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ORIGINAL RESEARCH ARTICLE

Maximal Strength Training Enhances Strength and Functional Performance in Chronic Stroke Survivors

ABSTRACT

Hill TR, Gjellesvik TI, Moen PMR, Tørhaug T, Fimland MS, Helgerud J, Hoff J: Maximal strength training enhances strength and functional performance in chronic stroke survivors. Am J Phys Med Rehabil 2012;91:393–400.

Objective: This study aimed to demonstrate that maximal strength training improves muscle strength and to assess the effect of training on function, aerobic status, and quality-of-life among chronic stroke survivors.

Design: Ten patients acted as their own controls for 4 wks, before an 8-week training intervention. Patients trained 3 days/wk, with four sets of four repetitions at 85%–95% one repetition maximum in unilateral leg press and plantarflexion with an emphasis on maximal mobilization of force in the concentric phase.

Results: After training, leg press strength improved by 30.6 kg (75%) and 17.8 kg (86%); plantarflexion strength improved by 35.5 kg (89%) and 28.5 kg (223%) for the unaffected and affected limbs, respectively, significantly different from the control period (all $P < 0.01$). The 6-min walk test improved by 13.9 m (within training period; $P = 0.01$), and the Timed Up and Go test time improved by 0.6 secs (within training period; $P < 0.05$). There were no significant changes in walking economy, peak aerobic capacity, Four-Square Step Test, or health-related quality-of-life after training.

Conclusions: Maximal strength training improved muscle strength in the most affected as well as in the nonaffected leg and improved Timed-Up-And-Go time and 6-min walk distance but did not alter Four-Step Square Test time, aerobic status, or quality-of-life among chronic stroke survivors.

Key Words: Stroke, Maximal Strength Training, Function, Rehabilitation

Strength training poststroke is widely acknowledged as an important part of a rehabilitation program. Muscle strength has been shown to be a significant contributor to physical disability after stroke,[1] which in turn has an immense impact on the reintegration of patients into society, affecting their quality-of-life.[2] Currently, a wide range of training regimens are used, and a consensus on the optimal training program is yet to be found.

Maximal intensity strength training (MST) involves three to five sets of one to five repetitions of nearly maximal weights (85%–95% one repetition maximum [1RM]), with emphasis on the maximal mobilization of force. During the last decade, this training regimen has demonstrated large increases in strength and increase in central commands to the muscles among patients[3–6] but has not yet been used with patients with stroke.

The efficacy of strength training programs is measured not only by improvements in strength but also by improvements transferred into functional tasks. However, although muscle strength is essential for activities of daily living, the effect of strength training on functional performance tasks is ambiguous.[7] The effect of MST on the common functional measures 6-min walk test (6MWT), Timed-Up-And-Go (TUG), and the Four Step Square Test (FSST) on chronic stroke survivors has not yet been tested.

Previous MST studies using the lower limbs have demonstrated an improved economy of walking, as measured by the energy cost of walking at a constant submaximal intensity.[4,5] As the characteristic hemiplegic gait of a stroke survivor can double the energy cost of walking compared with that of a healthy person,[8] it could be hypothesized that a better walking economy (C_w) would have significant effects on their level of physical disability and potentially their quality-of-life, but this has not yet been determined.

This study hypothesized that an 8-wk lower-limb MST program would improve muscle strength. It also aimed to test the effect of MST on three functional measures (6MWT, TUG, FSST), C_w, and quality-of-life. This study also monitored $\dot{V}O_2$peak, although it was not hypothesized to change after strength training. This was to ensure that any potential improvements in C_w were not caused by an overall increased aerobic capacity.

TABLE 1 Participant characteristics ($N = 10$)

Age, yrs	46.3 (22–61)
Time since stroke, yrs	7.4 (0.8–21)
Type of stroke, infarct/hemorrhage	7/3
Side of stroke, left/right	7/3
Sex, male/female	6/4
Walking aids	Walking stick (n = 1)
	Hyperextension orthosis (n = 1)
	Toe-off orthosis (n = 4)
Other conditions	Diabetes (n = 1)
	Epilepsy (n = 2)
	Total hip replacement (n = 1; 2 yrs before)
	Aorta valve malfunction (n = 1; operated 4 yrs before)
Medications	Antithrombotic (n = 9)
	Epilepsy (n = 2)
	Hypertension (n = 3)
	Antihypercholesterolemia(n=6)
	Antidiabetic medication (n = 1)
	Antidepressant (n = 1)

Data are presented as mean (range).

