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Stroke Rehabilitation – Enhancing Locomotor Function

Feasibility of lower-limb muscle power training to enhance locomotor function poststroke

Abstract—Poststroke motor control is characterized by greatly reduced muscle power generation. To date, the extent to which muscle power limits walking performance or whether its remediation should be a primary component of locomotor rehabilitation has yet to be established. The purpose of this study was to examine the feasibility and the effects of Poststroke Optimization of Walking using Explosive Resistance training, an intervention aimed at improving poststroke muscular and locomotor function. Twelve subjects (6–60 mo poststroke) participated in 24 training sessions (3 sessions/wk for 8 wk). Exercises included leg press, calf raises, and jump training, all performed at high concentric velocity, as well as trials of fast walking. We measured self-selected and fastest comfortable walking speeds as well as knee extensor and plantar flexor strength and power at pretraining, posttraining, and 8 wk follow-up time points. In addition, we also performed a number of clinical assessments commonly used in poststroke rehabilitation trials. Following training, significant improvements in lower-limb muscle strength and power were realized and accompanied by improvements in self-selected as well as fastest comfortable walking speeds. No changes in clinical assessments resulted from training.

Key words: exercise, locomotion, locomotor function, muscle, optimization of walking, poststroke, rehabilitation, strengthening, stroke, walking.

INTRODUCTION

There are nearly 6 million people with stroke living in the United States and approximately 700,000 new strokes occurring annually. Stroke is the leading cause of long-term disability in this country, where 73 percent of those experiencing stroke have some degree of long-term disability [1–2]. Less than half of people with stroke progress to independent community ambulation [3]. Even among those who do regain the ability to walk, significant residual deficits persist and the majority of these individuals report limitations in mobility related to walking [3]. Following stroke, the most consistent gait impairment observed is slow walking speed. Importantly, improving walking speed is (1) independently related to overall health status, (2) a strong predictor of functional recovery, (3) reflective of both physiological and functional changes, and (4) the most often stated goal during rehabilitation [4]. As such, interventions aimed at improving functional walking status are critical for improving quality of life for hemiparetic individuals and their caregivers.

Abbreviations: 6MWT = 6-minute walk test, DGI = Dynamic Gait Index, FCWS = fastest comfortable walking speed, FMA = Fugl-Meyer Assessment, KE = knee extensor, MVIC = maximum voluntary isometric contraction, PF = plantar flexor, POWER = Poststroke Optimization of Walking using Explosive Resistance, SSWS = self-selected walking speed.

Hemiparesis, strictly defined as a muscular weakness or partial paralysis of half of the body, is seen in three-quarters of individuals poststroke. It has been proposed that slow walking speeds following stroke are causally related to an inability to generate sufficient lower-limb power to meet the task demands of body forward progression. Decreased muscle power generation means that the necessary mechanical energy for the trunk and legs may not be available, thereby negatively affecting walking performance and decreasing functional independence. Muscle power generation involves both strength and velocity components and is determined by the force-generating capacity of the muscle as well as its speed of shortening. Although the loss of muscle mass, as well as the inability to activate paretic muscle, clearly contribute to the loss of muscle strength, these variables alone cannot account for the proportionally greater loss of muscle power than strength following stroke [5]. Pronounced velocity-dependent muscular deficits, in combination with substantial muscle weakness, significantly affect power generation when compared with neurologically healthy older counterparts [5–6]. Interestingly, muscle power is a significant predictor of functional ability to a greater extent than muscle strength in elderly subjects. In fact, direct comparisons of power and strength demonstrate that muscle power deficits consistently describe more of the variance in functional ability [7] and are associated with increased levels of dependence, greater risk of falls, and decreased walking speeds [8–10].

Although deficits in muscle power generation are linked to disability, data describing the effects of improving muscle power generation on functional performance following stroke are absent. By training individuals poststroke using a program that specifically targets impaired power generation, we expect neuromuscular adaptations to occur that translate to increased walking speeds. Thus, the purpose of this study was to examine the effects of 8 wk of Poststroke Optimization of Walking using Explosive Resistance (POWER) training, a high-intensity and high-velocity lower-limb power training program, on poststroke muscular and locomotor function.

