined soft tissues such as hip abductor muscles by shear wave elastography as preoperative factors affecting PLLD. In line, we believe that the identification of the preoperative factors involved in PLLD could facilitate the development of efficient preoperative physical therapy interventions. In the past, the stiffness (modulus) of the hip abductor muscles was qualitatively assessed by therapists through palpation and ROM measurements, for the lack of precise quantitative and non-invasive assessment techniques. However, the elastic modulus of a muscle can also be calculated using the recently developed shear wave elastography to indicate muscle stiffness. The technique makes it possible to compare the degree of elongation of the same muscle. In this study, we objectively assessed the preoperative elastic modulus of the hip abductor muscles by shear wave elastography and investigated the preoperative factors associated with PLLD at one month after THA, including the hip abductor elastic modulus.

Materials and Methods

Experimental design
A longitudinal, observational study

Subjects
The study population included 116 patients who met the inclusion criteria among a total of 289 patients who underwent THA at our hospital between August 1, 2018, and March 31, 2019. The inclusion criteria were as follows: 1) preoperative diagnosis of secondary osteoarthritis of the hip due to developmental dysplasia of the hip, 2) the first THA for hip OA performed using the posterolateral approach, 3) patient consent to participate in this study. The exclusion criteria were as follows: 1) required postoperative exemption (4), 2) history of orthopedic disease affecting leg length discrepancy (13), 3) preoperative knee joint flexion contracture of 5° or more (5), 4) dislocated, neurological diseases and infectious diseases after surgery (0), and 5) incomplete preoperative records or incomplete records at one month postoperation (21). The final analysis was conducted on 73 patients (Fig. 1).

Regarding the measurement of structural leg length difference, the left-right difference was assessed using the distance between the teardrop and the lesser trochanter on a simple X-ray frontal image of both hips in the supine position. The difference between the left and right sides was measured using the distance between the teardrop and the lesser trochanter. The measurements were made in units of 0.1 mm, with positive values for longer distances on the operative side and negative values for shorter distances on the operative side.

Ethical considerations
This study was conducted in accordance with the Declaration of Helsinki and the Ethical Guidelines for Clinical Research. The subjects were fully informed of the purpose of the study and their privacy protection. All of them provided written consent to participate in the study. This study was conducted following the review and approval by the Research Ethics Review Committee of the Medical Corporation Wajokai Eniwa Hospital and the Research Ethics Review Committee of the Hokkaido Bunkyo University (Wajokai Eniwa Hospital, Approval No. 77 and Hokkaido Bunkyo University Approval No. 01004).

Outcome Measures

Perceived leg length discrepancy
A block test was used for PLLD measurements. Specifically, a 5-mm plate was inserted under the sole in a spontaneous standing position with both upper limbs in a drooping position and the feet shoulder-width apart. The height at which the sensation of PLLD disappeared was
then measured\(^2\). The postoperative subjective leg length discrepancy was divided into two groups, namely one with a leg length discrepancy of 5 mm or longer than the structural leg length discrepancy and one without a leg length discrepancy lower than 5 mm (Fig. 2).

**Pain**

Preoperative gait pain was assessed to the nearest 1 mm using the Visual Analog Scale.

**Pelvic obliquity**

The angle of supine pelvic obliquity in frontal images was used. The lateral pelvic tilt angle in the anterior forehead plane was measured as the line connecting the bilateral teardrop and the horizontal line\(^{14}\). Measurements were taken in 0.1° increments. The pelvic tilt angle was measured in 0.1° increments, with positive values for the downward pelvic tilt direction and negative values for the upward pelvic tilt direction.

**Hip abductor muscle strength**

The Hand-Held Dynamometer (HHD) utilized in this study was a Power Track HTM Commander (Nihon Medix, Matsudo, Japan). Each patient was placed in the supine position with intermediate hip abduction, secured with a belt such that the lower end of the sensory part of the HDD was at the level of the knee joint. The maximum isometric contraction of hip abduction was performed for 5 s\(^2\). The average values of three measurements were multiplied by the measured value (N) and the lever arm length (m) from the femoral trochanter to the knee joint cleft (Nm), divided by the body weight (Nm/kg).
Kinoshita, et al.

**ROM for hip adduction**

The ROM for hip adduction was measured using an angle meter, according to the method established by the Japanese Society of Rehabilitation Medicine. The ROM was measured in 5° increments, considering compensatory movements such as the lateral pelvic tilt and lateral trunk flexion.