METHODS

Subjects

Twelve community-dwelling stroke survivors were recruited on a volunteer basis via the local stroke rehabilitation center. The inclusion criteria were age between 18 and 67 yrs, more than 6 mos since stroke, on stable medication, living within the Trondheim region such that travel time and costs were not prohibitive, and able to walk independently, although the use of walking aids was permitted. Exclusion criteria included severe cognitive difficulties such that the completion of testing and training was impaired, medically unstable needing aggressive treatment (as assessed by a medical doctor who checked for uncontrollable high blood pressure, arrhythmia, and heart problems or other known serious illnesses), and pregnancy. No subjects were excluded after recruitment.

All 12 subjects recruited fulfilled the criteria but one was deemed unable to take part in the $\dot{V}O_2$peak test because of a previous heart condition. Two patients did not complete one of the testing sessions because of illness, so all their results are excluded from analyses. The characteristics for the remaining ten participants that completed the entire study are presented in Table 1.

The project was given ethical approval by the Regional Committee for Medical Research Ethics and was carried out in accordance with the Helsinki Declaration. All participants provided written informed consent.

Design

The study was a one-group nonrandomized control intervention design and was part of a larger project.[9] The patients acted as their own controls during a 4-wk period before beginning 8 wks of strength training. There were three testing sessions: baseline, pretraining, and posttraining. The tests were split over 2 days during the testing week. They were instructed to wear the same shoes and orthoses for each testing session and were asked to continue with their normal daily activities throughout the control and training period.

Muscle Strength

The 1RMs for unilateral leg press and plantarflexion were measured on a horizontal leg press machine (Super Gym, Taiwan). Leg press was determined for a 90-degree knee joint angle. The plantarflexion movement started with the knee joint to be fully extended and the ankle joint at 90 degrees. Hip and quadriceps movement were monitored by the investigator placing their hand on the muscle to detect movement. This was to ensure that only the calf muscles were being activated while the patient applied pressure through the toes. Patients were given clear instructions and visual demonstration when necessary. They were familiarized with the movements at a low weight before increasing until a maximum, which is accurate to the nearest 1.25 kg. Leg order for testing was randomized. Some patients were unable to perform the plantarflexion movement at baseline because of paresis. Their 1RM was recorded as 0 kg.

Functional Tests

The 6MWT was performed in line with Enright[10] with two cones set 20 m apart. Patients were instructed to walk at a comfortable speed and informed of the time at 3:00, 5:00, 5:30, and 5:50. Distance was recorded accurate to the nearest meter.

The TUG test was carried out according to the procedure outlined by Podsiadlo and Richardson.[11] Again, patients were instructed to walk at a comfortable speed. A familiarization trial was given before three timed attempts, with the best time used for analysis. The 6MWT and the TUG have been shown to be reliable tests in chronic stroke patients.[12]

The FSST was carried out according to the procedure outlined in Dite et al.,[13] with crutches (3.5 cm high) providing the divisions between the squares. The standardized instructions were translated into Norwegian. After full familiarization, three trials were completed, with the fastest time used for analysis. The FSST has been validated for use within this population.[14]

Aerobic Status

C_w and peak aerobic capacity ($\dot{V}O_2$peak) testing were carried out on a treadmill (Woodway GmbH, Weil am Rhein, Germany) using the MetaMax II (Cortex Biophysik, Leipzig, Germany) for measurements of gas exchange and ventilation. The MetaMax II system has an accuracy of 2% according to the manufacturer. Heart rate (HR) was recorded using a Polar watch (Polar Electro Oy, Kempele, Finland).

Subjects completed a short warm-up at a comfortable walking speed before walking at 3 km/hr (n = 9) or 2.7 km/hr (n = 3) and 3% incline for 4 mins. The values of oxygen consumption, ventilation rate ($\dot{V}E$) and respiratory exchange ratio (R) from the last 30 secs were averaged. Patients indicated the intensity according to the Borg ratings of perceived exertion scale.[15]

The $\dot{V}O_2$peak protocol followed immediately after the C_w test. Speed and incline were increased whenever the $\dot{V}O_2$ stabilized until the patients reached exhaustion. Immediately after test completion, peak HR (HR_{peak}) and Borg ratings of perceived exertion scale were recorded. Blood lactate ($[La^-]_b$) was measured on completion of the test from the middle finger using an Arkray blood lactate test meter and using Lactate Pro test strips (Arkray Europe BV, Amstelveen, the Netherlands). $\dot{V}O_2$peak was calculated as the average of the highest three consecutive values and the corresponding ventilation and peak R values (R_{peak}) were used for analysis.