METHODS

Subjects

Twelve subjects between 6 and 60 mo poststroke participated in this study. Inclusion criteria were age 19 to 70, ability to walk for a minimum of 10 m without support from another person, lower than normal self-selected walking speed (SSWS) (i.e., < 1.2 m/s), no signs of orthopedic or visual problems that influence gait and balance, and no concomitant neurological disorders.

Intervention

Subjects completed the POWER training intervention, which included 24 training sessions (3 sessions/wk for 8 wk). It was determined a priori that all sessions had to be completed within a 10 wk period for subjects to be considered compliant to the protocol. Exercises included leg press, calf raises, and jump training, all performed on a supine exercise device (Shuttle MVP Pro, Shuttle Systems Inc; Glacier, Washington). The number of sets performed ranged from two to three and the number of repetitions ranged from 8 to 15, depending on the goals for progression for the given session. Exercise intensity (i.e., resistance and number of repetitions) was progressed throughout the duration of the intervention as tolerated by each individual. Unilateral training was performed, the goal being to maximize the gains possible in each leg. To emphasize muscle power generation during training, subjects were asked to perform the concentric phase of each exercise as quickly as possible. In addition, subjects also completed repeated 10 m trials of fast walking training (10 trials/session) at a minimum of 125 percent of SSWS to emphasize within-task power generation.

Outcome Measures

Muscle Strength and Power

Prior to training and at 2 wk intervals throughout the intervention, muscle strength and power assessments were performed using an isokinetic dynamometer (Biodex Medical Systems Inc; Shirley, New York). Prior to testing, each subject was allowed a period of familiarization and warm-up. During strength testing, maximum voluntary isometric contraction (MVIC), defined as the highest torque achieved during three maximal contractions (~3 s contractions separated by 60 s of rest), was determined bilaterally in the plantar flexor (PF) and knee extensor (KE) muscle groups.

During muscle power testing, peak isotonic power was assessed in the paretic and nonparetic KE muscle groups using an external resistance set at 40 percent of MVIC, because differences in lower-limb maximal velocity are shown to occur at relatively low external forces (e.g., 40% 1 repetition maximum) and are most closely associated with gait velocity in older individuals [7]. To optimize reliability of the testing, each test was repeated five times.

During all dynamometric testing, subjects were instructed to (1) develop torque as fast as possible and (2) produce a maximal contraction. All contractions were performed with subjects positioned in the dynamometer and the axis of the dynamometer aligned with the joint axis of rotation. Proximal stabilization was achieved with straps at the chest, hips, and knee as appropriate.

Overground Walking

Prior to the first training session of each week, subjects walked on a 20 ft-long gait mat (GaitRite, CIR Systems Inc; Sparta, New Jersey) to measure SSWS and fastest comfortable walking speed (FCWS). Pretraining, posttraining, and follow-up data collections included SSWS and FCWS as well as spatiotemporal parameters of walking. Three trials at each speed were performed, with data averaged over the trials for analyses.

Clinical Assessments

A number of clinical assessments commonly used in the poststroke population were performed to determine the effects of our intervention beyond the behavioral measures of walking. Assessments included the lower-limb portion of the Fugl-Meyer Assessment (FMA) as well as the FMA synergy subsection, Stroke Impact Scale [11–13], Berg Balance Scale, Dynamic Gait Index (DGI) [14], and 6-minute walk test (6MWT) [15]. All clinical assessments were performed by a licensed physical therapist.

Data Analyses

Statistical analyses were conducted using SPSS version 20 (IBM Corporation; Armonk, New York). Following confirmation of normality, group means were compared across time points (pretraining, posttraining, and follow-up) using a one-way analysis of variance. For all tests performed, the level of significance was set at $\alpha = 0.05$. Post hoc correction for multiple comparisons was made using the Bonferroni method.

