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Original Article

Measurement of piriformis muscle stiffness in athletes with lower back pain and piriformis syndrome: A shear-wave elastography study with consideration of the onset of piriformis syndrome

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Abstract:
Problem Statement: Piriformis syndrome is a common cause of buttock, leg, and lower back pain due to piriformis muscle stiffness. Only a few treatments for lower back pain are efficacious. **Purpose:** This study aimed to assess piriformis muscle stiffness by shear-wave elastography in athletes with lower back pain and piriformis syndrome to establish a standard diagnostic method and determine the onset of unexplained lower back pain in such athletes. This pre–post-test design study was conducted at Shibahara Orthopaedic Sports Joint Clinic. Twenty-eight athletes with lower back pain and piriformis syndrome and 30 healthy athletes were enrolled. After relaxing the piriformis muscle contracture using strain–counter strain techniques, therapeutic manual traction was employed to move the displaced femoral head forward via piriformis muscle contracture to the center of the hip joint acetabulum. Ultrasound examination using shear-wave elastography, straight leg-raise, flexion abduction external rotation, and Gillet test were performed. The pain scores were recorded on a numerical rating scale before and after treatment. **Results:** Significant differences between the scores of the lower back pain among athletes before and after treatment were noted on comparing the mean and maximum elasticity modulus values from all test results. Differences between the scores of athletes after treatment and controls were not significant. **Conclusions:** Piriformis syndrome may be one of the causes of nonspecific low back pain, and the treatment of sacroiliac joint dysfunction may well be useful in reducing piriformis syndrome. Moreover, shear-wave elastography provides a painless, noninvasive, and objective method for evaluating athletes with lower back pain and piriformis syndrome. The onset of most cases of unexplained low back pain in athletes with piriformis syndrome can thus be attributed to the sacroiliac joint.
Key Words: elastography, muscle hardness, low back pain, piriformis syndrome

Introduction

According to Deyo and Weinstein (2001), >80% of cases of lower back pain (LBP) are assigned as "unexplained LBP," in which there is no specific pathological cause. Although the incidence of LBP in athletes varies with sports type, its incidence in any sports is 20%–70% (McHardy et al., 2007). Several athletes have had a short-lived career because of LBP. Moreover, LBP is a mutual cause of missed playing time in competitive athletes and a crucial and common cause of lost games (Mortazavi et al., 2015).

The most usual causes of LBP in athletes are gradually deteriorating disk disease and spondylolysis. Detecting the exact cause of pain in athletes may create challenges for diagnosis and management. Hence, physicians should follow a comprehensive approach for LBP and consider the less common causes among athletes (Mortazavi et al., 2015). LBP treatment is focused on its obvious causes. However, the LBP is unexplained in >80% of patients (Deyo & Weinstein, 2001). Unexplained LBP is difficult to diagnose, and the pain is often accompanied by nerve symptoms in the lower extremity (Chou et al., 2009). Thus, a multifaceted approach toward various factors is required for LBP because existing modalities have not successfully resolved this issue. According to Hoskins (2012), the initial differential diagnosis directory for athletic LBP should include an exhaustive history, excluding red flag conditions, tests, and a focused evidence-based approach toward imaging.

The process should carefully consider the athlete's age and understand sport-specific biomechanics. However, the relevance of yellow flags for the refinement of lower back injuries and long-lasting and recurrent pain in athletes remains unclear considering the limited investigations on LBP management in these populations (Hoskins, 2012). According to Petering and Webb (2011), LBP is a common problem among athletes. Therefore, clinicians should identify athletes with high-risk lower back injuries. Although several treatment options are available for LBP, only a few treatment modalities have demonstrated efficacy (Petering & Webb, 2011).

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Piriformis syndrome (PS) is a controversial and unresolved diagnosis for LBP and buttock pain. It is secondarily attributed to an ill-defined consensus on the definition and pathophysiology of the syndrome (Silver & Leadbetter, 1998). PS is believed to be a fascial pain syndrome that arises from a trigger point. The symptoms are aggravated by prolonged sitting, prolonged flexing of the lower back, and simultaneously adducting and internally rotating the hip joint. Hip joint adduction and internal rotation with a low posture are essential for an athlete's movement.

The number of patients with PS is higher than those with radiculopathy due to disk herniation, with a female-to-male ratio of 6:1 among patients with PS (Pace & Nagle, 1976). Pain is directly derived from the fascia trigger point of the piriformis muscle in the gluteal, waist, and posterior femoral areas. For example, the superior gluteal nerve or sciatic nerve entrapment by piriformis muscle contracture may cause LBP or buttock tingling/numbness. Moreover, sacroiliac joint misalignment is often accompanied by PS, which is manifested as a sacral extension (Papadopoulos & Khan, 2004).

However, PS has not been academically proven yet. PS derives its name from the general symptoms such as self-symptomatic symptoms and laboratory findings. Although PS was originally described in 1947 (Robinson, 1947), there is no worldwide consensus on its diagnosis and intervention, which has affected its epidemiological analysis (Silver & Leadbetter, 1998). Moreover, several patients with PS may have been treated as for LBP because they reacted well to nonsteroidal anti-inflammatory drugs (NSAIDs) or epidural steroids (Mullin et al., 1998).

