Comparison in the Effect of Linear Polarized Near-infrared Light Irradiation and Light Exercise on Shoulder Joint Flexibility

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Objective: This study aimed at comparing the effect of linear polarized near-infrared light irradiation (PL irradiation) and bicycle exercise with 50%HRreserve on the flexibility of the shoulder joint.

Design: Placebo-controlled trial.

Setting: Twenty-four healthy young adults (10 males: mean ± SD, age 20.9 ± 3.1 y, height 171.0 ± 3.9 cm, body mass 63.4 ± 3.5 kg and 14 females: age 21.2 ± 1.7 y, height 162.0 ± 7.8 cm, body mass 56.2 ± 7.2 kg).

Interventions: PL-irradiation (100%, 1800 mW), placebo-irradiation (10%,180 mW), and light exercise (50%HRreserve) for 10 minutes.

Outcome Measurements and Results: The shoulder joint angles were measured twice-before and after each intervention. We measured the angles when the right shoulder joint extended forward and flexed backward maximally without support, and analyzed these shoulder joints and range of motion. Trial-to-trial reliability (intraclass correlations) of each joint angle was very high, over 0.98. All joint angles showed significant changes, and values in post-PL-irradiation and postlight exercise were significantly greater than that in postplacebo-irradiation. Shoulder forward flexion and backward extension angles had significantly greater change rates in PL-irradiation and light exercise than placebo-irradiation, and their range of motion angle was in the order of PL-irradiation, light exercise, and placebo-irradiation.

Conclusions: It is suggested that PL-irradiation produces almost the same effect on shoulder joint range of motion as light exercise.

Key Words: linear polarized near-infrared light irradiation, flexibility, light exercise, warm-up, shoulder range of motion, thermal therapy

(*Clin J Sport Med* 2006;16:293–297)

Received for publication January 11, 2006; accepted June 7, 2006.

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In competitive sports, warm-up promotes circulatory functions such as heart rate and cardiac output, raises body and muscle temperatures, improves flexibility of soft tissue such as muscles and tendons, accelerates calcium function in the cell, improves neurotransmission function, and motivates for exercise.[1] Of various warm-up methods, many athletes usually use exercise with light loads such as jogging, treadmill running, and bicycle ergometer exercise.[2–4]

In a general warm-up, athletes perform light exercise for 10 to 15 minutes, which enhances the heart rate to about 120 to 130 beats/min and warms the whole body. This can also somewhat enhance the flexibility of each body part. In addition, competitive sports such as track and field and swimming have many races from the preliminary to the finals over several days. Whenever athletes are in races, repeating light exercise as a warm-up may accumulate physical and mental fatigue and this makes it difficult to exert peak performance. Therefore, as an alternative to light exercise, the necessity of so-called passive warm-up, giving heat stimulus from the outside to each muscle group, has been recognized and some methods have been proposed. As representative examples, there are hot pads, warm showers, and polarized near-infrared light irradiation (PL-irradiation) methods that were primarily developed to relieve pain in a rehabilitative therapy setting. Because they have a similar effect to warm-up, that is, enhancing blood flow circulation or muscle temperature, the possibility of their use has been examined.[5,6]

Passive warm-up is divided broadly into 2 types. First, hot pads and warm showers are superficial thermal therapies that give extensive heat stimulus to the skin surface.[6–8] Hot pads at 70°C to 80°C are put on the target parts for 15 to 30 minutes. The hot pad method requires special skill for temperature control and takes a long time (about 15 to 30 min) to increase muscular temperature. A shower warms the whole body by showering with hot water over the skin surface. In addition to similar problems related to hot pads, a shower facility is needed near the game place. There are many positive or negative reports on the effect of passive warm-up by these superficial thermal therapies.[8]

PL-irradiation, called deep thermal therapy, uses heat stimulus with a wavelength of PL (0.6 to 1.6 μm) to reach the deep parts of the body. Other deep thermal therapies, that is short-wave diathermy, improves hamstring flexibility by irradiating in conjunction with prolonged stretching,[9] or irradiation before exocentric exercise, may be more beneficial than active warm-up or no warm-up in attenuating swelling.[10] PL-irradiation can also give concentrated heat stimulus to the target parts efficiently for a short time and has a similar effect to exercise warm-up because the inner muscles are warmed.