RESULTS

No adverse effects of training were reported. All but one subject completed the desired number of training sessions (i.e., 24) within the 10 wk period of time allowed. The one subject that did not complete training was withdrawn by the investigative team for noncompliance related to transportation issues. This subject did not report any adverse effects or perceptions of the training program. Data for this subject were not included in the analyses because they did not meet the a priori requirements for adherence.

Muscle Strength and Power

Following training, significant gains in bilateral PF and KE muscle strength were realized (**Table 1**). Specifically, PF MVIC increased by 25.0 and 23.3 percent in the paretic and nonparetic legs, respectively. Improvements in KE strength were not as large, with gains of 14.8 percent in the paretic side and 16.0 percent in the nonparetic side. Gains in KE peak power of 28.6 and 30.7 percent in the paretic and nonparetic limbs, respectively, were also found posttraining. Interestingly, gains in velocity of contraction were only found on the paretic side. With the exception of the KE peak velocity measures, all gains in muscle function were maintained throughout the follow-up period, with the indices of strength and power remaining significantly higher than pretraining values (**Table 1**).

Overground Walking

Both SSWS and FCWS increased following training (**Table 1**). SSWS increased from 0.71 to 0.92 m/s, and these gains were maintained (0.91 m/s) at the follow-up time point. Similarly, FCWS increased from 1.10 to 1.51 m/s posttraining, with speeds at follow-up (1.30 m/s) still higher than pretraining values. The increase in SSWS resulted from increases in cadence (13.6%) as well as both paretic (13.0%) and nonparetic (10.1%) step length, while changes in FCWS were primarily explained by faster cadences following training.

Clinical Assessments

No significant improvements in clinical assessments were found following training, although follow-up scores on the DGI were significantly higher than pretraining values (**Table 2**).

DISCUSSION

The results of this study demonstrate that 8 wk (24 sessions) of POWER training is feasible to implement in individuals following stroke and that increases in lower-limb

Table 1.
Muscle and locomotor function outcomes (mean ± standard deviation).

Outcome	Pretraining	Posttraining	Follow-Up
Overground Walking			
SSWS (m/s)	0.71 ± 0.39	0.92 ± 0.43*	0.91 ± 0.43*
FCWS (m/s)	1.10 ± 0.53	1.51 ± 0.78*	1.30 ± 0.60*
Muscle Strength and Power			
PF MVIC (ft/lb)			
Paretic	47.2 ± 27.0	59.3 ± 28.2*	55.9 ± 29.4*
Nonparetic	96.2 ± 25.4	118.6 ± 23.9*	113.6 ± 26.9*
KE MVIC (ft/lb)			
Paretic	93.8 ± 30.	107.8 ± 36.5*	111.4 ± 31.2*
Nonparetic	150.4 ± 34.52	174.4 ± 41.5*	172.3 ± 37.3*
KE Power (W)			
Paretic	6,369.0 ± 3,524.1	8,188.3 ± 3,878.0*	8,064.6 ± 2,421.1*
Nonparetic	12,540.1 ± 3,854.6	16,387.7 ± 4,441.5*	17,049.7 ± 6,847.0*
KE Velocity (°/s)			
Paretic	155.4 ± 63.5	198.0 ± 23.6*	179.3 ± 26.0
Nonparetic	224.0 ± 39.6	230.2 ± 58.8	238.1 ± 46.6

*Statistically significant difference compared with pretraining values ($p < 0.05$).
FCWS = fastest comfortable walking speed, KE = knee extensor, MVIC = maximum voluntary isometric contraction, PF = plantar flexor, SSWS = self-selected walking speed.

Table 2.
Clinical assessments (mean ± standard deviation).