The difficulty of noninvasively evaluating muscle stiffness in a living body is the primary reason for the existing challenge in the evaluation and treatment for PS-associated LBP, although Damirel et al. (2018) reported that some imaging techniques such as ultrasonography are useful for the diagnosis and treatment. Muscle mechanical props, such as rigidity and stiffness, have conventionally been evaluated through indirect approaches, such as tactile exploration, manual muscle testing, and measurement of the muscle strength and joint range of motion (ROM).

Although such judgments have supplied worthy information and have played a cardinal role in the physical examination of patients and research participants, their objectivity remains restricted. Moreover, such judgment approaches cannot differentiate between the mechanical props of human muscles and those of the associated skin, subcutaneous fat, joint capsule, tendons, or neurovascular structures. However, ultrasound elastography has been increasingly and successfully used to assess muscle hardness and stiffness. According to Demirel et al. (2018), the elasticity and hardness of the affected muscle increase on ultrasound elastography.

Ultrasound elastography may provide an early diagnosis of PS, and, consequently, timely treatment with a less invasive approach. Specifically, shear-wave elastography (SWE) is an ultrasound-based technique that employs shear waves to quantitatively measure tissue hardness. SWE assesses incomplete data regarding muscle hardness by utilizing an ultra-high-speed algorithm that calculates Young's modulus of elasticity based on the velocity of shear waves produced from the transducer. However, this method has not yet been established as a gold standard diagnostic method because the study included a relatively small number of cases (Demirel et al., 2018).

In the present study, we move toward standardization of the diagnostic technique of PS with LBP using SWE and the determination of the possible onset of unexplained LBP in athletes with PS. The results obtained may help athletes who had to discontinue their participation in sports competitions because of unexplained LBP.

Materials and methods

Study design and participants

This study was a single-center, outpatient, and pre–post-test design-based research. A total of 28 male athletes (patients) suspected of unexplained LBP with PS and 30 healthy male athletes (controls) were included in this study (Table I). All athletes were inquired about their medical history and then subjected to examinations and treatment (only for patients) at the Shibahara Orthopaedics Sports Joint Clinic, Japan, which was managed by the co-author of this study.

The inclusion criteria were as follows: patients with no obvious cause of LBP as per manual examinations, such as single-leg-raise, and imaging examinations, such as magnetic resonance imaging (MRI) and computed tomography, conducted by the co-author of this study; patients without lower limb neurological symptoms; and patients with piriformis muscle contraction. According to a previous study using elastography (Lieber, 2009), Young's rate of living tissue added to stiffness by adding a cross-sectional area element (Young modulus) was 10–20 kPa.

The LBP group took ≥30 kPa as the reference value, although only one patient was below the reference value. The average elastic modulus of the LBP group was 38.8 kPa. In other words, the participants were athletes with nonspecific LBP, and an average elastic modulus was clearly greater than that of the controls (mean value: 26.6 kPa) without LBP.

Table I. Details of the study participants of the attached excel data.

Patient No.	Age	Height (cm)	Weight (kg)	Event	Athletic Career (yr)	LB pain career (yr)	LB Pain Region(L/R)	Gillet Test
1	21	179	67	Soccer football	12	3	R	Positive
2	21	173	66	Baseball	10	4	R	Positive
3	24	178	67	Hurdle race	10	5	R	Positive
4	24	176	77	Soccer football	10	10	L	Negative
5	27	180.5	77	Soccer football	21	15	L	Positive
6	56	167	75	Golf	10	1	R	Positive
7	45	173	70	Baseball	15	5	R	Positive
8	65	167	77	Golf	35	0.5	R	Negative
9	47	175	73	Soccer football	14	10	L	Positive
10	62	174.5	66	Weight training	10	20	L	Positive
11	24	186	89	Baseball	15	3	L	Positive
12	40	177	67	Basketball	30	5	R	Positive
13	36	179	83	Badminton	5	5	R	Positive
14	70	170	61	Swimming	50	3	L	Negative
15	48	169	65	Tennis	20	2	R	Positive
16	48	172	62	Marathon	15	5	L	Positive
17	51	174	75	Road Bike	10	0.3	R	Positive
18	27	170	71	Judo	21	2	L	Positive
19	21	165	55	Wind surfing	8	1	R	Positive
20	31	172	75	American football	4	7	R	Positive
21	47	175	84	Golf	20	10	L	Positive
22	25	162	54	Gymnastics	10	0.3	L	Positive
23	43	165	64	Golf	8	1	R	Negative
24	17	162	56	Rugby	2	0.3	R	Positive
25	64	178	70	Golf	35	20	R	Positive
26	61	179	79	Tennis	40	29	L	Positive
27	39	174	62	Badminton	5	16	R	Negative
28	16	171	64	Baseball	10	0.3	R	Positive
Avg.	39.286	172.96	69.679	N/A	16.25	6.560714	N/A	N/A

The study protocol was approved by the Osaka Kyoiku University Ethics Committee (chaired by Eiji Morita; Protocol no. 344, and approved on 18 July 2018), and written informed consent was obtained from the participants before initiating the study. The test procedures were conducted according to the principles of the Declaration of Helsinki. No compensation was provided to any participants.