To monitor cardiovascular function, a 12-lead stress electrocardiogram was recorded during the baseline $\dot{V}O_2$peak testing using a Cardiovit CS-200 diagnostic system (Schiller AG, Baar, Switzerland).

Quality-of-life

The Medical Outcome Survey (36-item short form) questionnaire[16] was analyzed using the recommended scoring system from the Medical Outcomes Trust. The mental and physical component summary scores were calculated using the website http://www.sf-36.org/nbscalc/index.shtml. These are scored out of 100 and normalized to the Norwegian population. The Reported Health Transition Score is scored between 1 (health much better than a year ago) and 5 (health much worse than a year ago). Patients answered the questionnaire independently but were given help if unsure on any of the questions. Some patients asked an investigator to scribe. One subject completed the questionnaire with help from their spouse because of aphasia. The Medical Outcome Survey (36-item short form) questionnaire has been validated for use with patients with stroke.[17]

Intervention

The subjects trained for three sessions a week for 8 wks. Each subject started with a 10-min warm-up on either a treadmill (Woodway GmbH, Weil am Rhein, Germany) or a cycle ergometer (Merida, Yuanlin, Taiwan). All strength training was carried out on the same horizontal leg press used for testing. Five warm-up repetitions were completed at approximately 50% of 1RM before the main session of four sets of four repetitions unilaterally at 85%–95% of 1RM for both leg press and plantarflexion. When subjects were able to complete a fifth repetition, the weight was increased by 1.25–2.5 kg, dependent on subjective feelings of capability. Four subjects struggled to complete plantarflexion in the affected leg. They trained against manual resistance where the investigator opposed any movement to induce an isometric contraction. The investigator checked if a dynamic movement was possible on the weight machine on alternate sessions. Subjects used a short (1 sec) stop in between repetitions to avoid elastic energy contributing to the force produced. They were encouraged to focus of an explosive concentric movement and a controlled eccentric movement such that the time on each phase was in the ratio 1:2. In line with recommendations, the subjects were regularly reminded to focus on breathing during the contraction, preventing the valsalva maneuver and high rises in blood pressure.[18] Subjects had at least 90 secs of rest in between sets to allow blood pressure to normalize. The session finished with a minimum 5-min warm down on either the treadmill or cycle ergometer. Each training session lasted approximately 45 mins.

Statistics

SPSS version 16.0 (Chicago, IL) was used for all data analyses. Wilcoxon's signed-rank tests were used to compare the changes between the control and training periods and to compare changes within periods (i.e., baseline to pretraining and pretraining to posttraining).

RESULTS

All subjects completed testing without any unwarranted fatigue, musculoskeletal pain, or abnormal electrocardiographic, HR, or blood pressure responses. One subject had a transient ischemic attack but was recommended to resume training by a medical doctor within 4 days; no further problems were reported.

Muscle Strength

Leg press 1RM increased significantly after strength training in both the unaffected and affected legs by 75% (30.6 kg) and 86% (17.8 kg), respectively, both during the training intervention period compared with the control period ($P < 0.01$) (Table 2). The changes in leg press 1RM during the control period were −1.5% (−0.6 kg) and 8.3% (1.6 kg), respectively, and there were no significant differences between the baseline and pretraining means (Fig. 1). There was a significant difference between the changes in leg press 1RM during the control and training periods for both the unaffected and affects legs (both $P < 0.01$).

Plantarflexion 1RM increased after strength training in both the unaffected and affected legs by 89% (35.5 kg) and 224% (28.5 kg), respectively (both posttraining means are significantly different from pretraining means, with $P < 0.05$) (Table 2). The changes in plantarflexion 1RM during the control period were −1.5% (−0.6 kg) and 20% (2.2 kg), respectively, and there were no significant differences between the baseline and pretraining means (Fig. 1). There was a significant difference between the changes in plantarflexion 1RM during the control and training periods for both the unaffected and affected legs ($P < 0.01$ and $P < 0.01$, respectively). Four subjects recorded 0 kg affected plantarflexion at baseline, and three recorded 0 kg at pretraining. All patients were above 0 kg at posttraining.