**Hip abductor modulus of elasticity**

The measurements were performed by physical therapists with over six years of clinical experience. The examiner was positioned on the operative side of the patient and was in a sitting position. The dominant hand (right hand) grasped the probe, and the muscle was palpated and captured on ultrasound images based on the muscle’s anatomical structure. Each subject’s hip was measured in the dorsal recumbent position with intermediate hip abduction and internal/external rotation with 10° of hip flexion to avoid the flexion contracture and postoperative pain. A rolled bath towel was used in the knee socket to fix the flexion position. Efforts were made to measure the hip flexion angle with a goniometer and to fix the limb position during the measurement.

The modulus of elasticity was calculated for the tensor fasciae femoris, the gluteus medius and the gluteus minimus together as the hip abductor muscle. The extracted area of the abductor muscle was the longitudinal section of the muscle of the superior anterior iliac spine and the greater trochanter as a landmark, with the probe tilt angle defined as the angle at which the greater trochanter showed the highest intensity[23]. The probe’s position was determined by capturing the tensor fascia major, medius and gluteus medius muscles on ultrasound images. In addition to ensuring constant contact pressure of the probe, we specified manual contact using a gel without compressing the skin at the minimum pressure that allowed us to obtain an image (Fig. 3).

The hip abductor muscle’s elastic modulus was calculated from the ultrasound images taken using a shear wave elastography ultrasound system (GE Healthcare Japan’s LOGIQS8) and a linear probe (9 MHz center frequency). Shear wave elastography acquires the induced shear waves at an ultrafast frame rate and calculates their propagation velocity. Based on the shear wave propagation velocity, a quantitative color map image of the velocity distribution is created to obtain the shear modulus. The higher the value indicated as the elastic modulus, the stiffer the muscle, and the higher the chances of muscular limitation of the ROM. Each area was measured five times, and the average of the measurements was used for analysis.

**Physical Therapy Protocol**

In the postoperative protocol, the attending physician prescribed total loading for each patient in accordance with their pain levels. The patients walked with the help of a walker the day after surgery and with a cane on the third postoperative day. The patients were allowed to leave the hospital when they could walk with the help of a cane, climb stairs and perform their ADL. The postoperative stay duration was 14 days. The patients underwent regular checkups one month after the discharge. Exercise and lifestyle coaching were performed according to the patients’ recovery status.

**Statistical analyses**

Statistical analyses were performed using two-sample
Table 1. Comparisons of the demographic characteristics of participants in the PLLD and no-PLLD groups.

| Subject demographics | PLLD group (n=22) | No-PLLD group (n=51) | p Value |
|----------------------|------------------|---------------------|---------|
| Age, year            | 66.6±3.61        | 67.3±3.92           | 0.676*  |
| Female, % (n)        | 95.4 (21)        | 84.3 (43)           | 0.872a  |
| Height, m            | 1.53±0.05        | 1.56±0.06           | 0.334a  |
| Weight, kg           | 53.2±8.4         | 53.6±9.2            | 0.641a  |
| Body mass index, kg/m² | 0.65±0.12      | 0.62±0.03           | 0.103a  |
| Crowe class, type    |                  |                     |         |
| I, % (n)             | 86.3 (19)        | 90.1 (46)           | 0.432a  |
| II, % (n)            | 9.2 (2)          | 7.9 (4)             | 0.532a  |
| III, % (n)           | 4.5 (1)          | 2.0 (1)             | 0.321a  |
| IV, % (n)            | 0 (0)            | 0 (0)               |         |

Values are presented as mean±standard deviation
PLLD: perceived leg length discrepancy
Note: *t-test  aχ² test

Table 2. Measurements items and differences between the PLLD and no-PLLD groups.

|                      | PLLD group (n=22) | No-PLLD group (n=51) | p Value |
|----------------------|------------------|---------------------|---------|
| PLLD, mm             | 11.14±3.61       | 2.52±3.92           | <0.001* |
| Structural leg length discrepancy, mm | 2.32±2.51        | 2.61±2.21           | 0.633a  |
| VAS, mm              | 44.35±14.07      | 49.34±19.02         | 0.432a  |
| Pelvic obliquity, °  | 0.32±2.43        | 1.33±2.31           | 0.642a  |
| Hip abductor muscle strength, Nm/kg | 0.65±0.12        | 0.62±0.03           | 0.921a  |
| Range of motion for hip adduction, ° | 2.53±8.41        | 3.22±7.52           | 0.271a  |
| Hip abductor’s modulus of elasticity, kPa | 20.62±6.97       | 11.74±8.23          | <0.001* |

