

Investigation of the effect of passive therapy and active exercise therapy in athletes suspected of low back pain with Piriformis muscle contracture

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Abstract:

Problem statement: Recently, a relationship between piriformis syndrome and nonspecific low back pain has been proposed; however, this has only been investigated in terms of the patient's subjective pain and anatomical and structural perspectives. Furthermore, it has been suggested that evaluating changes in the piriformis muscle elastic modulus is a painless and noninvasive method for the measurement of changes in nonspecific low back pain after passive therapy; however, this was only evaluated cross-sectionally and did not clarify the long-term changes caused by continuous passive therapy intervention. **Purpose:** This study aimed to clarify the effects of continuous passive therapy and active exercise therapy in athletes with nonspecific low back pain accompanied by piriformis muscle contracture. **Approach:** We included 18 athletes with nonspecific low back pain accompanied by piriformis muscle contracture. Nine participants were placed in a passive therapy group that received only passive therapy once a week, while the other nine were placed in a passive therapy and active exercise therapy group that received daily active exercise therapy and passive therapy. Measurements included the mean (Emean) and maximum elastic modulus (Emax) of the piriformis muscle; the straight-leg test; the flexion, abduction, and external rotation test; and the numerical rating scale. We compared the differences in these values pre- and post-intervention, as well as the values at each week. **Results:** There was a significant difference between the pre- and post-intervention values in both the groups for each week. In the comparison according to each week, the passive therapy group did not exhibit a significant difference in the measurement items. However, the passive therapy and active exercise therapy group exhibited significant differences in all measurements except the straight-leg test after the third week of the experiment. In this group, a significant difference in the straight-leg test results was only observed after the fourth week. Notably, in the group that received passive therapy alone, the post-intervention values returned to those observed before intervention within a week, in both the functional and subjective assessments. **Conclusions:** This study revealed that performing daily active exercise therapy in addition to passive therapy for approximately 3 weeks alleviated nonspecific low back pain associated with piriformis contractures.

Key Words: nonspecific low back pain, piriformis muscle contracture, elastography, athletes

Introduction

Several studies have indicated that more than 80% of non-athlete patients with low back pain have nonspecific low back pain with unknown causes (Deyo et al., 1992; Deyo et al., 2001; Chou et al., 2009). This is collectively defined as “low back pain not attributable to a recognizable, specific pathology and without any neurological symptoms in the lower limbs” (Chou et al., 2009).

The rate of occurrence of back pain in athletes differs; however, it is estimated to be approximately 20–70% (Granhed & Morelli, 1988; Marks et al., 1988; McCarroll et al., 1986; McHardy et al., 2007; Semon & Spengler, 1981; Sward et al., 1991; Tall & DeVault, 1993). Furthermore, the prevalence of disc degeneration is higher in athletes than in non-athletes; however, it remains unclear whether this correlates with a higher rate of back pain (Bono, 2004).

The incidence of low back pain (LBP) in young athletes has been reported in a wide range of studies, ranging from 1% to 30% (Mortazavi et al., 2015). Notably, Hangai et al. (2010) reported that the occurrence rate of LBP was higher in athletes than in non-athletes in the same age groups, and that athletes have a higher risk of LBP than non-athletes, according to the results of the Comprehensive Survey of Living Conditions (Hangai et al., 2010). Therefore, competitive sports activities may be a risk factor for LBP, regardless of the patients' age.

Many medical professionals have studied the relationship between exercise movement and injury incidents, therapeutic methods for the injury, and the establishment of rehabilitation training programs for

athletes. Medical professionals and researchers have increasing opportunities to perform therapies and rehabilitation for athletes with LBP, and some have proposed a hypothesis suggesting a relationship between piriformis syndrome and nonspecific LBP (Chang et al., 2006; Filler, 2005; Nakajyuku et al., 2007). In fact, Nakajyuku et al. (2007) reported that piriformis muscle contracture causes sacroiliac joint dysfunction, leading to LBP. However, the relationship between piriformis muscle contracture and nonspecific LBP has only been investigated from the patients' subjective pain and anatomical and structural perspectives (Chang et al., 2006).

This is possibly because the noninvasive evaluation of the elastic modulus in the muscles of living organisms is challenging. Recently, the measurement of the deep muscle elastic modulus, which has not been possible in previous studies, has become possible using ultrasonic shear wave elastography (Koo et al., 2013). Elastic modulus is an index of the resistance of an object to deformation (Eby et al., 2013). Several previous studies have reported a high correlation between the elastic modulus and the degree of muscle stretching; in other words, the muscle is more stretched when the elastic modulus is high (Eby et al., 2013; Koo et al., 2013; Maïsetti et al., 2012).

Previously, using ultrasonic diagnostic equipment, Hashimoto et al. (2019) evaluated the elastic modulus of the piriformis muscle in athletes with nonspecific LBP accompanied by piriformis muscle contractures. They reported that passive therapy (PT) would release nerve entrapment from piriformis muscle contractures and contribute to reducing nonspecific LBP (2019).

Furthermore, Hashimoto et al. (2019) demonstrated that evaluating the piriformis muscle elastic modulus is a painless and noninvasive method for measuring nonspecific LBP. However, the changes in the piriformis muscle elastic modulus or levels of pain from PT intervention were only evaluated cross-sectionally in this study, and it did not clarify what changes might occur if the PT intervention was performed continuously.

Therefore, this study aimed to investigate the changes in nonspecific LBP in athletes with accompanying piriformis muscle contracture by continuously providing mid-to-long-term PT and using the measurement method newly established by Hashimoto et al. (2019), which uses ultrasonic shear wave elastography.