Functional Tests

The mean 6MWT distance improved by 13.9 m after strength training and the difference between the pretest and posttest in the intervention period was statistically significant ($P < 0.01$). The control

TABLE 2 Changes in muscle strength

Strength Exercise	Baseline	Pretraining	Posttraining
Leg press			
Unaffected leg, kg	41.4 (13.5)	40.8 (10.5)	71.4 (18.7)[a]
Affected leg, kg	19.1 (6.5)	20.7 (8.5)	38.5 (14.8)[a]
Plantarflexion			
Unaffected leg, kg	40.5 (13.1)	39.9 (13.6)	75.4 (14.0)[a]
Affected leg, kg	10.6 (11.2)	12.8 (12.6)	41.3 (17.6)[a]

Data are presented as mean (SD); $N = 10$.
[a]Significantly different from control period; $P < 0.01$.

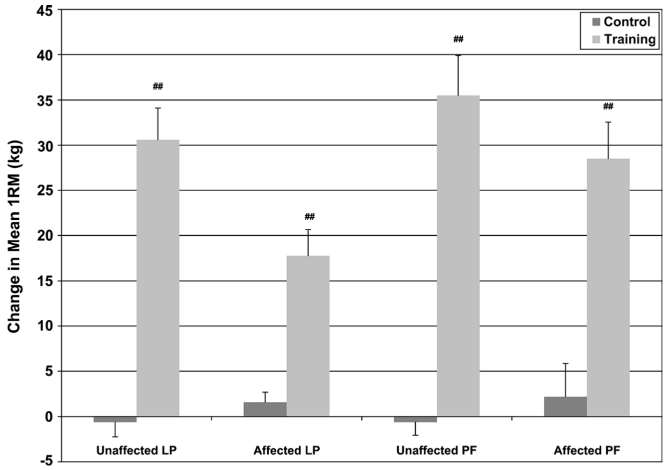

FIGURE 1 *The changes in 1RM in kilograms during the training and control periods. Error bars represent the standard error. ##Change during training period is significantly different from change during control period; P < 0.01. 1RM, one repetition maximum; LP, leg press; PF, plantarflexion.*

period change of 2.6 m was not statistically significant. The difference between the training and control period did not reach statistical significance. The mean TUG time remained the same after the control period but decreased by 0.6 secs posttraining. This was statistically significant from pretest to posttest in the intervention period ($P < 0.05$). The difference between the training and control period did not reach statistical significance. The mean FSST showed no change between conditions.

The mean values for all three tests across the three testing sessions are shown in Table 3.

Aerobic Status

There were no significant differences between the baseline and pretraining and the pretraining and posttraining means for C_w. There were no changes in $\dot{V}O_2$peak after the control or training periods with the exception of an increased $\dot{V}O_2$peak (when measured in milliliters per minute per kilogram) at pretraining ($P < 0.05$) and an increased R_{peak} at posttraining ($P < 0.05$). The difference between the changes during the control and training periods was not significant for any variable other than $[La^-]_b$ ($P < 0.05$). The means for all testing sessions for the variables associated with the C_w and $\dot{V}O_2$peak testing are shown in Table 4.

Quality-of-life

The changes after the training intervention did not result in changes in perceived mental, physical, or health transition (Table 5).

DISCUSSION

Muscle Strength

The main finding of this study is that maximal strength training, performed unilaterally on both limbs, improves strength and indicates modest improvements in some functional performance tasks, but did not affect C_w. The increases in strength are substantial because it is a dependent variable and trained in the same movement as tested. The large improvement in both legs are interesting also from the point of view that this type of training intervention has been shown to increase commands from the central neural system. This was, however, not tested in this setup. Even though the training is set

TABLE 3 Changes in functional tests

Functional Test	Baseline	Pretraining	Posttraining
6-min walk test distance, m	440.3 (78.1)	442.9 (87.1)	456.8 (88.7)[a]
TUG time, secs	8.5 (2.3)	8.5 (3.4)	7.9 (2.5)[b]
FSST time, secs	14.1 (11.0)	15.4 (15.6)	14.3 (12.4)

Data are presented as mean (SD); $N = 10$.
[a]Significantly different from pretraining; $P < 0.01$.
[b]Significantly different from pretraining; $P < 0.05$.
TUG, timed up and go; FSST, four-step square test.