Data collection

Young's modulus: This study was executed using the Aixplorer MultiWave Ultrasound System (Supersonic Imagine, France) with a curved array probe (operative frequency, 2.5–5 MHz; Figure Ia). SWE was used at a depth of up to 12 cm. Young's modulus is one of the mechanical properties of measuring hardness that was used for hardness assessment in this study. The scale of Young's modulus, which is utilized in gynecological mode (180 kPa), was up to 800 kPa as a requisite for patients in the test group. Young's modulus was measured in the areas of maximum piriformis hardness. Measurements were performed under full staining conditions of the color window (SWE imaging). The tissue hardness of the studied area was exposed using a color map in the real-time mode. Tissues of greater hardness were characterized by a high extent of Young's modulus and represented in red, green, and yellow. Less hard tissues with a lower extent of Young's modulus were exhibited predominately in blue. Tissue hardness was assessed in regions of interest (ROI) (Q boxes), which were represented by circles with an adjustable diameter of up to 10 mm. All images and data were recorded in the machine's memory for further assessment and processing. The numeric values (statistics) of the parameters for Young's modulus (E) were automatically set in ROI (Q box): standard deviation (SD), minimum value (Emin), average value (Emean), and maximum value (Emax). Emean and Emax SD were used for the analysis. Measurements were executed in five ROIs (Q boxes), and the diameter of each circle was 2 mm. Given the small thickness of the piriformis muscle, the diameter was limited to 2 mm so that the five circles would not overlap in each of the piriformis muscles. Thereafter, the average Emean and Emax were determined before and after the treatment.

Procedure

The procedure was designed to measure the shear modulus of the piriformis muscle before and after the treatment. Based on several pilots and ultrasound images in the middle of the piriformis muscle's locations, we found that the locations could be reproducible for keeping a shear-wave map in the marked muscle. First, a participant was asked to lay on his side, with the painful lower back facing outward. Then, the hip joint was bent at 40° (Figure Ib), and the knee joint was bent at 90° (Figure Ic) to relax the piriformis muscle and the participant. The probe was oriented parallel to the main axis of the piriformis muscle to measure the shear modulus along the muscle prolonging direction. The center of a line connecting the posterior superior iliac spine (PSIS) and the coccyx was then determined. Then, the center of a line connecting the point and the greater trochanter was considered the probe location (Figure Id). The examiner was skilled in the use of the Aixplorer machine for piriformis scanning. This step involved the upkeep of minimal transducer pressure on the skin. We conducted a retrospective analysis of SWE for the results of the morphological test of the operative material. Notably, the SWE image (color window) of the piriformis muscle was characterized by red, green, and yellow (predominately heterogeneous staining because of high hardness). Simultaneously, the 178 unremarkable areas of the piriformis muscle in all cases were represented in blue (homogenous staining contrary to the setting of normative values of Young's modulus) (Figure IIa). However, the color range was counted on the picked scale of Young's modulus. As mentioned earlier, the established value of the scale in gynecological mode is 180 kPa. During the study, increasing the scale (up to 800 kPa) could not determine Young's modulus obtained from elastography in the concerned area, but it did modify the color range (Figure IIb, c). The same examiner conducted the measurements of all participants.

Figure I. Protocol with the Aixplorer MultiWave Ultrasound System (Supersonic Imagine, France). (a) The Aixplorer MultiWave Ultrasound System (Supersonic Imagine, France). (b) A participant lying down on his side, with the painful lower back facing upward. Then, the hip joint was bent at 40°. (c) The knee joint was bent at 90°. (d) The center of a line connecting the point and the greater trochanter was considered as the probe location.

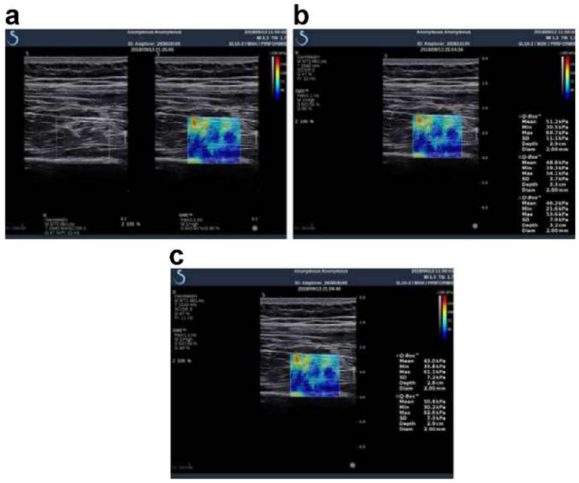

Figure II. (a) Gray-scale ultrasound in the left side and overlaid shear-wave elastography (SWE) imaging in the right side. Heterogeneous staining and high stiffness are demonstrated within a color window (SWE imaging).
(b) Color window (SWE imaging) is characterized by heterogeneous staining.
A wide range of Young's modulus numerical values in three regions of interest (Q Box) can be seen.
(c) Color window (SWE imaging) is characterized by heterogeneous staining.
A wide range of numerical values of Young's modulus in two other regions of interest (Q Box) can be seen.