In addition, the equipment is portable and the irradiation intensity and time can be changed easily. Therefore, this may be very useful. Demura et al[11] report that the angle of shoulder extension and flexion became greater by about 5 degrees, and the range of motion was greater by about 10 degrees with 10 minutes of PL-irradiation. PL-irradiation is deep thermal therapy on the body.[10] It relaxes contractural strength of ligaments, tendons, muscles, and the articular capsule by raising the temperature[7,11] and makes the shoulder range of motion larger. However, the effectiveness as a general warm-up method has not been examined. If flexibility of the shoulder joints by PL-irradiation can be improved similarly to light exercise within the same time, it may offer the possibility of a new warm-up method.

This study aimed to compare the effect of PL-irradiation and light exercise on flexibility of the shoulder joint.

METHODS

Subjects and Joint Angle Parameters

Subjects were 10 healthy, young males (mean ± SD; age 20.9 ± 3.1 y, height 171.0 ± 3.9 cm, body mass 63.4 ± 3.5 kg) and 14 females (mean ± SD; age 21.2 ± 1.7 y, height 162.0 ± 7.8 cm, body mass 56.2 ± 7.2 kg). Written informed consent was obtained from all subjects after a full explanation of the experimental purpose and protocol. An expert tester with enough experience (over 5 y) and practice measured the angles when subjects actively flexed the right arm forward or extended backward themselves without support, using an angle measurement method with high reliability and validity.[12] The measurement device used a regular goniometer (Yagami, S7110). Our group previously reported that intraclass coefficients of a range of motion of shoulder joint measured by this device were very high, over 0.98.[11] The angle of the shoulder joint was defined as the angle connecting the following 3 points at linearity: the greater tubercle, acromion, and caput ulnare. The range of motion of the shoulder joint was the total of shoulder forward flexion and backward extension angles (Fig. 1). The heart rate is commonly used as an index of exercise intensity, and we used it to confirm exercise intensity during light exercise.

Experimental Condition

A control condition was placebo irradiation. We tried to remove the psychologic effect on a tester and the subjects as much as possible in the experiment. The subjects were blinded on the irradiation intensity and all measurement results. Therefore, the subjects did not know their measurement values. A tester may have memorized the first measurement value of 2 trials because of 2 successive trials. However, it is judged that the tester could not memorize the former values accuracy when measuring after intervention because they were blinded to the tester.

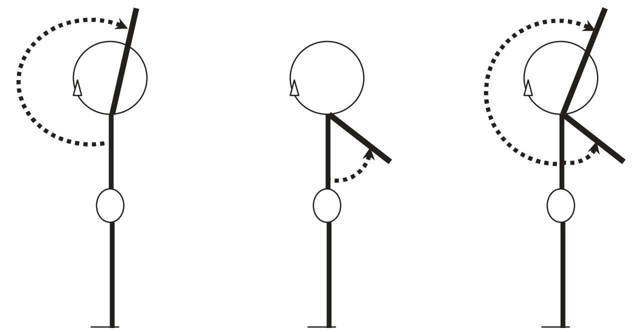

FIGURE 1. Measured parts.

The PL-irradiation used spot irradiation type linear polarized near-infrared light (Super Lizer HA-30, Tokyo Medical Laboratory, output power 1800 mW, focus radius 10 mm, wavelength band ~0.6 to 1.6 μm) that is often used in medical institutions or studies.[11] After the subjects laid in a prone position, a tester wholly irradiated their right trapezius and latissimus dorsi muscles using 1800 mW (100%) intensity with a cycle of 5 seconds with 1-second rest for 10 minutes. An electronic sound sounded during irradiation.

Light exercise was performed using a bicycle ergometer for 10 minutes because the heart rate can be measured steadily. Athletes generally use warm-up methods such as jogging because of simplicity and ease. An exercise warm-up activates blood flow state by increasing the heart rate and cardiac output, and can enhance muscle temperature of the whole body.[8] Also, exercise by a bicycle ergometer can enhance muscle temperature of the whole body similar to jogging. We calculated the maximal heart rate of each subject using the Karvonenn method and setup 50%HRreserve as the target heart rate. Each subject was told to reach the target heart rate within 2 to 3 minutes after starting exercise and maintain it until the end. Heart rate was measured with a HR monitor (SYSTEM-9, Fukuda Denshi: FCP-4720). A tester continued to watch the subjects during exercise and warned when the target-value decreased. The intensity of placebo-irradiation was very light (180 mW, 10%, none effect on body) with little effect.

