The Effects of Treadmill Gait Training and STS Exercise on Cardiopulmonary Function, Muscular Cross-Sectional Areas, and Insulin Resistance in Patients with Stroke

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Purpose The purpose of this study was to examine the effects of treadmill gait training and sit to stand(STS) exercises on stroke patients' cardiopulmonary functions, muscular CSAs, and IR. ***Methods*** 15 patients (treadmill group 8, STS group7) were selected from patients with stroke due to hemispheric lesions who were being treated as inpatients at Y Hospital in the Gyeonggi-do region. In this study, the average periods of time after the onset of stroke in the patients in the treadmill gait training group and in the STS exercise group were 7.6 months and 7.5 months, respectively. We analysis the differences in cardiopulmonary function, muscular CSA, and IR between treadmill gait and STS exercise and between intergroup. ***Results*** The treadmill gait training group's maximum oxygen consumption increased by 61%, from 1193.1 ㎖/min before exercise to 1808.6 ㎖/min afterward; meanwhile, the STS exercise group's maximum oxygen consumption increased by 29%, from 1335.6 ㎖/min before exercise to 1743.6㎖/min after exercise IR decreased by 19% from 1.3 before exercise to 1.0 after exercise in the treadmill gait training group. Moreover, it decreased by 12% from 2.7 before exercise to 1.9 after exercise in the STS exercise group. ***Conclusion*** Based on the results of this study, exercise programs for improving the body metabolism ability of patients with hemiplegia due to stroke should be made more effective. Furthermore, efforts to establish the importance of physical activity and its relationship with body metabolism are thought to be necessary to improve the future functional life of the patients.

Key words Treadmill Training, STS, Cardiopulmonary, Stroke

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Ⅰ. Introduction

Most stroke patients have received treatment to overcome disorders in terms of motor, sensory, cognitive, perception, psychological, social, or physical functions. However, although treatment that affects the body's metabolic functions is limited to only one out of 24 hours per day, comprising 30 minutes of 1:1 personal physical therapy and 30 minutes of occupational therapy, efficient exercise management is necessary in patients' personal time. Otherwise, stroke patients face the reality of physical disabilities such as declines in motor ability, decreases in balance ability, and muscle weakness and thus come to spenda greater part of their time in sitting positions compared to normal persons or spend all of their time in bed. This is caused by reductions in physical activity levels.[1-3)]

Lack of use of the affected side and the muscle activity of the unaffected side cause muscle weakening and a reduction in sugar storage capacity on the affected side due to changes in muscular cross-sectional areas (CSAs). Furthermore, the reduction in muscle activity comes to affect insulin resistance.[4)] Since less physical activity leads to declines in the body's metabolism, to increase stroke patients' regular physical activity, methods that can be easily implemented at other times than treatment times are necessary.

Increases in maximum oxygen consumption have been shown when exercises such as treadmill gait training are performed for 30 minutes or longer the maximum oxygen consumption increased by 10.7% when exercises were performed on the ground (walking, repeated standing up from a sitting position, functional muscle strengthening exercises, balance improving exercises) and by 19.7% in six-minute walking tests.[5-8)] Moreover, it was found that cardiopulmonary functions related to oxygen consumption affected the body's metabolism. Therefore, these exercises are thought to be necessary for stroke patients with low physical activity levels to enhance their body's metabolic action rather than to improve muscle function.

Since decreases in the CSAs of the lower limb muscles of the affected and unaffected sides due to reductions in stroke patients' physical activity levels cause muscle weakening[9] affected side muscles are correlated with walking speed and oxygen consumption, and deceases in muscle mass lead to low oxygen consumption.[10] Thus, studies of the characteristics of muscles are also necessary.