Straight leg-raise (SLR) test: SLR tests (Figure IIIa) were performed, and the results were measured using a goniometer by the same tester before and after the treatment. The patient was asked to lay in the supine position, with the hip in a neutral position and a small pillow was placed under the head. The patient's involved lower extremity was gripped over the distal calf, and care was ensured to not change the neutral resting position of the ankle. The tester then slowly raised the patient's relaxed involved lower extremity with his knee extension until the patient reported LBP. The results of two consecutive measurements were averaged for all participants. The goniometer was placed with the steady arm parallel to the table, movable arm along the lateral midplane of the thigh, and axis above the greater trochanter. Before the treatment, all participants with subjective complaints of LBP or fundamental symptoms with a positive unilateral SLR test <75° were included. The SLR test is a sensitive test for observing any lower back problems, with accuracy of 91% (Speed, 2004). In the SLR test, the painless mobility of the lower limb was measured before and immediately after the treatment of the piriformis muscles. The same examiner measured all the participants.

Flexion abduction external rotation (FABER) <Patric> test: The FABER test (Figure IIIb) is commonly utilized as a provocation test to detect hip, lumbar spine, or sacroiliac joint pathology (Magee, 2014). To quantify FABER ROM, the perpendicular distance from the table to the tibial tuberosity was measured (Dutton 2008; Martin et al., 2006; Philippon et al., 2013). Specifically, limb asymmetry in FABER height may indicate potential femoroacetabular impingement (FAI) or hip pathology on the side with reduced ROM (Martin et al., 2006; Philippon et al., 2013). Specifically, a cutoff of 3–4 cm of asymmetry between limbs has been suggested as a possible indication of FAI (Philippon et al., 2013). Figure IV shows the FABER ruler measurement testing position. The examiner stabilized the contralateral anterior superior iliac spine and applied pressure to the ipsilateral medial knee during exposure while measuring the perpendicular range from the tibial tuberosity to the table utilizing a ruler. The FABER test was executed before and after the treatment. According to Bagwell et al. (2016), the FABER test presents with excellent intra-rater reliability, with the highest ICC demonstrated for inclinometry (ICC 0.86, 0.86, and 0.91). In addition, the sensitivity for the identification of hip pathology recognized with arthroscopy was 0.89. The same examiner conducted the measurements on all participants.

Gillet Test: This test (Figure IIIc) was used to evaluate the unnatural movement of the sacroiliac joint. This test is also known as the ipsilateral flexion kinetic test, sacral fixation test, marching test, or ipsilateral posterior rotation test. Several versions of the test have been reported in the literature (Dutton, 2008; Konin et al., 2002). To perform this test, the participant is asked to stand while the tester palpates the sacrum with one thumb kept parallel to the first thumb and then palpates the PSIS with the other thumb. Subsequently, the patient is instructed to stand on one leg while flexing the hip of the side being palpated into ≥90° of the hip joint flexion. Then, the test is repeated on the other side, and the results are compared bilaterally (Dutton, 2008; Konin et al., 2002). The tester then compares each side for quality and amplitude of movement (Lee, 2004). In a normally functioning pelvis, the PSIS of the side being palpated should move inferiorly or drop (Magee, 2008). A positive test is considered when the PSIS on the same side of the knee flexion is not active or moves minimally in the superior direction (Dutton, 2008). A positive test is signified by sacroiliac joint hypomobility (Magee, 2008). According to Dreyfuss (1996), the specificity and sensitivity of the Gillet test were 60% and 43%, respectively. The Gillet test had been executed before and after the treatment. The same examiner conducted the measurements on all participants.

Figure III. (a) Straight leg-raise (SLR) test, (b) flexion abduction external rotation (FABER, Patric) test, and (c) Gillet test.

Figure IV. (a) Strain–counter strain method and (b) the therapeutic manual traction

Numerical rating scale <NRS-11>: The NRS-11 is an 11-point scale for patients' self-reporting pain. It can be used for adults and children aged ≥10 years. In this study, the NRS was performed before and after the treatment. The participants verbally reported their level of pain on a scale of 0–10 (Table II). A verbal report of 0 indicated "no pain" and 10 indicated "severe pain." According to Ferraz et al. (1990), this scale demonstrated high reliability in the analysis of literate and illiterate patients. Each participant was asked to verbally convey the level of pain immediately before the intervention and then again after the intervention.

Table II. Numeric Rating Scale (NRS-11)

Rating	Pain Level
0	No pain
1–3	Mild pain (nagging, annoying, and interfering slightly with ADLs)
4–6	Moderate pain (interferes significantly with ADLs)
7–10	Severe pain (disabling; unable to perform ADLs)

ADL, activities of daily living.

Treatment

Strain–counter strain method: According to Wong (2012), the strain–counter strain intervention elicits an immediate and quantifiable reduction in the tenderness at digitally tender points. Increases in the pressure pain threshold at digitally tender points following the strain–counterstain intervention were not maintained between 24 and 96 h after the treatment. It is common to forcibly extend the contracted muscle; however, this technique uses the contrary method of creating a state or attitude that increasingly contracts the already contracted muscles. When the contracted muscles are stretched, the participant feels pain and discomfort. However, at the moment of contraction, they do not feel any pain or discomfort. The state in which the problem muscles are most contracted is created as follows: a state was created where the origin and insertion of the muscle were brought close to each other, allowed to rest for 90 s, and then gently returned to its original position. Then, the muscle contracture was released. Briefly, this method was performed to release muscle contracture by stimulating the muscle spindle, neurotransmission mechanism responsive to the muscle length, and shrinking the muscles until they no longer shrunk. By feeding back the stimulus, this muscle could not contract anymore; therefore, the central nervous system sends signals to relax the muscle (Figure IVa). The same examiner performed all the treatments for all the participants. The examiner is the co-author of this study and a certified physical therapist for 21years. He also has performed the strain–counter strain treatment for 21years.