In addition, the effects of combination therapy with PT and active exercise therapy (AET), which has been suggested to relax the piriformis muscle and improve the movable range of the hip joint (Nakajyuku et al., 2007), were investigated to propose a more effective treatment method than conventional therapies for nonspecific LBP with piriformis muscle contracture. We hypothesized that performing daily AET and PT would more effectively improve the condition of LBP than performing only PT once a week.

Material & methods

Participants

The participants of this study, which was conducted throughout 2022 and 2023, were university students who belonged to athletic clubs in the Kansai region. We specifically selected patients who were diagnosed based on various findings, including imaging findings from MRI or CT and physiotherapy tests such as the straight-leg raise (SLR) test performed by an orthopedist and a co-author of this paper. Furthermore, we selected patients with nonspecific LBP, which is LBP with no apparent cause or crural neurological symptoms, and all participants had piriformis contractures.

Moreover, participants aged 20–22 years who had an athletic career of approximately 10 years were selected. According to Lieber's previous study (2009), in which the elastic modulus of non-athletes without LBP was calculated using ultrasonic shear wave elastography and cross-sectional elements for stiffness, the elastic modulus of muscles was reported to be approximately 10–20 kPa. Another previous study by Hashimoto et al. (2019) reported the mean elastic modulus of the piriformis muscle in participants without LBP as 20.1 ± 3.1 kPa, while that of participants with nonspecific LBP accompanied by piriformis muscle contracture was 39.12 ± 18.7 kPa. Therefore, in this study, we set the median value of these (≥ 30 kPa) as the criterion value of piriformis muscle contracture.

The participants were divided into two groups as follows: nine were placed in the PT group, which received PT only, once a week, for a total of six times, while the other nine were placed in the PT + AET group, which received both PT and AET daily (Table I). When dividing the participants, care was taken so that neither group was imbalanced in terms of athletic abilities or physical fitness levels. However, the timing was not specified for the AET treatment, which was instructed to be performed once daily.

The participants practiced technical/weight training as usual during the study period. They practiced more than five times a week for 3 hours per day; however, the duration differed according to the type of sport. The effect size of the two scales in the first numerical value was indicated by a Cohen's *d* value of 0.83.

We informed the participants of the purpose and methods of our research and received their consent to participate in the study, which was conducted with the approval of the Research Ethics Committee of Osaka Kyoiku University (approval number: 23001).

Table I. The subjects' physical characteristics, competition, competition history, LBP history, and LBP location

PT group							
Patient No.	Age	Height (cm)	Weight (kg)	Event	Athletic career (yr)	LBP career (yr)	LBP region (L/R)
1	22	178	67	Hurdle race	10	5	R
2	22	176	77	Soccer/Football	10	10	L
3	22	186	89	Baseball	15	3	L
4	21	165	55	Wind Surfing	8	1	R
5	22	162	54	Gymnastics	10	0,3	L
6	21	176	67	Soccer/Football	10	7	L
7	20	180	67	Soccer/Football	12	5	L
8	21	167	65	Golf	10	1	R
9	21	172	71	Baseball	9	5	R
Avg.	21,3	173,6	68,0		10,4	4,1	
PT + AET group							
Patient No.	Age	Height (cm)	Weight (kg)	Event	Athletic career (yr)	LBP career (yr)	LBP region (L/R)
10	22	173	62	800m track	12	3	R
11	22	176	66	400m track	10	2	L
12	22	171	67,5	200m track	10	3	R
13	21	179	67	Soccer/Football	12	3	R
14	21	173	66	Baseball	10	4	R
15	21	178	67	Soccer/Football	12	3	R
16	21	174	66	Baseball	10	4	R
17	20	179	67	110m hurdle	10	5	R
18	22	169	68	Baseball	8	6	L
Avg.	21,3	174,7	66,3		10,4	3,7	

PT, passive therapy; AET, active exercise therapy; LBP, low back pain

Measurements and instruments

Using an ultrasonic diagnostic device (Aixplorer, SuperSonic Imagine, France), we measured the mean (E_{mean}) and maximum elastic modulus (E_{max}) of the midsection of the piriformis muscle. We also performed the SLR test; the Flexion, Abduction, and External Rotation (FABER) test; and the numerical rating scale (NRS-11). The experimental period was divided into five weeks, from week 0 to week 5, during which both groups received PT intervention once per week (six in total). The aforementioned items were measured before and after the intervention. Ultrasonography and the SLR and FABER tests were performed on the side affected with pain (on the right in 11 participants and on the left in 7). The flow of the measurements is depicted in Figure I.

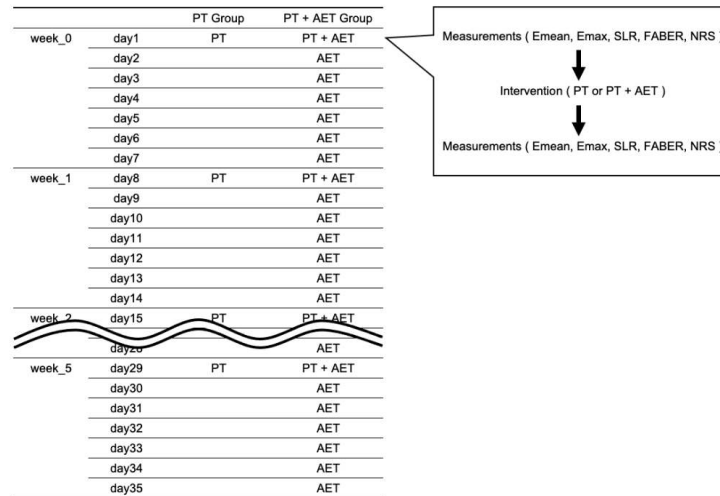


Figure I. Flow of the measurements. PT, passive therapy; AET, active exercise therapy; E_{mean}, mean elastic modulus; E_{max}, maximum elastic modulus; SLR, straight-leg raise; FABER, flexion, abduction, and external rotation; NRS, numerical rating scale