The enhancement of insulin sensitivity resulting from exercises suppresses insulin secretion by the pancreas and improves the skeletal muscles' insulin sensitivity, thereby improving the human body's insulin sensitivity.[11-13]

With regard to the effects of exercise on insulin sensitivity, increases in energy expenditure due to exercise increase the consumption of blood sugar to suppress the elevation of blood sugar levels. During convalescence, exercise promotes the recovery of muscle and liver glycogen so that low blood sugar and insulin concentrations can be maintained. Exercise improves insulin-related functions such as by promoting glucose absorption from peripheral tissues, and improves insulin sensitivity by increasing insulin receptors to facilitate blood sugar control thus, studies of the IR of stroke patients with low physical activity levels are also necessary.[14,15]

Due to the effects of greater physical activity levels on cardiopulmonary functions for the body's metabolism, changes in the CSAs of the muscles on the affected and unaffected sides and insulin sensitivity can be expected. Thus, it is important to determine the amount of treatment that can affect the body's metabolism using treadmill gait training. This method can easily be carried out by stroke patients during time other than treatment time. Moreover, the effect of sit to stand (STS) exercises, which are necessary for daily living activities, should also be determined. As a result, the aim of this study was to examine the effects of treadmill gait training and sit to stand(STS) exercises on stroke patients' cardiopulmonary functions, muscular CSAs, and IR.

II. Materials and Methods

1. Study subjects

As the subjects of this study, 15 patients (treadmill group 8, STS group 7) that satisfied the criteria described below were selected from patients with stroke due to hemispheric lesions who were being treated as inpatients at Y Hospital in the Gyeonggi-do region.

First, patients needed to be able to maintain a speed of 0.8 km/h in treadmill gait training.[16] Second, they had to be able to walk independently for at least six minutes without using any walking aid. Third, patients needed to agree to observe hospital diet sheets. Fourth, they needed to be able to communicate and had to agree to participate in this study.

The selected patients' general characteristics, medical characteristics, functional characteristics, and physical activity levels are as shown in Table 1, 2, 3, and 4 respectively. These characteristics did not show any significant difference in homogeneity tests.

Table 1. General characteristics of subjects

	Treadmill (n=8)	STS (n=7)
Age (years)	47.6 ± 13.7	50.0 ± 6.8
Weight (kg)	65.9 ± 8.3	64.9 ± 9.8
Height (cm)	167.3 ± 9.8	166.6 ± 9.2
Time since onset (months)	7.6 ± 7.9	7.5 ± 4.9

M±SD: mean± standard deviation
*$p<.05$

Table 2. Medical characteristics of subjects

Unit: (%)

	Treadmill (n=8)	STS (n=7)
Sex		
Male	6(75)	5(71.4)
Female	2(25)	2(28.6)
Stroke type		
Hemorrhage	6(75)	4(57.1)
Infarction	2(25)	3(42.9)
Paretic side		
Left	6(75)	4(57.1)
Right	2(25)	3(42.9)
Hypertension		
Yes	4(50)	5(71.4)
No	4(50)	2(28.6)
Diabetes		
Yes	4(50)	2(28.6)
No	4(50)	5(71.4)
Smoking history		
Yes	6(75)	5(71.4)
No	2(25)	2(28.6)

*$p<.05$

Table 3. Patients' functional level

			Treadmill (n=8)	STS (n=7)
CMSA(score)	Impairment	Shoulder	4.3 ± 1.2	3.9 ± 1.6
CMSA(score)	Impairment	Postural	5.3 ± 0.5	5.5 ± 0.5
CMSA(score)	Impairment	Arm	3.8 ± 1.6	4.2 ± 1.0
CMSA(score)	Impairment	Hand	3.5 ± 1.7	3.5 ± 1.8
CMSA(score)	Impairment	Leg	5.0 ± 0.8	4.5 ± 1.1
CMSA(score)	Impairment	Foot	4.6 ± 1.1	4.0 ± 1.5
CMSA(score)	Disability	GMF	6.6 ± 0.3	6.4 ± 0.3
CMSA(score)	Disability	Walking	4.9 ± 0.4	4.8 ± 0.5
SIAS(score)	Motor function		3.3 ± 0.8	2.8 ± 0.8
SIAS(score)	Muscle tone		2.0 ± 0.2	1.9 ± 0.3
SIAS(score)	Sensory function		2.3 ± 0.9	1.9 ± 0.9
SIAS(score)	Pain & ROM		2.2 ± 0.4	2.0 ± 0.3
SIAS(score)	Trunk control		2.4 ± 0.2	2.5 ± 0.0
SIAS(score)	High cortical function		2.2 ± 0.6	1.8 ± 0.8
SIAS(score)	Unaffected function		1.8 ± 0.3	1.6 ± 0.2
MBI			57.1 ± 11.9	66.9 ± 16.1