Therapeutic manual traction: According to Medeiros and Rocklin (2016), the therapeutic manual traction technique provides immediate pain relief and improves general mobility in the treatment of LBP caused by hip joint pathology. The hip joint contains the acetabular cup and a bone-like ball called the femoral head. Generally, in restricted hip joint cases, the position of engagement between the acetabulum and the femoral head is slightly misaligned. This misalignment of the femoral head and shallow engagement limits the hip joint ROM. Specifically, it is often displaced forward. This happens because of the unbalanced use of deep layer muscles around the hip joint. However, the muscles related to the hip joint vary. When the hip joint is in the correct position, normal working and mechanical relations are maintained; thus, hip joint restriction barely occurs. However, keeping the normal position of these structures is often difficult, especially with the incorrect usage of deeper hip joint muscles. If a normal position is not maintained, the hip joints cannot move, thereby causing ROM restrictions. Moreover, in osteoarthritis, there is damage to the acetabulum, femoral head, or labrum, which causes degenerative hypertrophy. Orthopedic surgeons with expertise in sports injuries, osteopathic clinics, or athletic trainers can recommend stretching and training methods to such cases. In addition, people with national qualifications, such as Judo therapists, massage therapists, physical therapists, and athletic trainers, may perform hip joint mobilization exercises. In this experiment, after relaxing the contracture of the piriformis muscle using the strain–counter strain techniques, the examiner employed the therapeutic manual traction technique to move the displaced femoral head forward through the contracture of the piriformis muscle to the center of the hip joint acetabulum. Burns et al. (2011) also suggested that an impairment-based approach, such as the therapeutic manual traction, which is directed at the hip joints, may lead to improvements in pain, function, and disability in patients with chronic LBP (Figure IVb). The same examiner provided all the treatments to all participants.

Statistical analyses

The correlation between pre- and post-therapeutic outcomes was evaluated using the NRS-11 pain score and calculated using the Wilcoxon signed-ranked test. Comparison of the SLR test score with goniometry, piriformis muscle stiffness (Emean and Emax) with SWE, and the FABER test score between the pre- and post-therapeutic outcomes were analyzed using the paired t-test. Moreover, piriformis muscle stiffness (Emean and Emax) with SWE between the post-therapeutic outcomes and control group outcomes was examined using an independent t-test. Spearman's rho method was also used for assessing correlations among each score of the Emean, Emax, NRS, SLR, and FABER tests, except for the score of the control group. All analyses were performed using IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, NY, USA), and the level

of significance was set to 1%. In the medical field, the significance level is customarily set to 5%, but owing to the limited sample size of the present study, the significance level was set to 1%, and a more cautious attitude was taken.

Results

The SWE results among the scores of the participants before and after the treatment and that of the control group were analyzed (Table III).

Table III. Young's modulus numerical values (kPa) before and after the treatment intervention (minimum and maximum values)

Participants (n = 28)	Emean ± SD	Emax ± SD
Before	38.8 ± 15.6 (11.4–99)	50.2 ± 17.1 (17.9–110.3)
After	23.1 ± 8.0 (9.0–43.9)	32.6 ± 10.1 (12.3–60.3)
Control group (n = 30)	26.6 ± 3.2 (10.0–32.1)	31.2 ± 1.7 (13.6–58.8)

Significant of differences comparing the # before with the # after the treatment and # before the treatment with # the score of the control group. The difference between # after the treatment and # score of the control group was not significant ($P < 0.01$).

Figures V, VI, and VII illustrate the differences between the mean pre- and post-therapeutic outcomes of Emean, Emax, and NRS, respectively. Of the 28 participants, 16 showed no post-therapeutic LBP. All patients showed decreased NRS scores after the treatment. Figures VIII and IX show the differences between the mean pre- and post-therapeutic outcomes of the SLR and FABER tests, respectively.

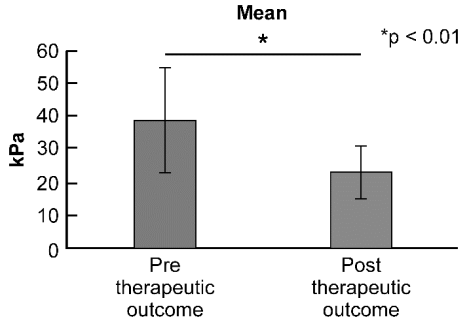

Figure V. Emean scores of shear-wave elastography before and after treatment.

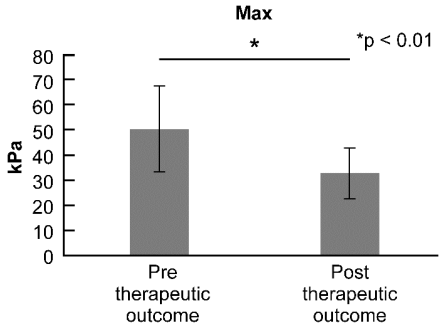

Figure VI. Emax scores of shear-wave elastography before and after treatment.