Values are presented as mean±standard deviation
PLLD: perceived leg length discrepancy
VAS: Visual Analog Scale
Pelvic obliquity: +tactical underhand, −tactical overhand
Note: *t-test

Table 3. Preoperative factors affecting PLLD at one month.

|                      | Odds Ratio | 95%CI  | p Value |
|----------------------|-----------|--------|---------|
| PLLD: perceived leg length discrepancy |           |        |         |
| β² test: p=0.012     |           |        |         |
| Hosmer-Lemeshow test: p=0.064 |           |        |         |

The t- or Mann-Whitney test was used to assess the difference between the two groups after confirming the normality by Shapiro-Wilk tests. To identify the preoperative factors affecting PLLD at one month after THA, stepwise multiple logistic regression analysis was performed using the presence or absence of PLLD at one month after THA as the dependent variable and each preoperative examination as the independent variable.

Also, the PLLD at one month postoperatively was classified into two groups based on the presence or absence of PLLD. Receiver operating characteristic (ROC) curves were used for the variables extracted by multiple logistic regression analysis to calculate the cutoff value, sensitivity, specificity and area under the curve (AUC) to determine the presence or absence of PLLD using R2.8.1 (CRAN: free-ware; http://www.r-project.org/and accompanying software packages) with a significance level of p<0.05.
Results

Patient selection in the THA group is shown in Figure 1. Finally, 73 patients were included in the analysis. PLLD assessed at one month after surgery revealed 22 (30%) and 51 (70%) patients with and without PLLD, respectively. Preoperative hip abductor muscle elasticity was significantly higher in the PLLD group (p<0.001). Details of the two groups are shown in Table 1, 2.

A multiple logistic regression analysis showed that the model $\chi^2$ test was significant and identified hip abductor modulus as a preoperative factor affecting PLLD at one month postoperatively (odds ratio = 1.13; 95% confidence interval = 1.06-1.21; p<0.004). The result of the Hosmer-Lemeshow test was not significant. (Table 3).

Using the presence or absence of PLLD at one month postoperatively as the dependent variable, ROC curves were drawn to examine the cutoff value of hip abductor modulus, as the preoperative factor identified by the multiple logistic regression analysis. The cutoff value for the presence or absence of PLLD was 16.32 kPa. The sensitivity and specificity were 81.8% and 72.5%, respectively, with an AUC of 0.8137 (Fig. 4).

Discussion

The novelty of our study lies in the addition of hip abductor muscle elasticity to the preoperative factors affecting PLLD after THA. Our results showed that the hip abductor modulus is a preoperative factor affecting PLLD after THA.

When the femur is displaced proximally in patients with hip OA, the soft tissues around the affected hip joint contract, causing leg length discrepancy and hip instability. A computed tomography imaging study in patients with THA revealed significant shortening of the gluteus medius muscle on the affected side. In contrast, a magnetic resonance imaging study investigating the association between hip OA and muscle atrophy reported that the medius muscle is atrophic as the hip OA becomes more severe. These findings suggest that the preoperative shortening of the hip abductor muscle may continue after THA.

The evaluation of the hip abductor modulus by shear wave elastography in this study captured the changes in modulus due to muscle shortening associated with preoperative structural changes. It has been reported that the reproducibility of the conventional assessment of qualitative muscle stiffness by palpatation is low. Therefore, objective and non-invasive evaluation methods are needed. Shear wave elastography acquires evoked shear wave signals at a very high frame rate and calculates their propagation speed. Based on the velocity of these shear waves, the shear modulus is determined by quantitative color-mapping of the velocity distribution. Shear wave elastography is highly valid and reliable for muscle tissue assessments. Niitsu et al. evaluated muscle stiffness and recovery after exercise using shear wave elastography. They reported that muscle stiffness continued to increase immediately after exercise, peaked on the second day after the exercise, and then was decreasing until the fourth day. Guo et al. evaluated the preoperative case of gluteal contracture using shear wave elastography and reported that the hip abductor muscle’s elastic modulus was higher than that of healthy subjects and reported its usefulness in preoperative evaluation. This study’s results indicate that the assessment of muscle function and disability may be helpful in clinical practice.

Because THA involves placing a cup in the primordial position, the postoperative hip abductor is expected to be stretched. A high preoperative hip abductor modulus of elasticity may affect the severity of PLLD after THA. These results suggest that the relaxation and stretching of the hip joint’s abductor muscle as preoperative physical therapy may help improve PLLD after surgery. However, the effects of exercise therapy and stretching methods in patients with hip OA require further study.