Measurement of the elastic modulus

The ultrasonic shear wave elastography function of the ultrasonic diagnostic device was used to perform the elastic modulus measurements (Figure II). First, participants were instructed to lie down with the affected side's piriformis muscle facing upward. The piriformis muscle was then relaxed by flexing the hip joint to a 40° angle (Figure III) and the knee joint to a 90° angle (Figure IV). Subsequently, using a linear probe (50 mm, 15–4 MHz), the elastic modulus of the midsection of the piriformis muscle (kPa) was measured on a

straight line from the midsection of the posterior superior iliac spine and coccyx to the midsection of the greater trochanter. Following the procedure previously described by Eby et al. (2019), the probe was set parallel to the muscle fibers' running direction to capture ultrasonic images (Figure V). For image analysis, a square region of interest (ROI) was set at the center of each measurement site (Figure VI). The elastic modulus was measured at five locations (indicated by circles with a diameter of 2 mm) in the ROI to obtain the mean (E_{mean}) and maximum elastic modulus (E_{max}) for quantitative analysis. Measurements were performed before and after the PT intervention.

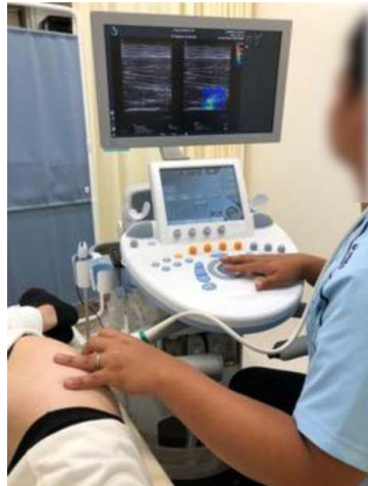


Figure II. The Aixplorer device used in this study



Figure III. 40° hip flexion



Figure IV. 90° knee flexion



Figure V. Measurement of the piriformis muscle's midsection elastic modulus

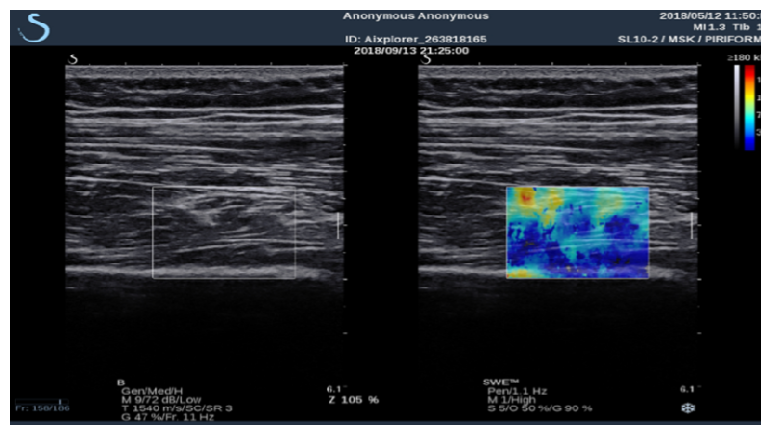


Figure VI. Ultrasonic shear wave elastography

The SLR test

The SLR test effectively detected problems in the lower back and was performed before and after the PT intervention. The participants were instructed to lie on their backs and stretch the knee joint; subsequently, the measurer slowly flexed the hip joint until the participant complained of pain in the lower back (Figure VII). A goniometer was placed with its fixed arm parallel to the table, while the movable arm was positioned alongside the lateral median line of the femur and shaft on the greater trochanter. We used the measurement values that matched twice a row in this test.



Figure VII. The SLR test

The FABER test

The FABER test is an induction test used to detect the pathology of the hip joint, lumbar spine, or sacroiliac joint (Nakajyuku et al., 2007). Participants were instructed to lie in the supine position and flex, abduct, and externally rotate the hip joint of the examined side, with the lateral malleolus placed on the contralateral patella to apply pressure externally on the medial part of the patella on the examined side (Figure VIII). After allowing the participants to relax, the distance between the examination-side tibial tubercle and the table was measured using a tape measure. We employed the FABER test in this study because it allows objective numerical values to be obtained using a tape measure, in addition to the participants' subjective evaluation in the flexion, adduction, and internal rotation (FADIR/FAIR) test. The FABER test was performed before and after PT intervention.



Figure VIII. The FABER test

The NRS-11

The NRS-11 is a subjective scale used to assess the pain levels of patients in clinical settings (Chang et al., 2006). The scale has 11 levels, from 0, representing "no pain," to 10, representing "extreme pain that makes you unable to move." The participants were orally requested to assess their level of pain prior to the intervention.

Interventions

PT

The strain-counterstrain (SCS)/origin-insertion (OI) technique

Muscle contraction was released by gently creating a state where the origins and insertions of the muscle came close to each other, maintaining the posture for 90 seconds, and slowly resuming the original

posture (Figure IX). An OI technique using the responses of Golgi tendon organs was also employed. Although muscle contraction caused a slipped epiphysis, tension was eliminated by the SCS/OI technique, leading to the resolution of epiphysis displacement.