Clinical Assessment	Pretraining	Posttraining	Follow-Up
FMA-S	14.6 ± 5.4	15.5 ± 5.1	14.7 ± 4.7
BBS	44.7 ± 11.6	45.0 ± 10.9	46.8 ± 12.4
DGI	16.9 ± 5.1	16.5 ± 6.3	18.0 ± 4.4*
6MWT	264.7 ± 147.3	319.1 ± 160.6	338.2 ± 167.9

*Statistically significant difference compared with pretraining ($p < 0.05$).
6MWT = 6-minute walk test, BBS = Berg Balance Scale, DGI = Dynamic Gait Index, FMA-S = Fugl-Meyer Assessment synergy subsection.

muscle strength and power as well as walking function may be realized. Unique aspects of POWER training include (1) the focus on high-velocity concentric contractions during resistive exercise (i.e., focus on muscle power generation) and (2) the combined use of task-specific and resistive exercise.

Velocity-dependent muscular deficits following stroke appear to be unique to high-velocity concentric muscle actions, with normalized muscle power generation seemingly preserved during eccentric contractions, thus the focus on high shortening velocities in the present study [5]. Moreover, interventions targeting muscle power (i.e., training at concentric high velocities) in the older adults significantly increase muscle strength yet elicit an over twofold greater improvement in peak power compared with training at normal velocities [16–17]. The high-velocity component is suggested to be critical to elicit these responses, because losses in muscle power with aging (as well as stroke) appear to be due to greater declines in the velocity of contraction rather than the force generating component of muscle power production. In the present study, greater gains in muscle power compared with strength were noted, although with the present design we were not able to test the functional significance of strength versus power.

Progressive resistance training is widely accepted as the most effective method for increasing muscular strength. Traditional clinical perspectives, however, often caution against high-exertion activities (e.g., muscle strengthening) following stroke because it is thought that these approaches can worsen spasticity [18]. To date, contemporary investigations have failed to demonstrate exacerbation of spasticity with high-exertion exercises and these activities are increasingly recognized as critical components of rehabilitation treatment following stroke [19–21]. Though some studies have questioned the effect of muscle strengthening on functional performance poststroke [22], resistance training is shown to improve lower-limb strength and, when delivered at appropriate intensities, provide significant functional benefit [23–24]. In fact, a recent quantitative review by Dickstein concluded that gains in lower-limb strength following resistance training have significant functional consequences in individuals poststroke [25].

Despite the relatively short duration of POWER training, the magnitude of increase in walking speed achieved in the present study (0.21 m/s) is comparable with recent, more lengthy task-specific approaches [26–27]. Importantly, this change in SSWS is greater than the minimally clinically important difference recently reported in subacute poststroke subjects [28]. Furthermore, gains in walking speed following POWER training also exceed the values for clinically important change reported by Fulk et al. following outpatient physical therapy [29]. Fulk et al. suggest that changes that exceed 0.175 and 0.190 m/s to be important to both patients and therapists, as well as useful for clinicians and researchers to set goals and interpret important change in patients poststroke [29].

Following stroke, there is a proportionally greater loss of muscle power than strength [5]. Pronounced velocity-dependent muscular deficits, in combination with substantial muscle weakness, significantly affect power generation when compared with neurologically healthy aged counterparts [5–6]. In mobility-limited elders, direct comparisons of power and strength demonstrate that muscle power consistently describes more of the variance in functional ability [7] and deficits in power generation are associated with increased levels of dependence, greater risk of falls, and decreased walking speeds [8–10]. Our focus in this study was on the (in)ability of poststroke muscle to generate power both in and away from functional task performance and to determine the feasibility and effects of an intervention targeting lower-limb power generation in both the paretic and nonparetic legs on functional (locomotor) recovery. Following POWER training, robust improvements in walking performance were realized, suggesting the potential effect of this type of training following stroke.

The lack of improvement in the clinical assessments in this study is not altogether surprising. The relatively high-functioning sample of poststroke subjects studied, as evidenced by the pretraining scores on clinical assessments, likely contributed to the lack of change in these outcomes. Given that one of the questions in this study was whether muscle power training may increase walking function, we think it noteworthy that although differences in 6MWT were not statistically significant (p = 0.06), the 72 m average improvement did exceed the minimal detectable change (i.e., 54.1 m) reported for individuals following stroke [30] as well as the minimally clinically important difference (30.1 m) reported in individuals with heart failure [31].