M±SD: mean±standard deviation
GMF: gross motor function
MBI: modified Barthel index
CMSA: Chedoke-McMaster stroke assessment
SIAS: stroke impairment assessment set
*$p<.05$

2. Study procedure

The procedure of this study is as shown in Figure 2.

3. Exercise methods

The exercise methods used in this study are as shown in Table 5.

4. Measurement tools

The measurements of the stroke patients' cardiopulmonary functions were analyzed using K4b².[17] Among the cardiopulmonary functions, oxygen consumption, energy expenditure, and metabolic units or metabolic indexes (MET) were analyzed using portable wireless metabolism analyzers (K4b² Cosmed, Italy). Considering the stroke patients' muscular weakening and decreases in motor control due to exercise loads, the Bruce protocol[18] was revised and supplemented so that the subjects could perform treadmill exercise for 3 minutes at a speed of 0.8 km/h without any slope on the treadmill. The speed was increased by 0.2 km/h per minute and the test was terminated when the subject's heart rate reached 85-90% of the maximum heart rate expected for the age of the subject at maximum oxygen consumption. The subjects'

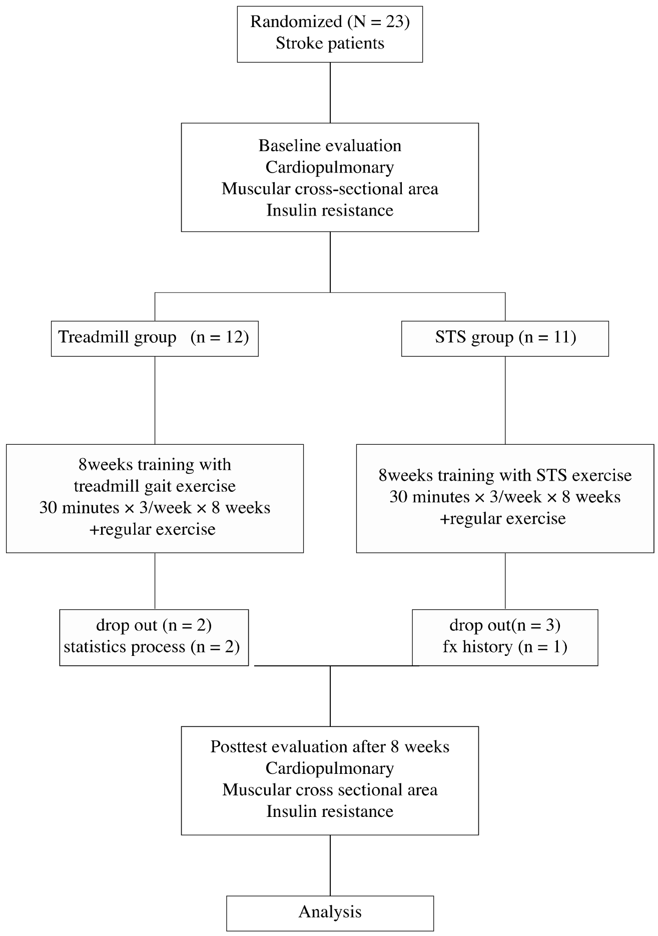

Figure 2. Schematic diagram of the study procedure

Table 4. Patients' physical activity levels

	Treadmill(n=8)	STS(n=7)
Total cal (kcal)	1868.9±262.1	1942.8 ± 300.5
Total activity cal (kcal)	82.8±65.7	114.3 ± 58.9
Total steps (steps)	3297.3±2416.7	4514.3 ± 1608.6