Figure IX. The strain-counterstrain/origin-insertion method

Traction therapy (TT)

The hip joint contains an acetabular cup and a bone with a ball-like shape called the caput femoris (Nakajyuku et al., 2007). One of the well-known causes of hip joint problems is the displacement of the joint between the acetabular cap and caput femoris, which should be located at the centripetal position (Nakajyuku et al., 2007). Thus, misalignment and shallow occlusion of the caput femoris limit the range of hip joint motion, and extra consideration must be given to the fact that the caput femoris often moves forward. In contrast, normal function and functional relationships are maintained when the hip joint is in the correct position. In this study, the therapist employed TT to bring the misaligned caput femoris resulting from the piriformis muscle contraction back to the centripetal position (Figure X).



Figure X. The traction method

AET

In addition to the PT session, the PT + AET group participants performed the following five types of training exercises daily: active straight-leg raises (ASLR), hip joint abduction-adduction exercises, hip joint range-of-motion improvement exercises, hip rotation exercises, and hip dynamic stretches (Figures XI–XV).

ASLR

This exercise aimed to improve the strength and stability of the hip joint (iliopsoas muscle). First, the exercising leg was extended, while the non-exercising leg was held in both hands (Figure XI). Second, the the exercising leg was raised close to the hip joint, with a bending angle of 90°, and lowered toward the floor. Third, the lower limb was raised and lowered repeatedly, in such a way that the scapula would not float from the floor during the exercise (repetition: 10 times × 3 sets).

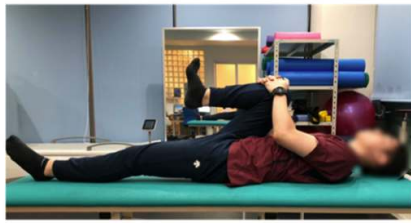


Figure XI. Active straight-leg raises
Hip joint abduction-adduction exercises

This exercise aimed to stretch the adductor muscles of the hip joint. The participants were required to lie on their backs while connecting the soles of their feet to spread their hip joints. Subsequently, they were requested to repeat hip joint adduction and abduction movements (repetition: 10 times $\times$ 3 sets) (Figure XII).



Figure XII. Hip joint abduction-adduction exercise
Hip joint range-of-motion improvement exercises

This exercise aimed to improve the range of motion of the hip joint. The participants were instructed to assume a posture on their hands and knees, spread their knees apart, pull their hips backward to engage the hip joints, and push them forward again while bending themselves backward (repetition: 10 times $\times$ 3 sets) (Figure XIII).



Figure XIII. Hip joint range-of-motion improvement exercises
Hip rotation exercise

This exercise aimed to improve the range of motion of the hip joint and stretch the hip joint extensor (piriformis muscle) and outer thigh. The participants were instructed to lie on their backs, spread their legs shoulder-width apart, and bend their knees. From this posture, they were instructed to lower their knees one-at-a-time in such a manner that the inner side of each knee touched the floor (Figure XIV). This process was alternately repeated on each side (repetition: 10 times $\times$ 3 sets).



Figure XIV. Hip rotation exercise

Hip dynamic stretches (Figure XV)

This exercise aimed to stretch the hip muscles. The participants were instructed to lie on their backs, cross the ankle of the exercising leg over the knee of the non-exercising leg, hold the back of the thigh of the non-exercising leg with both hands, and rock their bodies back and forth (repetition: 10 times $\times$ 3 sets).

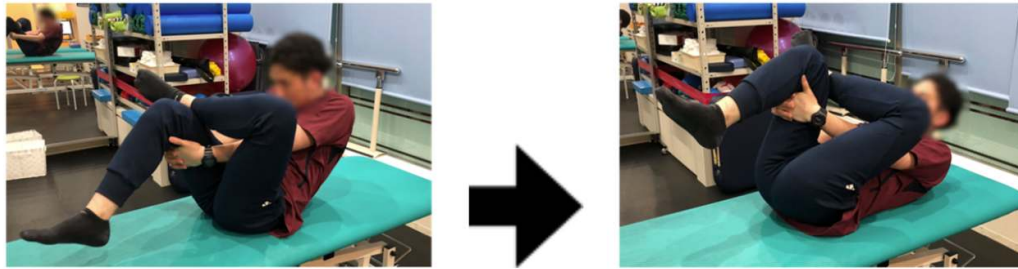


Figure XV. Hip dynamic stretch

Statistical analyses

Descriptive statistics were used to summarize the demographic and clinical characteristics of the study groups. Categorical variables were summarized using frequencies and proportions, while continuous variables were summarized as means with standard deviations or medians. Statistical analysis was performed for the comparison of pre- and post-intervention values, and the results of the Emean, Emax, SLR test, and FABER test were investigated using paired t-tests. In contrast, the NRS was analyzed using the Wilcoxon signed-rank test. The comparison of the values in each week was examined by split-plot analyses of variance using the pre-intervention measurement of each item in each week, with the groups as the factor without correspondence and the period (weeks 0–5) as the factor of repeated measurement with correspondence. The sphericity assumption was not established by Mendoza's Multisample Sphericity; therefore, the Greenhouse-Geisser correction was conducted. Furthermore, Shaffer's multiple comparison test was performed as a follow-up test. All statistical analyses were performed using SPSS Statistics Base 18 (IBM Japan, Ltd., Japan), with a significance level set at $p < .05$.

Results

The participants' physical properties

The participants' physical properties did not exhibit significant differences between the two groups. For example, participants in the PT group were aged 21.3 ± 0.7 years, 173.6 ± 8.3 cm tall, and weighed 68 ± 11.3 kg, while those in the PT + AET group were aged 21.3 ± 0.7 years, 174.7 ± 3.1 cm tall, and weighed 66.3 ± 1.7 kg. In addition, the histories of athletic activities and LBP did not exhibit significant differences between the groups, with values of 10.4 ± 2.6 years and 4.1 ± 3.8 years in the PT group and 10.4 ± 1.0 years and 3.7 ± 0.7 years in the PT + AET group, respectively.