STUDY LIMITATIONS

Limitations of this study require discussion. The design of this study does not allow determination of the effectiveness of this type of training because there is no comparison group. Although there seems little benefit in making comparisons to an untrained group (e.g., control group) in studies of chronic stroke, future studies should determine whether and to what extent changes in function differ between this type of training and other common approaches to enhance locomotor recovery. In addition, the two types of activities integrated into the training in this study (i.e., high-velocity resistance exercises and fast walking) limit conclusions as to the independent contributions of each to improvements in muscle function or walking performance. It is likely that both approaches would positively affect functional performance; and thus, there could be benefit in determining the independent effects of each type of training. Finally, the relatively small sample size may limit the generalizability of the findings. Although these limitations are important to consider when interpreting the results of this study, we think the magnitude of the effects found within the relatively short duration of training provide a foundation for future studies of this intervention approach.

CONCLUSIONS

Twenty-four sessions of POWER training appear feasible and well tolerated in individuals with chronic poststroke hemiparesis. Further, improvements in muscular and locomotor function in these individuals may result from this type of training. Future studies should determine the efficacy of this intervention compared with other established approaches to improve poststroke locomotor function.

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Effects of Kinesio Tape application to quadriceps muscles on isokinetic muscle strength, gait, and functional parameters in patients with stroke

Abstract—The aim of this study was to evaluate the effects of Kinesio Tape (KT) application to quadriceps muscles on isokinetic muscle strength, gait, and functional parameters in patients with stroke. Twenty-four patients were allocated into KT and control groups. All patients participated in the same conventional rehabilitation program 5 times/wk for 4 wk. In addition, KT was applied to quadriceps muscles bilaterally to the patients in the KT group. Compared with baseline, peak torque levels increased significantly in both groups (all $p < 0.05$). However, change levels were significantly higher in the KT group than the control group at 60 degrees/second angular velocity (AV) in extension ($p = 0.04$) and 60 and 180 degrees/second AV in flexion (both $p = 0.02$) on the paretic side. Moreover, the change levels were more prominent in the KT group at 60 and 180 degrees/second AV in extension ($p = 0.03$ and $p = 0.04$, respectively) on the nonparetic side. Gait, balance, mobility, and quality of life values improved significantly in both groups (all $p < 0.05$), yet the change levels between the groups did not reach significance ($p > 0.05$). KT application to quadriceps muscles in addition to conventional exercises for 4 wk is effective on isokinetic but not functional parameters.

Key words: cerebrovascular disorders, gait, isokinetic, Kinesio Tape, Kinesio Taping, muscle strength, peak torque, quadriceps muscle, quality of life, rehabilitation, stroke.

INTRODUCTION

Kinesio® Tape (KT) has been widely used as an alternative therapy in people with several musculoskeletal disorders, those engaged in sports or neurological rehabilitation, and those with lymphedema because of its advantages (aesthetic, comfort, ease of application, and lack of side effects [aside from skin reactions]) [1–2]. It has been previously documented that KT enhances muscle activation and reeducation by increasing the subcutaneous space, enhancing blood flow, and providing tactile stimulation [1–2].

Effects of KT on muscle strength have been studied in nondisabled subjects and subjects with knee osteoarthritis, yet the results of these studies are conflicting [3–11]. Furthermore, previous studies focused on short-term effects of KT application. Effects of long-term KT application have not yet been studied. Effects of KT on muscle strength in patients with stroke have also not been studied.

Abbreviations: 6MWT = 6-minute walk test, 10 MWT = 10-meter walk test, AV = angular velocity, BBS = Berg Balance Scale, BMI = body mass index, FAC = Functional Ambulation Category, FIM = Functional Independence Measure, KT = Kinesio® Tape, MAS = Modified Ashworth Scale, PT = peak torque, RMI = Rivermead Mobility Index, SCT = Stair-Climbing Test, SS-QLS = Stroke-Specific Quality of Life Scale, TUG = Timed “Up and Go” test.