$^*p<.05$

Table 5. Exercise type

Exercise type	1-4 weeks	5-8 weeks	intensity	Duration
	Frequency			
Treadmill exercise	1.0 km/h(10 minutes) 1.2 km/h(10 minutes) 1.4 km/h(10 minutes)	1.6 km/h (10 minutes) 1.8 km/h (10 minutes) 2 km/h (10 minutes)	RPE 9_14 Target HR range:60~65%of age	Warn up/cool down(10minute) 30minutes 3_d/wk
† STS	Hand: neutral position 8_10frequency/4_5_set	Hand" cross bustline 12_15frequency/3_5set		
	1) Symmetrecal 2) Asymmetrecal with the affected foot positioned behind the unaffected foot 3) Asymmetrecal with the unaffected foot position behind affected foot			
†Regular exercise	Regular exercise			

muscular CSAs were measured using computed tomography (Simense, Syngo 2007P). Images were taken by a skilled radiological technologist when the subject was in a supine position in casual clothes on the scanning table. To analyze the data, muscular CSAs within the regions of interest (ROIs) were obtained along the boundaries of muscular cross-sections using a Mango system after setting the shrink wrap ROIs for fat, muscles, and bones as -200 to 0, 0 to 150, and 50 to 2,000, respectively.

The averages of the CSAs of affected side muscles and fat and unaffected side muscles and fat measured in individual computed tomography images were converted into actual areas (㎟).[19-20] To analyze IR, blood was collected when fasting had been maintained for 8 hours and blood sugar and insulin values were obtained by requesting tests from the S Medical Test Co. The HOMA method was used to estimate IR and pancreatic beta cells' insulin secretion functions, considering insulin and glucose concentrations during fasting.[21] In practice, including clinical studies, IR can be obtained by the formula HOMA-IR=< fasting blood insulin (μU/mL)> x <fasting blood sugar (mmol/L)/ 22.5, which is used as an indicator of IR.

5. Data analysis

Kolmogorov-Smirnov tests were conducted to examine the normal distribution of the general characteristics and various measurement items of the study subjects with stroke. According to the results of the tests, the normal distribution was determined. Therefore, the subjects performed treadmill gait training or STS exercise for 8 weeks and independent t-tests were conducted to compare differences in cardiopulmonary functions, muscular CSAs, and IR between the groups. Paired t-tests were conducted to compare values before and after the exercise within each group. Effect sizes were compared between the groups. The effect sizes were considered small when the value was approximately 0.2, medium when the value was approximately 0.5, and large when the value was approximately 0.8 (Cohen, 1988).[22] All cases of statistical processing were tested with a significance level of a=0.05.

III. Results

1. Comparisons of changes in cardiopulmonary functions, muscular cross-sectional areas, and insulin resistance after treadmill gait training and STS exercise

The comparisons of cardiopulmonary functions, muscular CSAs, and IR before and after treadmill gait training or STS exercise between the two groups are as shown in Table 6.

2. Comparisons of the sizes of effects of treadmill gait training and STS exercise on cardiopulmonary functions, muscular cross-sectional areas, and insulin resistance

The comparisons of the sizes of effects of treadmill gait training and STS exercise on cardiopulmonary functions, muscular CSAs, and IR are as shown in Table 7.

IV. Discussion

Treadmill gait training, underwater exercise, and walking activity on the ground performed by stroke patients bring about great improvements in the patients' cardiopulmonary functions. Among these improvements, increases in the maximum oxygen consumption should be particularly emphasized to stroke patients because such increases not only affect the body's metabolism, but can also be connected with muscle endurance. When chronic stroke patients performed endurance exercise underwater, the patients' maximum oxygen consumption increased by 22.5%.[17] Moreover, when they performed treadmill gait training, their maximum oxygen consumption increased by 17%.[7] In addition, when chronic stroke patients performed exercises on the ground (walking, repeated STS exercise, functional muscle strength exercise, and balance exercise), the patients' maximum oxygen consumption increased by 10.7%.[8] Finally, when stroke patients in the acute phase walked on a treadmill while bearing their weight, their maximum oxygen consumption increased by 34.8% .[5,23]