This study has some limitations. Because the study was conducted in a single institution, a selection bias in patient selection may have occurred. It is therefore necessary to conduct a multicenter collaborative study in the future. Moreover, we did not assess the lateral lumbar mobility related to PLLD, as previous studies have reported an association between PLLD and lumbar lateral mobility. Total spine alignment was difficult to assess due to simple X-ray bilateral hip frontal views used in this study. Second, the lateral pelvic tilt and hip abductor modulus were evaluated in the supine position only. Although standing radiographs are commonly used to measure pelvic obliquity, we used...
dorsal radiographs in this study. The measurement of pelvic obliquity from standing radiographs is more likely to be affected by postural deviation due to pain. However, it is essential to examine the difference in pelvic obliquity between non-weighted and weighted positions to clarify the factors affecting PLLD. Dorsal assessment was also used to assess the hip abductor modulus in the supine position.

In line, we utilized the dorsal supine position to avoid muscle weakness and postural deviation related to pain occurring in the standing position. However, we could not deduce how the hip abductor modulus affected dynamic situations such as standing and walking. Hence, future studies should evaluate the hip abductor modulus in the standing position. The present study defined the midpoint of the superior anterior iliac spine and the midpoint of the greater trochanter as the measure points of the hip abductor’s modulus. However, this is a localized assessment of the abductor hip muscle which does not represent the entire muscle. Therefore, separate evaluations of the anterior, middle and posterior regions of the hip abductor muscle are required in future studies. Finally, this study examined only preoperative factors. Therefore, it did not consider the effects of offset length, leg extension, surgical technique and implants, which are thought to be related to PLLD after THA. In the future, it would be beneficial to define all the factors that affect PLLD, including postoperative factors.

**Conclusion**

This study shows that hip abductor modulus was a preoperative factor affecting PLLD one month after THA to determine the presence of PLLD, we calculated a cutoff value for preoperative hip abductor modulus. If the preoperative hip abductor elastic modulus was higher than the cutoff value, PLLD might remain one month after THA.

**Acknowledgments:** We thank Professor Yoshie Tanabe and Professor Shinji Matsuoka for their helpful insights. We also acknowledge all participants and the staff of the Wajokai Eniwa Hospital.

**Conflict of Interest:** None of the authors has any conflict of interest to disclose.

**References**

1. Bahl JS, Nelson MJ, *et al.*: Biomechanical changes and recovery of gait function after total hip arthroplasty for osteoarthritis: a systematic review and meta-analysis. Osteoarthritis Cartilage. 2018; 26: 847-863.
2. Gurney B: Leg length discrepancy. Gait Posture. 2002; 15: 195-206.
3. Abraham WD and Dimon JH 3rd: Leg length discrepancy in total hip arthroplasty. Orthop Clin North Am. 1992; 23: 201-209.
4. Hofmann AA and Skrzynski MC: Leg length inequality and nerve palsy in total hip arthroplasty: a lawyer awaits! Orthopedics. 2000; 23: 943-944.
5. Pakpianpairoj C: Perception of Leg Length Discrepancy after Total Hip Replacement and Its Impact on Quality of Life. J Med Assoc Thai. 2012; 95: S105-S108.
6. Nakanowatari T, Suzukamo Y, *et al.*: The influence of functional leg length discrepancy on health-related quality of life after total hip arthroplasty: A structural model of disabilities with a path analysis. Physical Therapy Japan. 2016; 43: 30-37 (in Japanese).
7. Friberg O: Clinical symptoms and biomechanics of lumbar spine and hip joint in leg length inequality. Spine. 1983; 8: 643-651.
8. Nakanowatari T, Suzukamo Y, *et al.*: True or apparent leg length discrepancy: Which is a better predictor of short-term functional outcomes after total hip arthroplasty? J Geriatr Phys Ther. 2013; 36: 169-174.
9. Holtzman J, Khal Saleh, *et al.*: Effect of baseline functional status and pain on outcomes of total hip arthroplasty. J Bone Joint Surg Am. 2002; 11: 1942-1948.
10. Wang L, Lee M, *et al.*: Does preoperative rehabilitation for patients planning to undergo joint replacement surgery improve outcomes? A systematic review and meta-analysis of randomised controlled trials. BMJ Open. 2016; 6: 1-15.
11. Moyer R, Ikert K, *et al.*: The Value of Preoperative Exercise and Education for Patients Undergoing Total Hip and Knee Arthroplasty: A Systematic Review and Meta-Analysis. JBJS Rev. 2017; 5: e2.
12. Torisho C, Mohaddes M, *et al.*: Minor influence of patient education and physiotherapy interventions before total hip replacement on patient-reported outcomes: an observational study of 30,756 patients in the Swedish Hip Arthroplasty Register. Acta Orthop. 2019; 90: 306-311.
13. Fujita K, Makimoto K, *et al.*: Three-year follow-up study of health related QOL and lifestyle indicators for Japanese patients after total hip arthroplasty. J Orthop Sci. 2016; 21: 191-198.
14. Kawabata Y, Goto K, *et al.*: Factors Affecting the Perceived Leg Length Discrepancy after Total Hip Arthroplasty: Using a Hierarchical Multiple Regression Analysis. Physical Therapy Japan. 2015; 42: 408-412 (in Japanese).
15. Fujimaki H, Inaba Y, *et al.*: Leg length discrepancy and lower limb alignment after total hip arthroplasty in unilateral hip osteoarthritis patients. J Orthop Sci. 2013; 18: 969-976.
16. Chi AS, Long SS, *et al.*: Prevalence and pattern of gluteus medius and minimus tendon pathology and muscle atrophy in older individuals using MRI. Skeletal Radiol. 2015; 44: 1727-1733.
17. Jasty M, Webster W, *et al.*: Management of limb length inequality during total hip replacement. Clin Orthop. 1996; 333: 165-171.
18. Eby SF, Song P, *et al.*: Validation of shear wave elastography in skeletal muscle. J Biomech. 2013; 46: 2381-2387.
19. Koo TK, Guo JY, *et al.*: Relationship between shea elastic modulus and passive muscle force: an ex-vivo study. J Biomech. 2013; 46: 2053-2059.
20. Woolson ST and Harris WH: A method of intraoperative limb length measurement in total hip arthroplasty. Clin Orthop Relat
21) Harris I, Hatfield A, et al.: Assessing leg length discrepancy after femoral fracture: clinical examination or computed tomography? ANZ J Surg. 2005; 75: 319-321.