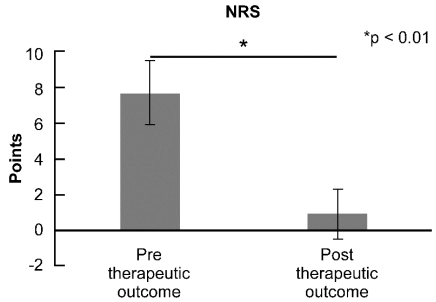

Figure VII. Numerical rating scale scores before and after treatment.

Significant differences between the pre- and post-therapeutic outcomes were obtained by comparing the pre- and post-therapeutic scores of Emean, Emax, NRS, SLR, and FABER tests ($P < 0.01$ for all). Significant differences were also found between the pre-therapeutic outcomes of the patient group and those of the control group by comparing the pre-scores of the patient group and the scores of the control group in Emean and Emax (Figures X and XI, respectively). Furthermore, significant differences between the pre-therapeutic outcomes of the patient group and the outcomes of the control group were obtained by comparing the pre-scores of the patient group and the scores of the control group in the SLR and FABER tests ($P < 0.01$) for all comparisons with pre-therapeutic outcomes of the patient group and control group's outcomes (Table IV). Moreover, Figures XII and XIII illustrate that the difference between the scores of the patient group after the treatment and the scores of the control group (Emean, Emax, SLR test, and FABER test) was not significant. The difference between the scores of the patient group after the treatment and the scores of the control group (by SLR test and FABER test) was also not significant (Table IV). Table I shows the pre-therapeutic outcomes of the Gillet test. Of the 28 participants, 23 showed positive outcomes before the treatment. All patients showed negative outcomes after the treatment (Table I). Table VI shows the significance of differences based on the comparison of the scores before and after the treatment and the scores before the treatment with the scores of the control group. The difference between the scores after the treatment and the scores of the control group was not significant, except for the scores of NRS (*$P < 0.01$; Table VI).

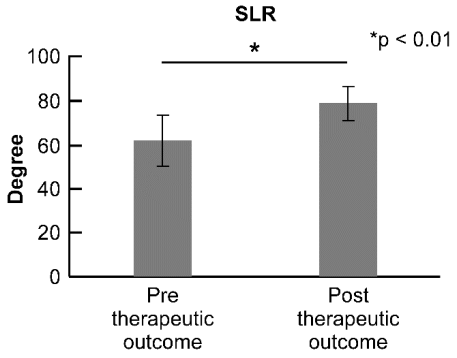

Figure VIII. Straight leg-raise scores before and after treatment.

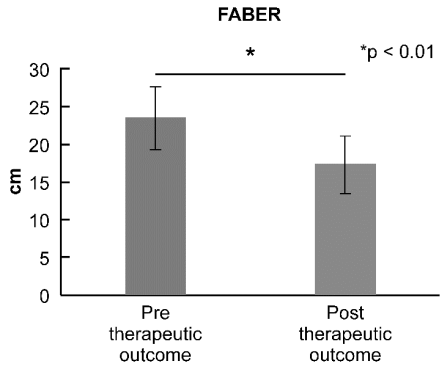

Figure IX. Flexion abduction external rotation scores before and after treatment.

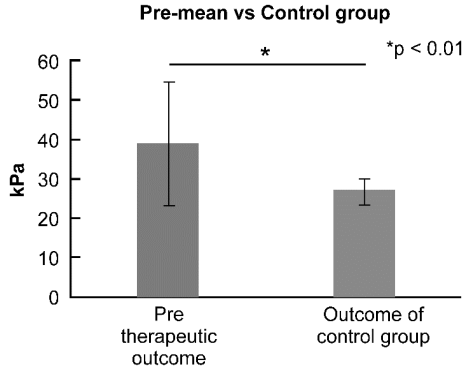

Figure X. Emean scores of shear-wave elastography before treatment and that of the control group.

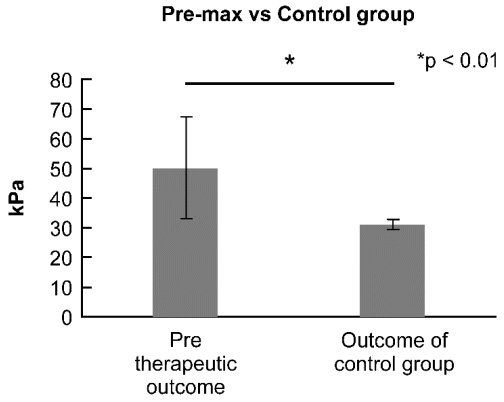

Figure XI. Emax scores of shear-wave elastography before treatment and that of the control group.

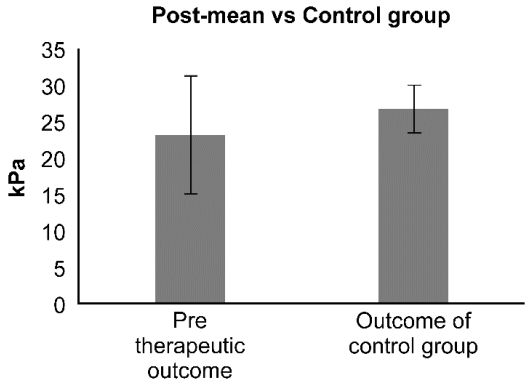

Figure XII. Emean scores of shear-wave elastography after treatment and that of the control group.