TABLE 4 Changes in aerobic status

Variable	Baseline	Pretraining	Posttraining
Body weight, kg	80.6 (12.3)	80.8 (12.6)	80.0 (12.3)
$\dot{V}O_2$peak			
liters/min	2.51 (0.57)	2.59 (0.57)	2.56 (0.64)
ml/kg per min	31.4 (4.6)	32.7 (5.2)[a]	32.4 (6.3)
$\dot{V}E_{peak}$, liters/min	94.2 (27)	90.1 (20)	96.9 (30)
HR_{peak}, beats/min	170 (29)	171 (20)	174 (15)
R_{peak}	1.12 (0.07)	1.12 (0.06)	1.17 (0.07)[a]
Borg rating	16.7 (1.8)	17.6 (2.1)	17.8 (1.8)
$[La^-]_b$, mmol/liter	8.25 (2.0)	7.31 (1.3)	8.47 (2.1)[b]
C_w			
liters/min	1.17 (0.20)	1.21 (0.13)	1.15 (0.18)
ml/kg per min	14.6 (1.4)	15.2 (1.7)	14.4 (1.8)
$\dot{V}E$, liters/min	28.0 (4.9)	28.4 (3.6)	29.5 (5.3)
HR, beats/min	110 (16)	108 (14)	112 (16)[b]
R	0.86 (0.03)	0.87 (0.03)	0.87 (0.04)
Borg rating	9.9 (1.7)	9.4 (2.6)	9.5 (1.8)

Data presented as mean (SD). Variables connected with the $\dot{V}O_2$peak testing, $n = 9$; Variables connected with the C_w testing, $n = 11$.

[a]Significantly different from previous testing; $P < 0.05$.

[b]Training period change is significantly different from control period change; $P < 0.05$.

$\dot{V}O_2$peak, peak oxygen consumption; $\dot{V}E_{peak}$, peak total pulmonary ventilation; HR_{peak}, peak heart rate; R_{peak}, respiratory exchange ratio at peak test; $[La^-]_b$, blood lactate concentration; C_w, walking economy, oxygen cost at a standardized submaximal workload; $\dot{V}E$, total pulmonary ventilation; HR, heart rate; R, respiratory exchange ratio.

up to try and affect the central neural commands, there seems not to be a limitation for the development of the most affected side. The large percentage increase in plantarflexion strength on the most affected side may be somewhat distorted by the subjects who recorded 0 kg for plantarflexion at baseline.

Functional Tests

The present study showed a significant 0.6 sec or approximately 7% improvement in TUG time posttraining. Flansbjer et al.[19] expressed, based upon their test-retest data, that the smallest change that indicates a clinical change for TUG is approximately 8%, making the changes in this experiment of borderline clinical importance. No previous strength training studies found improvements in TUG time immediately after lower limb strength training.[19–21] The lack of improvements in previous research may be explained by the modalities of training used. Bourbonnais et al.[20] used static training, which is suboptimal for promoting transfer of strength to functional tasks.[22] Sharp and Brower[21] carried out maximal effort isokinetic training of the paretic limb, while Flansbjer et al.[19] used low-speed high-intensity (80% 1RM) training of both knee joints. The present study used maximal intensities with high intended movement velocities. This training approach has been shown to be effective for improving the rate of force development,[5] which, in turn, has linked with performance in functional tasks and may explain the positive result.[23]

TABLE 5 Summary of SF-36 responses

Summary Component	Baseline	Pretraining	Posttraining
MCS	46.8 (10.5)	47.3 (14.0)	48.4 (8.1)
PCS	42.7 (9.2)	44.7 (8.2)	46.5 (3.6)
RHTS	2.50 (1.2)	2.40 (1.3)	2.20 (1.2)

Data presented as mean (SD); $N = 10$.

MCS, mental component summary; PCS, physical component summary; RHTS, reported health transition score; SF-36, 36-item Short-Form Health Survey.