Accordingly, the objective of this study was to evaluate the effects of long-term KT application to quadriceps muscles on isokinetic muscle strength, gait, and functional parameters in patients with stroke. Moreover, KT was applied bilaterally in our study to allow us to compare the effects of KT on the paretic and nonparetic sides.

METHODS

Study Design

A total of 24 patients with subacute, chronic stroke were allocated into KT and control groups. The subjects participated in the same conventional rehabilitation program, including neurophysiologic exercises, range-of-motion exercises, posture training, walking training, and balance coordination training 5 times/wk for 4 wk. In addition, KT was applied to quadriceps muscles bilaterally to the participants in the KT group for 4 wk. All patients were evaluated before and after the treatment with respect to isokinetic muscle strength, balance, gait, mobility, and quality of life.

Participants

Patients with stroke who participated in an inpatient rehabilitation program in our rehabilitation center between June 2013 and June 2014 were enrolled.

Exclusion criteria were not cooperative, history of previous stroke, severe cardiovascular or pulmonary problems, uncontrolled hypertension, hemiplegia due to trauma/tumor, severe aphasia (which could affect evaluations), cerebellar infarct, musculoskeletal pain or other lower-limb disorder (e.g., fracture, severe osteoarthritis), or KT allergy or skin lesions in lower limbs.

Data Collection and Assessment Tests

Demographic and clinical features of the patients such as age, sex, body mass index (BMI), paretic side, time poststroke, and stroke type (thromboembolism/hemorrhage) were noted. Brunnstrom stages were used to evaluate motor recovery. Spasticity levels were assessed by the Modified Ashworth Scale (MAS). Ambulation levels were evaluated by the Functional Ambulation Category (FAC). Functional parameters, quality of life, gait parameters, mobility, and balance parameters of all patients were assessed by the Functional Independence Measure (FIM) Motor scale, Stroke-Specific Quality of Life Scale (SS-QLS), Timed "Up and Go" test (TUG), 10-meter walk test (10MWT), 6-minute walk test (6MWT), Stair-Climbing Test (SCT), Berg Balance Scale (BBS), and Rivermead Mobility Index (RMI).

Isokinetic Test Protocol

Peak and average isokinetic torque can be reliably used for assessing muscle strength of the lower limbs in patients with stroke [12–13]. The Biodex System 3 Pro multijoint isokinetic dynamometer (Biodex Medical Systems; Shirley, New York) was used to assess muscle strength in our study. All participants were informed about the test procedure to achieve maximum orientation.

The patients were seated in a reclined position (85° from the horizontal plane). A hip-waist belt, a cross-trunk belt, and a Velcro strap across the thighs were used for stabilization. The dynamometer was adjusted according to the line passing through the femoral condyles. The dynamometer effort arm was adjusted according to the length of the leg. The leg was fixed (over the lateral malleolus) by using a pad (**Figure 1**). Range of motion was set individually according to the active range of motion of the patients. Three submaximal trial repetitions were performed at both angular velocities (AVs) (60 and 180 °/s) before the test. Power graphics were shown on the monitor to provide visual feedback. The isokinetic test protocol was 5 maximal reciprocal contractions at 60 °/s AV,

Figure 1.
Isokinetic muscle strength measurement setup.

15 s rest period, then 10 maximal reciprocal contractions at 180 °/s AV.

Kinesio Taping

KT (Kinesio Tex Gold, Kinesio®; Albuquerque, New Mexico) was applied to the vastus medialis, vastus lateralis, and rectus femoris muscles bilaterally using the muscle stimulation technique (from origin to insertion without tension) in Kase et al. [1]. Subjects wore the tape for 4 wk, and it was changed every 3–7 d. All tapes were prepared individually as "Y-bands." The edges of the bands were squared.

For the rectus femoris muscle, the tape was applied from 10 cm below the anterior superior iliac spine to the superior edge of the patella (without tension). Then, the tape was crossed from the edges of the patella (with maximum tension) and fixed below the inferior edge of the patella while the knee was flexed. For the vastus lateralis muscle, the tape was applied from the great trochanter to the lateral edge of the patella (without tension). The tape was then crossed from the lateral edge of the patella (with maximum tension) and fixed below the inferior edge of the patella while the knee was in flexed position, and then another piece of tape was fixed over the fibular head. For the vastus medialis muscle, KT was applied from the middle third of the medial thigh to the medial edge of the patella (without tension). Next, the tape was crossed from the medial edge of the patella (with maximum tension). Finally, another piece of tape was fixed over the tibia (**Figure 2**).