Experimental Procedure

All subjects were instructed not to exercise, sleep, eat, and drink 2 hours before measurement. The laboratory room was kept at about 23°C during the measurement, and clothes were controlled so as to not influence irradiation. Before and after light exercise and

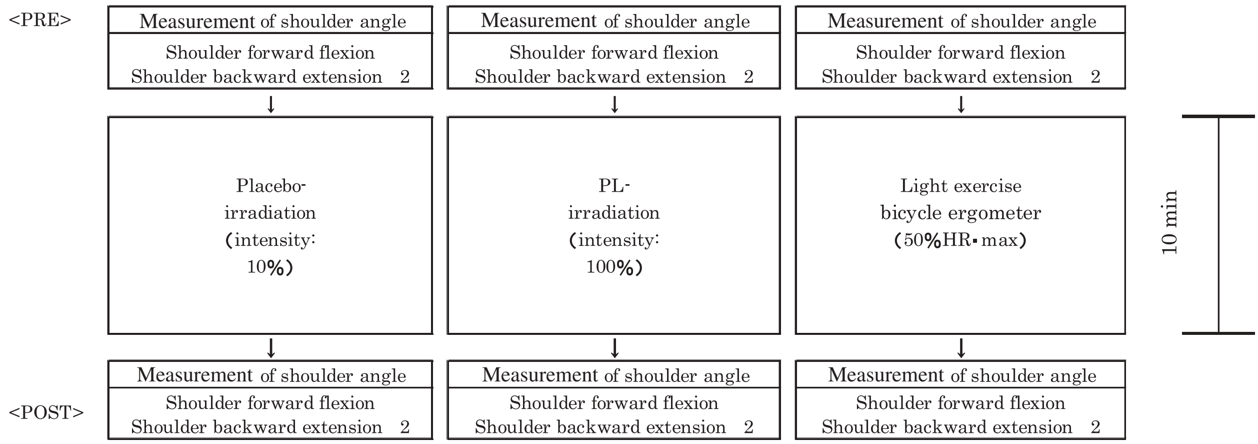

FIGURE 2. Experimental procedure. Subjects were divided into 3 groups (G1, G2, and G3) at random and each group participated in 3 experimental conditions: G1: (1) placebo-irradiation, (2) PL-irradiation, (3) light exercise. G2: (1) PL-irradiation, (2) light exercise, (3) placebo-irradiation. G3: (1) light exercise, (2) placebo-irradiation, (3) PL-irradiation.

PL-and placebo-irradiations, shoulder joint angles were measured twice (Fig. 2). The same tester measured all subjects twice with a few minutes interval. Both irradiations and light exercise were performed on separate days considering the influence of the irradiation (Fig. 2.).

Statistical Analysis

A tester measured the angles of shoulder joint flexed forward and extended backward each twice before/after intervention, and intraclass correlations of each 2 trials for the above 2 parameters and shoulder range of motion were calculated. Student *t* test was used to examine a sex difference. Two-way analysis of variance (PL, placebo and light exercise × preirradiation and postirradiation or exercise) for repeated measures was used to test the effect of PL-irradiation. Multiple comparisons used the Tukey Honestly Significant Difference method. The difference of percentage changes was tested using 1-way analysis of variance. The probability level of 0.05 was setup as indicative of statistical significance.

TABLE 1. Test Results of Sex Difference and 2-way Analysis of Variance for Repeated Measures for Shoulder Joint Angles