Table 6. Comparison of differences in cardiopulmonary function, muscular CSA, and IR between treadmill gait and STS exercise and between intergroup differences (Treadmill (n=8), STS (n=7))

Variable		Group	Pre	Post	T	p
Cardiopulmonary function	VE (l/min)	Treadmill	30.9 ± 8.6	46.9 ± 13.0	−2.79*	ns
cardiopulmonary function	VE(l/min)	STS	33.8 ± 12.1	47.4 ± 36.4	−1.19	ns
cardiopulmonary function	VO_2peak (ml/min)	Treadmill	1193.1 ± 336.7	1808.6 ± 766.0	−2.41*	ns
cardiopulmonary function	VO_2peak (ml/min)	STS	1365.6 ± 582.4	1743.6 ± 1143.7	−1.30	ns
cardiopulmonary function	VO_2kg (ml/min/kg)	Treadmill	18.2 ± 5.3	27.0 ± 9.6	−2.39*	ns
cardiopulmonary function	VO_2kg (ml/min/kg)	STS	20.4 ± 6.9	25.7 ± 13.1	−1.53	ns
cardiopulmonary function	VO_2max Time (sec)	Treadmill	721.4 ± 373.5	1009.8 ± 348.0	−5.24*	ns
cardiopulmonary function	VO_2 max time(sec)	STS	641.4 ± 271.5	929.1 ± 435.8	−2.46†	ns
Muscular CSA	Muscle CSA (affected side)	Treadmill	10521.1 ± 3593.7	11061.97 ± 3138.1	−1.12	ns
muscular CSA	muscle CSA(affected side)	STS	10810.8 ± 483.6	11657.0 ± 4435.8	−1.65	ns
muscular CSA	Muscle CSA (unaffected side)	Treadmill	12336.6 ± 2387.3	11773.9 ± 4009.4	.67	ns
muscular CSA	muscle CSA(unaffected side)	STS	12829.7 ± 4520.0	12125.5 ± 3438.4	.87	ns
Insulin resistance	IR	Treadmill	1.3 0.7	1.0 0.4	1.96	ns
Insulin Resistance	IR	STS	2.7 2.5	1.9 1.6	1.00	ns

*$p<.05$

Table 7. Effect sizes of treadmill gait and STS exercise on cardiopulmonary function, muscular CSA, and IR

		Effect size (95% CI)	
		Treadmill (n=8)	STS (n=7)
Cardiopulmonary Function	VE (l/min)	1.06 (.22~1.89)	.80 (−0.22~1.83)
cardiopulmonary function	VO_2peak(ml/min)	1.5	1.01 (.02~1.99)
cardiopulmonary function	VO_2kg(ml/min/kg)	1.23 (.8~1.65)	1.01 (.02~1.99)
cardiopulmonary function	VO_2maxtime(sec)	1.5	1.01 (.02~1.99)
Muscular CSA	Affected side	.70 (−.39~1.80)	.81 (−.22~1.83)
muscular CSA	Unaffected side	.35 (−.87~1.57)	.20 (−1.19~1.60)
Insulin resistance	IR	−.70 (−1.60~.19)	−.20 (−.69~.29)

In this study, the average periods of time after the onset of stroke in the patients in the treadmill gait training group and in the STS exercise group were 7.6 months and 7.5 months, respectively. The treadmill gait training group's maximum oxygen consumption increased by 61%, from 1193.1 ㎖/min before exercise to 1808.6 ㎖/min afterward; meanwhile, the STS exercise group's maximum oxygen consumption increased by 29%, from 1335.6 ㎖/min before exercise to 1743.6㎖/min after exercise. The increase in the maximum oxygen consumption of the treadmill gait training group could be explained by the contribution of the muscle actions of the lower extremities to generate energy. Although there was no statistically significant difference between groups, large effect sizes could be identified after the exercises.