Pre-and post-intervention results in each measurement item in each week

Table II shows the mean values and standard deviations of the pre-intervention measurement results for each item during weeks 1–5, while Table III shows that of the post-intervention measurements during weeks 1–5. Compared to the pre-intervention values, both the PT and PT + AET groups exhibited significant decreases in the post-intervention measurement values in each week (all $p < .05$). Furthermore, regarding the SLR test values, the post-intervention measurement values at each week in both groups were significantly higher ($p < .05$) than those measured before the intervention.

Results of the split-plot analysis of variance

Table IV presents the results of the split-plot analysis of variance for each measurement item.

Table II. Pre-intervention measurements for each measurement item in each week

PT group (n=9)																		
	Week_0			Week_1			Week_2			Week_3			Week_4			Week_5		
Emean (kPa)	48,3	±	2,0	50,0	±	1,1	50,8	±	0,6	51,2	±	1,1	50,4	±	1,9	48,0	±	3,3
Emax (kPa)	63,4	±	5,8	65,8	±	6,0	65,6	±	5,4	64,2	±	6,0	63,2	±	4,8	65,2	±	6,2
SLR (°)	58,7	±	13,5	60,0	±	13,8	59,3	±	12,9	60,2	±	13,8	64,2	±	14,7	64,0	±	15,4
FABER (cm)	22,3	±	3,0	23,3	±	3,9	21,6	±	2,2	21,3	±	3,9	21,9	±	2,9	20,6	±	3,8
NRS (pts)	7,4	±	1,6	6,9	±	1,6	7,2	±	2,7	6,4	±	1,6	6,7	±	1,7	6,8	±	1,7
PT + AET group (n=9)																		

	Week_0		Week_1		Week_2		Week_3		Week_4		Week_5	
Emean (kPa)	51,5	± 31,4	52,1	± 32,4	46,9	± 30,0	40,4	± 29,8	34,7	± 21,5	30,6	± 19,5
Emax (kPa)	69,3	± 36,3	69,1	± 36,9	62,8	± 34,9	57,2	± 34,9	52,8	± 28,4	47,4	± 24,1
SLR (°)	61,4	± 13,0	61,1	± 13,9	64,2	± 13,2	70,6	± 8,1	78,0	± 7,6	82,6	± 7,7
FABER (cm)	19,4	± 4,3	19,2	± 5,2	17,4	± 3,9	15,8	± 3,4	12,9	± 3,6	11,4	± 4,1
NRS (pts)	6,9	± 1,4	7,3	± 1,1	6,0	± 0,9	4,6	± 1,0	2,6	± 0,7	1,9	± 0,9

PT, passive therapy; AET, active exercise therapy; Emean, mean elastic modulus; Emax, maximum elastic modulus; SLR, straight-leg raise; FABER, flexion, abduction, and external rotation; NRS, numerical rating scale Table III. Post-intervention measurement values for each measurement item in each week

PT group (n=9)

	Week_0		Week_1		Week_2		Week_3		Week_4		Week_5	
Emean (kPa)	17,4	± 10,7	23,8	± 2,8	27,0	± 4,8	26,0	± 2,2	17,3	± 10,1	25,0	± 5,0
Emax (kPa)	28,1	± 15,7	33,6	± 4,3	35,4	± 6,5	34,6	± 3,7	27,2	± 15,3	34,8	± 6,8
SLR (°)	73,8	± 9,3	80,0	± 6,1	81,9	± 6,6	80,0	± 5,6	75,0	± 9,7	80,6	± 5,8
FABER (cm)	17,6	± 3,6	17,3	± 3,0	15,8	± 2,7	17,5	± 4,5	19,1	± 2,6	16,9	± 2,5
NRS (pts)	0,8	± 1,1	0,6	± 0,7	0,5	± 0,5	0,8	± 0,7	0,8	± 0,7	0,6	± 0,7

PT + AET group (n=9)

	Week_0		Week_1		Week_2		Week_3		Week_4		Week_5	
Emean (kPa)	16,7	± 8,6	22,7	± 2,8	25,7	± 4,5	24,8	± 2,6	15,9	± 9,3	22,7	± 5,1
Emax (kPa)	27,0	± 15,0	32,4	± 3,6	36,0	± 5,2	33,7	± 3,5	25,8	± 14,8	33,1	± 6,5
SLR (°)	74,4	± 8,8	81,9	± 4,3	83,8	± 7,4	82,5	± 4,3	83,1	± 5,6	86,3	± 4,1
FABER (cm)	15,8	± 3,2	15,3	± 1,9	12,9	± 2,6	15,3	± 4,5	11,4	± 2,0	11,0	± 1,7
NRS (pts)	0,5	± 0,7	0,4	± 0,5	0,4	± 0,5	0,3	± 0,4	0,1	± 0,3	0,1	± 0,3

PT, passive therapy; AET, active exercise therapy; Emean, mean elastic modulus; Emax, maximum elastic modulus; SLR, straight-leg raise; FABER, flexion, abduction, and external rotation; NRS, numerical rating scale Table IV. The results of the split-plot analysis of variance