22) Ieiri A, Tushima E, et al.: Reliability of measurements of hip abduction strength obtained with THA hand-held dynamometer. Physiother Theory Pract. 2015; 31: 146-152.

23) Mitomo S, Ichikawa K, et al.: Effects of Isometric Hip Abduction Contraction in Different Directions on Muscle Thickness and Muscle-tendon Junction Distance of Fibers of the Gluteus Medius Measured by Ultrasonography. Rigakuryoho Kagaku. 2017; 32: 869-874 (in Japanese).

24) Lai KA, Lin CJ, et al.: Gait analysis of adult patients with complete congenital dislocation of the hip. J Formos Med Assoc. 1997; 96: 740-744.

25) Liu R, Wen X, et al.: Changes of gluteus medius muscle in the adult patients with unilateral developmental dysplasia of the hip. BMC Musculoskelet Disord. 2012; 13: 2-7.

26) Zacharias A, Pizzari T, et al.: Hip abductor muscle volume in hip osteoarthritis and matched controls. Osteoarthritis Cartilage. 2016; 24: 1727-1735.

27) Jonsson A and Rasmussen-Barr E: Intra- and interrater reliability of movement and pain in patients with neck pain: A systematic review. Physiother Theory Pract. 2018; 34: 165-180.

28) Yoshitake Y, Takai Y, et al.: Muscle shear modulus measured with ultrasound shear-wave elastography across a wide range of contraction intensity. Muscle Nerve. 2014; 50: 103-113.

29) Tas S, Onur MR, et al.: Shear wave elastography is a reliable and repeatable method for measuring the elastic modulus of the rectus femoris muscle and patellar tendon. J Ultrasound Med. 2017; 36: 565-570.

30) Niitsu M, Michizaki A, et al.: Muscle hardness measurement by using ultrasound elastography: a feasibility study. Acta Radiol. 2011; 52: 99-105.

31) Guo R, Xiang X, et al.: Shear-wave elastography assessment of gluteal muscle contracture: Three case reports. Medicine (Baltimore). 2018; 97: 1-6.

32) Fujishiro T, Nishiyama T, et al.: Predicting leg-length change after total hip arthroplasty by measuring preoperative hip flexion under general anaesthesia. J Orthop Surg (Hon Kong). 2012; 20: 327-330.

33) Koga D, Jinno T, et al.: The effect of preoperative lateral flexibility of the lumbar spine on perceived leg length discrepancy after total hip arthroplasty. J Med Dent Sci. 2009; 56: 69-77.