			PRE				POST						
			Male	Female	Total		Male	Female	Total			2-way Analysis of Variance	
	N =		10	14	24	*t* Value	10	14	24	*t* Value	Difference	(*F* Value)	Tukey HSD
Shoulder forward flexion	P	Mean	195.5	194.3	194.8	0.43	196.9	194.9	195.8	0.66	1.25	$F1 = 170.11^*$	Pre/Post: I, E
		SD	8.81	4.94	6.67	$P = 0.67$	9.77	4.75	7.15	$P = 0.52$	1.63	$P = 0.00$	
	I	Mean	198.4	193.1	195.3	2.06	204.1	201.6	202.6	0.85	7.77	$F2 = 9.86^*$	Post: $P < I, E$
		SD	7.06	5.59	6.66	$P = 0.05$	8.19	6.35	7.12	$P = 0.40$	3.97	$P = 0.00$	
	E	Mean	197.7	195.0	196.1	1.04	204.1	200.3	201.8	1.40	5.48	$F3 = 35.50^*$	
		SD	8.21	4.51	6.30	$P = 0.31$	8.44	4.81	6.68	$P = 0.17$	2.18	$P = 0.00$	
Shoulder backward extension	P	Mean	74.7	67.1	70.3	1.40	74.9	67.4	70.5	1.37	− 0.08	$F1 = 120.75^*$	Pre/Post: I, E
		SD	12.84	13.26	13.36	$P = 0.18$	13.15	13.42	13.56	$P = 0.18$	1.89	$P = 0.00$	
	I	Mean	73.9	65.1	68.8	1.50	80.5	71.3	75.1	1.69	6.83	$F2 = 2.88$	Post: $P < I, E$
		SD	16.10	12.83	14.64	$P = 0.15$	13.82	12.57	13.62	$P = 0.10$	3.95	$P = 0.07$	
	E	Mean	74.8	67.1	70.3	1.25	79.7	72.1	75.3	1.25	4.35	$F3 = 29.89^*$	
		SD	15.10	14.51	14.93	$P = 0.22$	15.48	13.85	14.71	$P = 0.22$	2.17	$P = 0.00$	
Range of motion	P	Mean	270.2	261.4	265.1	1.44	271.8	262.3	266.3	1.45	1.17	$F1 = 214.81^*$	Pre/Post: I, E
		SD	17.07	12.87	15.08	$P = 0.16$	19.24	13.07	16.26	$P = 0.16$	2.80	$P = 0.00$	
	I	Mean	272.3	258.1	264.0	2.19	284.6	272.9	277.8	1.82	14.60	$F2 = 12.42^*$	Post: $P < I, E$
		SD	19.18	12.53	16.84	$P = 0.04$	18.53	13.13	16.33	$P = 0.08$	6.18	$P = 0.00$	
	E	Mean	272.5	262.1	266.5	1.39	283.7	272.4	277.1	1.54	9.83	$F3 = 62.87^*$	
		SD	20.72	15.95	18.41	$P = 0.18$	20.83	15.42	18.35	$P = 0.14$	2.84	$P = 0.00$	

$\alpha' = \alpha/3 = 0.0167$, PRE and POST mean before and after irradiation or exercise. A significant sex difference was not found in any joint angle.

$^*P < 0.01$.

E indicates light exercise; *F*1, main factor between pre-post measurements; *F*2, main factor between experimental conditions; *F*3, interaction factor; I, irradiation; P, placebo.

RESULTS

Intraclass correlation coefficients of all joint angle parameters were very high, over 0.98 in both males and females. Therefore, means of each 2 measurement values before and after intervention were used as representative values for further analysis. Table 1 shows fundamental statistics for each parameter and the test results of analysis for a sex difference. As a result of Tukey multiple comparison, all parameters were significantly greater in postirradiation than preirradiation and in postexercise than preexercise. Postirradiation and postexercise showed significantly greater values than postplacebo-irradiation ($P < 0.05$). Table 2 shows a comparison between experimental conditions for change rates. Shoulder forward flexion and backward extension angles were significantly greater in PL-irradiation and light exercise than placebo-irradiation ($P < 0.05$), and the range of motion angle was significantly greater in the order of PL-irradiation ($P < 0.05$), light exercise ($P < 0.05$) and placebo-irradiation. The backward extension and range of motion angles of the shoulder joint increased 10.3% and 5.3% in PL-irradiation and 7.4% and 4.0% in light exercise, respectively. A premeasured value and a percentage change only in the backward extension angle showed significant moderate correlations in PL-irradiation ($r = -0.61$, $P < 0.05$) and light exercise ($r = -0.48$, $P < 0.05$) conditions (Table 2).

DISCUSSION

It was reported that linear PL-irradiation improves joint flexibility.[11] However, the degree of PL-irradiation effect when compared with other general warm-up methods has not been examined.

In this study, we did not inform the subjects of the effect of PL-irradiation in advance and used placebo-irradiation. Namely, the experiment was performed with completely blind conditions. The shoulder joint angles significantly changed after PL-irradiation and light exercise, but not after placebo-irradiation. Therefore, an improvement in the shoulder joint angles is considered to depend largely on PL-irradiation or light exercise. Although the range of motion angle in PL-irradiation increased 10.3%, Demura et al[11] reported also that it increased 8.7% by PL-irradiation.