Variables	Factor	<i>df</i>	<i>F</i>	<i>Sig.</i>	η^2
Emean	Group	1, 16	0,49	.493	.028
	Week	1.70, 27.22	12,60	.000 **	.047
	Group × week	1.70, 27.22	12,21	.000 **	.045
Emax	Group	1, 16	0,10	.754	.006
	Week	2.10, 33.63	13,93	.000 **	.032
	Group × week	2.10, 33.63	14,23	.000 **	.032
SLR	Group	1, 16	3,71	.072	.175
	Week	1.77, 28.33	44,05	.000 **	.195
	Group × week	1.77, 28.33	14,36	.000 **	.073
FABER	Group	1, 16	12,93	.002 **	.415
	Week	3.11, 49.73	36,39	.000 **	.220
	Group × week	3.11, 49.73	17,89	.000 **	.122
NRS	Group	1, 16	19,59	.000 *	.437
	Week	2.91, 46.51	32,07	.000 **	.423
	Group × week	2.91, 46.51	25,22	.000 **	.366

**, highly-significant ($p < .01$); *, significant ($p < .05$); Emean, mean elastic modulus; Emax, maximum elastic modulus; SLR, straight-leg raise; FABER, flexion, abduction, and external rotation; NRS, numerical rating scale

Emean and Emax (Figures XVI, XVII)

The results of the split-plot analysis of variance for Emean and Emax indicated that the main effect of the period for both items was significant ($F(1.70, 27.22) = 12.60, p < .001$; $F(2.10, 33.63) = 13.93, p < .001$), whereas the main effect of the group was not significant ($F(1, 16) = 0.49, p = .493$; $F(1, 16) = 0.10, p = .754$). In addition, the interaction effect of group $\times$ period was significant in each item ($F(1.70, 27.22) = 12.21, p < .001$; $F(2.10, 33.63) = 14.23, p < .001$). Furthermore, the simple main effect of the period was significant in the PT + AET group ($F(5, 35) = 16.35, p < .001$; $F(2.72, 19.04) = 18.70, p < .001$) but not in the PT group ($F(5, 35) = 1.56, p = 0.07$; $F(5, 35) = 1.43, p = .237$). To evaluate the effect of the period on Emean and Emax in the PT + AET group, Shaffer's multiple comparison test was conducted on the simple main effect of the period, and this indicated that the results in weeks 3–5 were significantly lower than those in weeks 0–2 ($p < .05$).

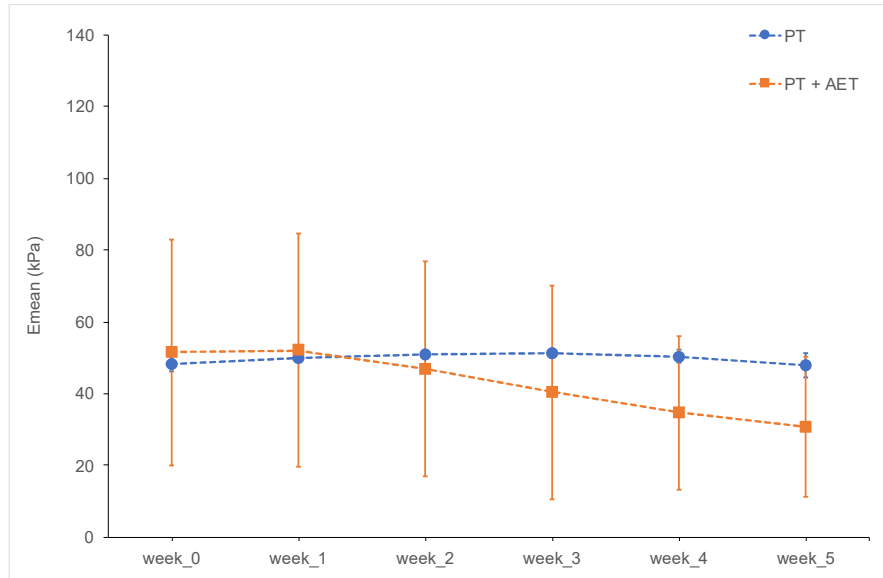


Figure XVI. Split-plot analysis of variance of Emean. PT, passive therapy; AET, active exercise therapy; Emean, mean elastic modulus

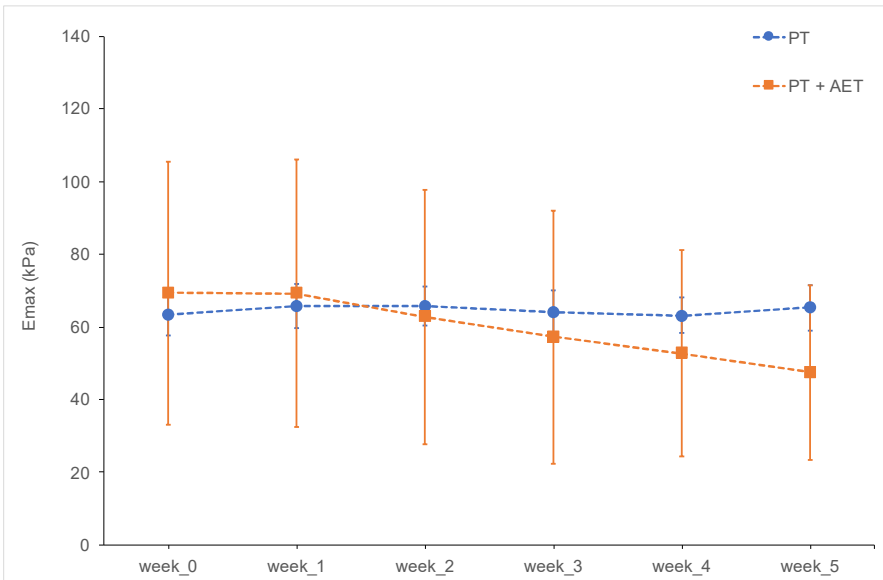


Figure XVII. Split-plot analysis of variance of Emax. PT, passive therapy; AET, active exercise therapy; Emax, maximum elastic modulus