Mean 6MWT distance improved significantly by 13.9 m or 3.5% posttraining. Flansbjer et al.[19] found no significant difference in 6MWT improvements between the experimental and control groups and show in their data that the smallest change that indicates a clinical change for 6MWT is approximately 5%, making the changes in this experiment of borderline clinical importance. Ouellette et al.[24] found a 22-m improvement in 6MWT distance (baseline, 217 m) after high-intensity (70% 1RM) resistance training. However, the control group also improved (221–235 m), so the improvements were attributed to the extra activity both groups incurred while traveling to and from the laboratory.

It must also be noted that the participants in the present study were clearly at the higher end of functional abilities compared with the wider stroke population. This is demonstrated by the mean TUG time of around 8 secs compared with the range of 13–30 secs reported in the referenced studies and the 6MWT distance of around 440 m compared with 220–350 m in others.

For the first time, the effect of strength training on the FSST was assessed, and no significant change was found. The lack of improvement could be explained by the complex nature of the task. Despite familiarization, cognitive difficulties may have been a limiting factor. In addition, the backward phase caused particular problems and improvements in stepping forward and sideways, and changing directions may have been masked by the more difficult phases.

Aerobic Status

This is the first study to look at the effect of strength training on the economy of walking after stroke. Currently, there is not enough evidence to conclude that strength training poststroke benefits walking.[25] Our hypothesis that maximal strength training would improve C_w was based on several studies using this intervention in other patient groups.[4,5,26] The authors of those studies suggested two explanations for the improvements. Firstly, a reduced relative workload on the muscle, implying a shift to use of motor units with lower recruitment thresholds, was previously shown to be more economic. Secondly, an improved rate of force development means faster contractions and relaxations, allowing for longer relaxation periods for a given workload, giving more time for oxygenated blood flow to the muscle. However, there were no significant differences in C_w whether expressed as oxygen cost of a submaximal workload in liters per minute or milliliters per kilogram of body mass and minute despite the substantial improvements observed for other patient groups such as chronic obstructive pulmonary disease and cardiovascular disease.[4,26]

Alternatively, it may be that there is another overriding factor that limits C_w for stoke survivors other than muscular strength. Leg strength asymmetry has been shown to correlate with C_w among hemiplegics[27] and to be a predictor of gait performance.[28] This might suggest that training only the paretic leg might be a more feasible approach, which should be investigated. It is widely recognized that adaptations to strength training are specific to the movement trained, and it may be that the stroke survivors require maximal strength training in combination with walking exercise training to promote transfer.

Strength training caused no increase in $\dot{V}O_2$peak as demonstrated by no significant difference between the pretraining and posttraining means. There was a significantly higher R value during the posttraining compared with pretraining. This result combined with a trend toward a higher $\dot{V}E_{peak}$ implies that the participants pushed themselves harder in the posttraining test.

There was an improvement in $\dot{V}O_2$peak between baseline and pretraining, although this is only significant when measured in milliliters per kilogram per minute. After a close investigation of the data, it appears that this result may be skewed by one subject losing a considerable amount of weight (approximately 5 kg) combined with recording a higher absolute $\dot{V}O_2$peak.

Quality-of-life

There were no significant differences between the Medical Outcome Survey (36-item short form) questionnaire mental and physical component summary scores during the control or training period. This is in line with the results from Kim et al.,[29] which showed no changes in the Medical Outcome Survey (36-item short form) questionnaire responses after a strength training intervention. The fact that there was no negative change implies that the subjects tolerated the intense training well. This is supported by high attendance figures (98%).

Limitations

This study is weakened by the small sample size, which may have resulted in type II errors or may have skewed some of the results. Because the participants in our study were at the higher end of motor and cognitive abilities compared with most stroke survivors, the results may not transfer to the wider stroke population. The study may have been stronger with a separate control group because it would limit the number of potential confounding variables. Multiple hypotheses were tested in this experiment, and the risk for a chance finding is possible. Adjusting the *P* values however, would increase the risk of a type II error. This must be taken into consideration when interpreting the results. It would also have been preferable to measure the rate of force development to give further insight into the results.

CONCLUSIONS

Maximal strength training improved muscle strength in stroke survivors in both the most affected leg and the least or not affected leg and improved TUG time and 6-min walk distance but did not affect FSST time, aerobic status, or quality-of-life among chronic stroke survivors. The study demonstrates that with the necessary safety precautions, it is effective in both time and results to train at maximal intensities.

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