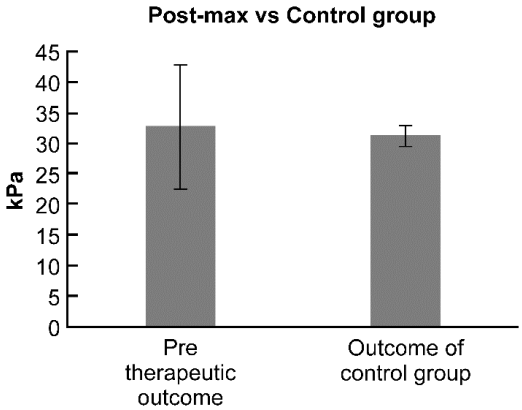

Figure XIII. Emax scores of shear-wave elastography after treatment and that of the control group.

Table IV. SLR(°), FABER (cm), and NRS (pts) mean scores before and after the treatment intervention (minimum and maximum values)

Participants (n = 28)	**SLR ± SD (°)**	**FABER ± SD (cm)**	**NRS ± SD (pts)**
Before	62.1 ± 11.8 (35–85)	23.4 ± 4.2 (15–32)	7.6 ± 1.8 (4–10)
After	78.9 ± 7.9 (60–90)	17.2 ± 3.8 (10–27)	0.8 ± 1.4 (0–6)
Control group (n =30)	71.5 ± 2.2 (67–87)	22.3 ± 3.2 (10–32)	N/A

The correlation among the piriform muscle modulus, NRS score, SLR test, and FABER test is depicted in Table V. A correlation was noted among each score of Emean, Emax, NRS, SLR, and FABER tests ($P < 0.01$). Especially, a significant correlation was found between the NRS score and the SLR test outcome ($r = 0.576$, $P < 0.01$; Figure XIV). No significant correlation was noted between the outcomes of the SLR test and piriform muscle modulus.

Table V. Correlation coefficient between each tested item

	NRS	FABER	SLR	Max	Mean
NRS	1	*0.512	*−0.576	*0.507	*0.474
FABER	N/A	1	*−0.450	*0.454	*0.416
SLR	N/A	N/A	1	−0.023	−0.004
Max	N/A	N/A	N/A	1	*0.952
Mean	N/A	N/A	N/A	N/A	1

*P < 0.01

Table VI. Differences among NRS, FABER, SLR, Max, and Mean scores before and after the treatment intervention

	Before: NRS	Before: FABER	Before: SLR	Before: Max	Before: Mean
After: NRS	*	*	*	*	*
After: FABER	*	*	*	*	*
After: SLR	*	*	*	*	*
After: Max	*	*	*	*	*
After: Mean	*	*	*	*	*

Significant of differences on comparing the # before with the # after treatment scores and # before the treatment with # scores of the control group. The difference between # after the treatment and # score of the control group was not significant, except for # of NRS (*P < 0.01).

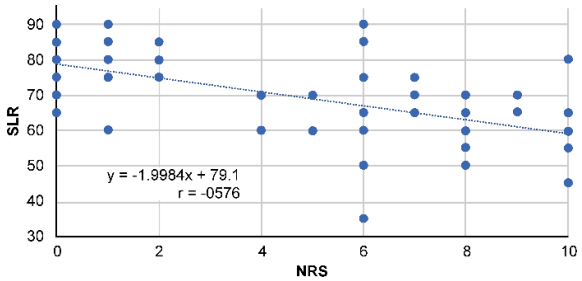

Figure XIV. Correlation coefficient between the NRS and SLR test score
NRS, numerical rating scale; SLR, straight-leg raise

Research on the influence of piriformis muscle treatment on unexplained LBP for athletes has been predicted to be primarily effective in alleviating pain only from a subjective evaluation; however, only a few studies on LBP alleviation were based on an objective assessment and treatment of the piriformis muscles, which is closely related to unexplained LBP. According to Mortazavi et al. (2015), most patients improve with nonoperative treatment because most athletes with LBP have a benign source of pain. Numerous modalities for nonoperative treatment include the use of NSAIDs, heat, ultrasound laser therapy, steroids, manipulation, traction, injections, acupuncture, massage, and exercise in the literature.

Moreover, the diagnosis of PS has rarely been studied. According to Chang et al. (2006), magnetic nerve stimulation provides an objective method for evaluating sciatic nerve function in patients with PS (Medeiros & Rocklin, 2016). Moreover, according to Filler (2005), a high-quality evaluation of the diagnostic effect of MR neurography revealed piriformis asymmetry and hyperintensity of the sciatic nerve in the sciatic notch. The results demonstrated 93% and 64% specificity in distinguishing between patients with PS and asymptomatic patients, respectively.

Huang et al. (2018) reported that the thickness, area, and volume of the pathological side of the piriformis muscles in the PS group were all significantly higher than on the normal side in an MRI-based study. Indeed, MRI can be a functional method for correct PS diagnosis by evaluating lumbar hernia, lumbar stenosis, and sacroiliac syndromes that cause sciatic nerve symptoms and other differential diagnoses such as pathology located around the piriformis muscle, although MRI is an expensive method (Krepkin et al., 2017).