The SLR test (Fig. XVIII)

Split-plot analysis of variance for the SLR test revealed that the main effect of time was significant ($F(1.77, 28.33) = 44.05, p < .001$); however, the main effect of the group was not significant ($F(1, 16) = 3.71, p = .072$). Additionally, the interaction between group and time was significant ($F(1.77, 28.33) = 14.36, p = .001$), but not in the PT group ($F(1.68, 11.77) = 3.41, p = .073$). Multiple comparison tests using the Shaffer method were conducted to examine the effects of time. As a result,

both weeks 2 and 3 were higher than week 1, while weeks 4 and 5 were both higher than weeks 0–3. ($p < .05$ and $p < .001$, respectively). In other words, the PT group showed no significant change in the SLR test values during the experiment; however, the PT + AET group showed an increase.

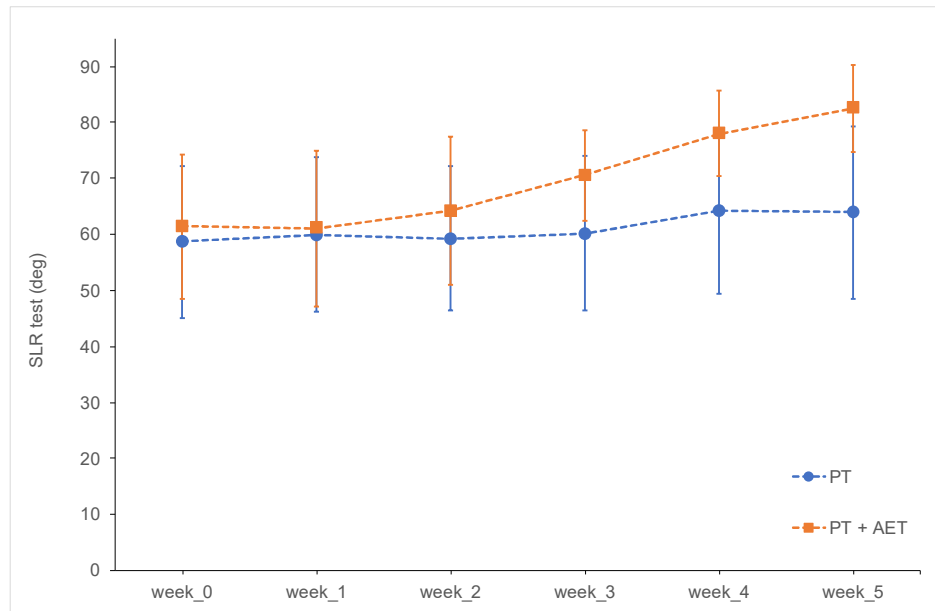


Figure XVIII. Split-plot analysis of variance of the SLR test results. PT, passive therapy; AET, active exercise therapy; SLR, straight-leg raise

The FABER test (Fig. XIX)

Split-plot analysis of variance for the FABER test results revealed that the main effects of group and time, and the interaction of group and time, were both significant ($F(1, 16) = 12.93$, $p = .002$; $F(3.11, 49.73) = 38.39$, $p < .001$; $F(3.11, 49.73) = 17.89$, $p < .001$). Additionally, significant differences were observed between the groups (all $p < .05$). It was significant in both groups ($F(5, 35) = 3.11$, $p = .020$; $F(2.8, 19.62) = 43.94$, $p < .000$). A multiple comparison test using the Shaffer method for the simple main effect showed no significant differences between weeks in the PT group, and week_2, showing a significant difference ($p < .01$). In summary, the FABER test results showed no significant change in the PT group; however, it improved in the PT + AET group. There was a tendency.

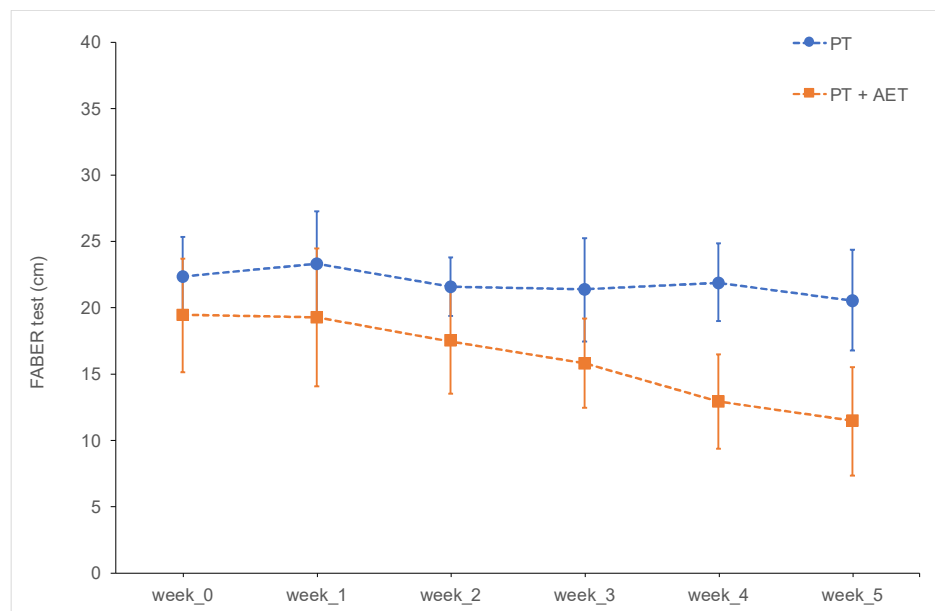


Figure XIX. Split-plot analysis of variance of the FABER test results. PT, passive therapy; AET, active exercise therapy; FABER, flexion, abduction, and external rotation