The irradiated trapezius muscle is the biggest muscle near the shoulder joint, which involves auxiliary muscles for elevation and depression of the shoulder blade or flexion and extension of shoulder joints. Because PL-irradiation percolates very deeply into the inner body, it can give heat stimulus directly to a part of the latissimus dorsi or the inner muscle groups that consist of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles. When raising an arm backward from the body side, the trapezius and the inner muscle groups contribute to elevation of the shoulder blade or the pulling-up of the upper arm bone. The trapezius is also involved in movement that elevates the arm over the height of the shoulder. The muscle tightness of the antagonists such as the latissimus dorsi and the peripheral area of the scapula against the agonist such as the deltoid, greater pectoralis, and coracobrachial muscles work as a restricting factor in shoulder joint motion.[1,4,6] It is inferred that heat stimulus by PL-irradiation contributes to an increase of shoulder joint flexibility.

Also, in light exercise by bicycle ergometer, joint angles improved significantly.[1,6,13] In addition, Zakas et al,[14] using junior handball players, reported that jogging and shooting practice for 15 minutes increased the passive angles of knee and ankle joints about 4.9% and 19.1%, respectively.

Bicycle ergometer exercise mainly imposes a large burden on leg muscles, but there is little use of shoulder joints. The present result suggests that light bicycle exercise can somewhat increase shoulder flexibility of little used joints. Exercise enforcement that increases the heart rate to about 130 bpm enhances cardiac output and blood flow circulation of the whole body. Asmussen and Bojo[15] reported that bicycle exercise for 10 minutes increased the rectal temperature by about 0.7°C and working muscle temperature by 2.1°C. It is inferred that warmed blood circulated to muscle groups of the shoulder joint circumference such as the trapezius, deltoid, greater pectoralis, latissimus dorsi, and inner muscles, and increased their muscle temperature, resulting in an increase in shoulder joint angles.

TABLE 2. Test Results of 1-way Analysis of Variance: Percent Changes (%) for Shoulder Joint Angles, and Correlation Coefficients for Shoulder Joint Angles

		Placebo			PL-irradiation			Light Exercise				
N = 24		**Pre**	**Percent Change**	***r***	**Pre**	**Percent Change**	***r***	**Pre**	**Percent Change**	***r***	***F* value**	**Tukey HSD**
Shoulder forward flexion	Mean	194.8	0.5	0.09	195.3	3.8	−0.22	196.1	2.9	−0.06	34.84**	$P <$ I, E
	SD	6.67	0.80		6.66	2.09		6.30	1.19		$P = 0.00$	
Shoulder backward extension	Mean	70.3	0.3	−0.02	68.8	10.3	−0.61**	70.3	7.4	−0.48*	22.41**	$P <$ I, E
	SD	13.36	2.91		14.64	8.27		14.93	3.86		$P = 0.00$	
Motion range	Mean	265.1	0.4	−0.37	264.0	5.3	0.32	266.5	4.0	−0.29	57.95**	$P <$ I $<$ E
	SD	15.08	1.08		16.84	2.53		18.41	1.15		$P = 0.00$	

**$P < 0.01$, *$P < 0.05$.
E indicates light exercise; I, irradiation; P, placebo; Pre, pre-measured value.

On the other hand, although differing from the purpose of this study, people with poor shoulder backward extension tended to show a larger effect in PL-irradiation and light exercise. Demura et al[11] reported a similar result to the present results. People with poor backward flexibility extension may be able to obtain a larger effect by PL-irradiation. However, this problem should be examined in detail by setting groups with poor or better flexibility in future study.

In addition to preventing injury, warm-up by light exercise has important roles as follows: increases the heart rate, blood flow, breathing rate, and motivation to exercise.[5] In competitive sports, athletes frequently perform games or races many times in a day. Repeating light exercise may promote physical fatigue because it imposes a large burden on the body. Therefore, only to improve flexibility is not a reason to recommend PL-irradiation as an alternative to light exercise.[11] It is reported that PL irradiation activates blood flow circulation and promotes the elimination of blood lactate.[16] From the viewpoint of shortening the time for light exercise and reducing or recovering from muscle fatigue, an efficient combination of PL-irradiation and light exercise should be examined.

In conclusion, PL-irradiation on shoulder joint flexibility produces almost the same effect as light exercises, and is a very useful warm-up because it can directly and intensively warm special muscle groups.

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