Discussion

Although this is one of the first studies to employ ultrasound SWE for the diagnosis of PS with unexplained LBP, the results are promising. A significant relationship between LBP and piriformis muscle stiffness was noted in athletes. The significant 379 difference in stiffness of the piriformis muscles in comparison with the pre- and post-therapeutic outcomes is presented from an objective evaluation (P < 0.01). Consequently, 26 of the 28 study participants showed a negative unilateral SLR test result of >70° after the treatment. In

addition, the length of the FABER test after the treatment was reduced in all participants. Moreover, all post-therapeutic NRS pain scores, which were subjective evaluations, decreased when compared with all pre-therapeutic NRS pain scores. In other words, this study demonstrated a significant increase in the piriformis muscle stiffness estimated through SWE in patients with unexplained LBP. The treatment of unexplained LBP by releasing the piriformis muscle contracture appears to be useful for modifying the malfunction caused by sacroiliac joint misalignment and for diminishing LBP in the superior gluteal nerve entrapment, which is often accompanied by PS. Nakajyuku et al. (2004) classified PS into three major types based on the LBP onset. The first is a PS derived from the sacroiliac joint. Approximately 80% of tenderness in the 18-sacroiliac joint has been confirmed. The front of the sacroiliac joint is dominated by the L4, L5, and S1 neural fore branch, and the rear is dominated by the lateral branches of the L5, S1, and S2 nerve trunk. Thus, any noxious stimuli generated in the sacroiliac joint could cause a reflective spasm in the piriformis, gemellus muscles, and rectus femoris muscle dominated by L5, S1, and S2. Simultaneously, the enhancement of reflective spasm of the multifidus muscles supporting the sacroiliac joint controlled by the same nerve promoted the reaction of the sacroiliac joint itself and is therefore believed to further stimulate the reflection cycle of the piriformis muscles. Most PS can be classified into this type. The second type of PS is derived from the facet joint. The facet joint is dominated by the inner branch of the spinal nerve trunk. The first branch of the medial branch dominates the lower portion of the adjacent facet joint capsule. The second branch dominates the multifidus muscle, and the third branch dominates the superior facet joint capsule. Any noxious stimulus generated in the facet joint of L5 S1 could cause a reflective spasm in the L5 inner branch to the six deep external rotators of the hip.

In addition, it seemed that a reflective spasm occurred in the multifidus muscle dominated by the same nerve. Thus, this type is the most common one in cases where the lumbar spine is merged, and there is no pressure pain in the sacroiliac joint. The third is PS caused by the piriformis muscle alone. In this case, pain is assumed to disappear only through block injection or relaxation of the piriformis muscle. In this study, the Gillet test was performed before and after the treatment. A positive test was indicative of sacroiliac joint hypomobility. Of the 28 participants, 23 showed positive test results before the treatment. However, all patients showed negative test results after the treatment. Thus, sacroiliac joint hypomobility could be deeply related to LBP onset due to PS. In other words, in this study, most onsets of unexplained LBP in athletes with PS may have been derived from the sacroiliac joint. Of course, further research is warranted to confirm our hypothesis.

According to Nakajyuku et al. (2004), the variety of pre-referral treatments, including the manipulation in most cases, and the low incidence of PS present obstruction in performing sufficient numbers of managed clinical therapeutic experiments of numerous treatments and modalities. The difference between primary and secondary PS has not been previously reported, although it has been suggested. Owing to the differences in the etiology and treatment, primary and secondary PS can be distinguished based on the history and physical examination results. The effects of the mass should be reduced, and sacroiliac joint hypomobility should be treated primarily along with the treatment of the piriformis. Therefore, by focusing on the piriformis muscle contracture of athletes with unexplained LBP, this study revealed that LBP is successfully reduced by treating piriformis muscle contracture with the strain–counter strain method and positioning the femoral head at the centripetal point with the therapeutic manual traction method. Moreover, ultrasound SWE provides a painless, noninvasive, and objective method for the evaluation of LBP with PS. Furthermore, this study suggests that specific muscle dysfunction may produce unexplained LBP and presents new findings to elucidate the mechanism of PS in unexplained LBP cases. Various indices can evaluate muscle activity. The results of this study elucidate the causes of PS in athletes with unexplained LBP; however, further research related to unexplained LBP or PS is still warranted to validate the present findings.

This study has several limitations. First, the methodologic quality was limited by the quantity and quality of studies on PS. Many studies, including the present study, regarding PS include significant methodological flaws, such as the small sample size, retrospective data evaluation, and the lack of a control group for comparison. Future examinations with a larger data set should be considered to confirm the present findings and to support the proposed clinical benefit to patients, orthopedic surgeons, and all healthcare providers in general. Second, the follow-up period was extremely short. In this study, post-therapeutic data collections were executed immediately after the treatment, which takes approximately 40 min, that is, the examiner did not collect data at any other time point. Third, 20 of 28 athletes with LBP belonged to some types of ball game sports. In the future, participants should be selected from diverse sports backgrounds.

Conclusions

In summary, ultrasound SWE can be used as a criterion standard for PS evaluation. It supports that PS is a contributing factor to the LBP in athletes. Moreover, the strain–counter strain method and therapeutic manual traction method can help evaluate unexplained LBP in athletes with PS.

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