The NRS (Figure XX)

The split-plot analysis of variance for the NRS results revealed that the main effects of group and time and the interaction of group and time were both significant ($F(1, 16) = 19.59, p = .000$; $F(2.91, 46.51) = 32.07, p < .001$; $F(2.91, 46.51) = 25.22, p < .001$). Furthermore, the simple main effect of time was significant in the PT + AET group ($F(2.61, 18.25) = 61.76, p < .001$), but not in the PT group ($F(2.05, 14.37) = 0.30, p = .751$). As a result of the multiple comparison test using Shaffer's method, the values from weeks 3–5 were significantly lower than those from weeks 1 and 2 ($p < .01$). Although no significant changes were observed, the numerical values tended to be lower in the PT + AET group, and subjective pain was reduced by performing AET and PT.

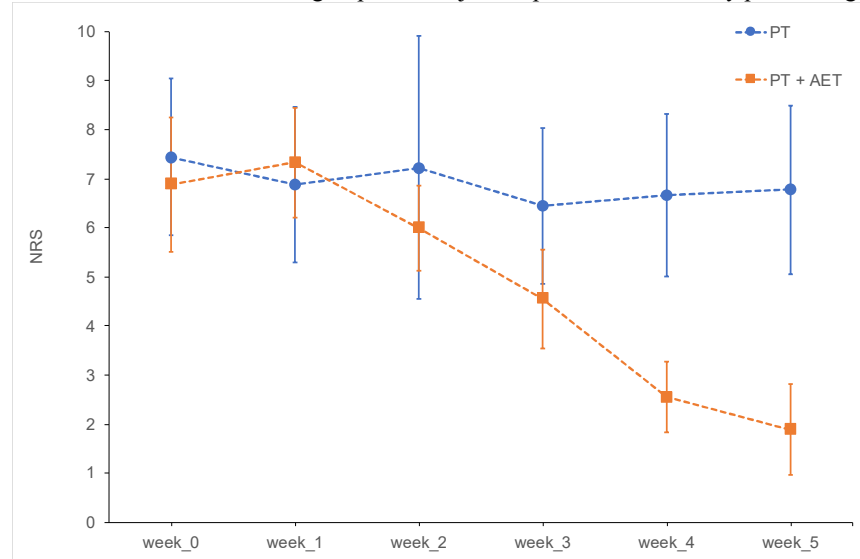


Figure XX. Split-plot analysis of variance for the NRS results. PT, passive therapy; AET, active exercise therapy; NRS, numerical rating scale

Discussion

Our results revealed that in both the functional and subjective assessments, the values returned to those of pre-intervention within a week in the group that received PT alone. In contrast, performing daily AET in addition to PT for approximately three weeks improved the condition.

Similar to a previous study by Hashimoto et al. (2019), the objective value of piriformis muscle elasticity estimated using ultrasound shear wave elastography in patients with nonspecific LBP was 30 kPa. We were able to confirm a higher value; therefore, it was considered that the piriformis muscle was overtensioned. Additionally, it is conceivable that the treatment (PT) performed in 2012, although temporary, may be performed as a response to the frequent entrapment neuropathy that accompanies piriformis contracture.

A novel finding of this study was that PT alone did not show significant improvement in either the objective or subjective evaluations during the 5-week experimental period, and measurements returned to the original values 1 week after the intervention. In contrast, a previous cross-sectional study by Hashimoto et al. (2019) considered PT to be effective for LBP accompanied by piriformis contracture among nonspecific LBP patients. Furthermore, in this study, the numerical values of each measurement item improved significantly from the third week of the intervention in the PT + AET group. In other words, continuous AET for more than 3 weeks, in addition to PT, promoted the spontaneous release of the piriformis contracture, and the femoral head, which deviated anteriorly due to the piriformis contracture, was continuously brought to the hip joint centripetal position. Therefore, restoration of the hip and sacroiliac joint function by repositioning the hip joint is thought to be useful in reducing persistent LBP. In this study, in participants whose muscles were stimulated by technical practice and training for more than 5 days a week, the PT group showed improvement in the flexibility of the piriformis muscle and hip joint. Therefore, we were able to bring the femoral head into the afferent position of the acetabulum. In the PT + AET group, daily induction may have contributed to decreased piriformis contracture, increased range of motion of the hip joint, and recovery and maintenance of sacroiliac joint function. However, future studies are required to determine whether age-related differences in the elastic modulus and function of the piriformis muscle exist. This study had some limitations, including the lack of a control group. Moreover, the sample size was small ($n=18$), which may have limited the generalizability of the findings. In addition, the participants were recruited from a specific region of Japan, which may limit the generalizability of the findings to a broader population. Furthermore, the study design was nonrandomized, and there was a potential for selection bias in participant recruitment. The intervention period in this study was also relatively short (5 weeks); therefore, longer intervention periods are required to assess the sustained effects of the treatment and potential long-term outcomes. Although PT was performed once a week in this study, it is important to examine the changes that would have occurred if PT were performed more frequently for a longer period. In

future research, which is expected to use more data, we will make proposals to patients and medical professionals based on the findings obtained from this research. In this way, we aim to achieve a shared clinical benefit.

Conclusions

PT using the SCS/OI and traction methods is suspected to be beneficial for pain associated with piriformis contracture in patients with nonspecific LBP. Therefore, we conclude that it is useful for athletes. In this study, we showed that daily AET and PT for approximately 3 weeks alleviated nonspecific LBP associated with piriformis contractures.

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