The ability to perform exercise varies according to the tension generated by the muscles' contractile force, as well as various physiological variables. In particular, since the tension generated by muscles is known to be proportional to muscular CSA if there is no problem with the nervous system's adaptation, many studies have evaluated muscle functions using computed tomography or magnetic resonance imaging.[24-26] However, stroke patients lose their ability to control their muscles due to damage to their upper motor neurons, and this leads to decreases in their physical activity, as well as in their muscular CSAs on the affected side[6] and muscle efficiency. In addition, one study reported that if the lower extremities do not bear body weight for 4 weeks, muscle strength and muscular CSAs will decrease.[27] Stroke patients' affected side muscular CSAs were shown to be smaller by 3–4% than their unaffected side muscular CSAs.[10] Another study reported that stroke patients' affected side muscle mass was smaller than their unaffected side muscle mass. Moreover, since the affected side muscle mass was correlated with walking speed and oxygen consumption, when the lower limb muscle mass decreased, low oxygen consumption was expected.[19]

In the present study, in the treadmill gait training group, whereas the subjects' affected side muscular CSA increased by 8% from 10521.1 ㎟ before exercise to 11062.0 ㎟ after exercise, their unaffected side muscular CSA decreased by 6%, from 12336.6 ㎟ before exercise to 11773.9 ㎟ after exercise. This decrease is considered to be due to the fact that, although stroke patients come to walk asymmetrically due to temporal and spatial decreases in their affected side's ability to bear weight, most of the subjects performed the exercise with the motivation to control the movements of their trunk and lower extremities. As a result of this, their weight could be borne by their affected side rather than their unaffected side. In the STS exercise group, whereas the subjects' affected side muscular CSA increased by 6%, from 10910.8 ㎟ before exercise to 11657.0 ㎟ after exercise, their unaffected side muscular CSA decreased by 3% from 12829.7 ㎟ before the exercise to 12125.5 ㎟ after the exercise.

Although the differences before and after exercise were not statistically significantly different between the exercise methods, effect sizes on the affected side were shown to be medium in the treadmill gait training group and large in the STS exercise group. This difference is attributed to the fact that while the treadmill gait training group performed lower extremity muscle endurance exercise, the STS exercise group performed lower extremity muscle strength exercise.

Blood sugar and insulin concentrations are improved by exercise because the reduction in blood sugar due to exercise suppresses the pancreas' insulin secretion[11] and enhances skeletal muscles' sensitivity, thereby improving the human body's insulin sensitivity.[12,13] In terms of the IR-related effects of exercise, one-shot, short-term, and long-term exercises have all shown effects.[28] Moreover, insulin sensitivity increased after exercise using a cycle ergometer for 12 weeks.[15] In addition, during treadmill gait training, insulin decreased over time at 60 minutes, 120 minutes, and 150 minutes, and blood sugar also decreased at 90 minutes and 120 minutes.[29]

In this study, rather than progress over time, differences between before and after the treatment period were compared. IR decreased by 19% from 1.3 before exercise to 1.0 after exercise in the treadmill gait training group. Moreover, it decreased by 12% from 2.7 before exercise to 1.9 after exercise in the STS exercise group. Although the difference between the treadmill gait training group and the STS exercise group was not statistically significant, the effect size was shown to be medium in the treadmill gait training and small in the STS exercise group. Therefore, the decreasing trends of blood sugar, insulin, and IR can be explained by differences before and after exercise; furthermore, moderate and diverse intensities of physical activities were effective in reducing IR compared to a sedentary lifestyle.[29,30] These results could support the theory that endurance exercises will reduce blood sugar and insulin and increase insulin sensitivity.[31]

Based on the results of this study, exercise programs for improving the body metabolism ability of patients with hemiplegia due to stroke should be made more effective. This can be by supplementing the functional and sensory integration and endurance improvement. Furthermore, efforts to establish the importance of physical activity and its relationship with body metabolism are thought to be necessary to improve the future functional life of the patients.

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