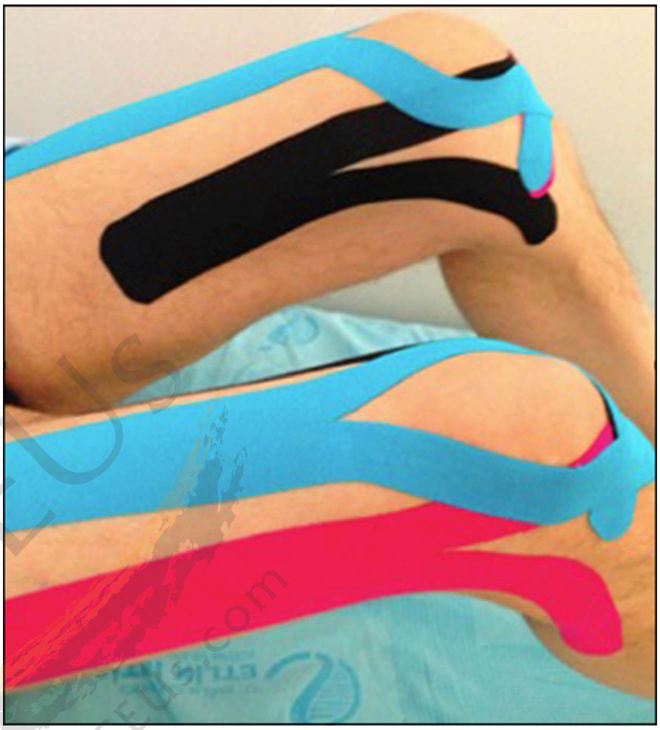

Figure 2.
Kinesio Tape application to vastus medialis, vastus lateralis, and rectus femoris muscles.

Functional Independence Measure

The FIM is composed of 18 items. While 13 of the items assess motor tasks, 5 assess cognitive tasks. In this study, FIM Motor scores were used. Motor items mainly include self-care activities, sphincter control, transfers, and locomotion. Each item is scored from 1 to 7, and higher scores demonstrate better functioning. FIM is valid and reliable for assessing functionality in patients with stroke [14].

Rivermead Mobility Index

RMI is a valid and reliable test for subacute, chronic stroke that is used for assessing functional mobility such as gait, balance, and transfers. The RMI includes the following items: turning over in bed, lying to sitting, sitting balance, sitting to standing, standing, transferring, walking inside/outside, climbing stairs, picking up off floor, climbing up and down four steps, and running. Each item is scored 0 or 1. Higher scores show better mobility performance. RMI has been previously reported to be a useful scale for the assessment of mobility in patients with stroke [15].

Timed "Up and Go" Test

Subjects were asked to stand up from a chair with an armrest, walk 3 m at a comfortable and safe walking speed, turn around, and sit down. The time required to carry out this task was measured. The TUG can be used for measuring basic mobility skills after stroke [16].

6-Minute Walk Test

6MWT assesses endurance. The subjects were instructed to walk (at their preferred speed) through a corridor (flat surface), and the distances walked in 6 min were measured. Subjects were allowed to use assistive devices. 6MWT is reliable for patients with stroke [17].

10-Meter Walk Test

This test is used to assess walking speed. Subjects are instructed to walk 10 m without personal assistance. The time is measured for the middle 6 m. An average of three repetitions was calculated. 10MWT is valid and reliable for patients with stroke [18].

Berg Balance Scale

BBS assesses static balance. It has the following items: reaching forward with an outstretched arm, standing with eyes closed with one foot in front, turning, retrieving an object from the floor, standing on one foot, sitting to stand, turning 360°, standing, placing the alternate foot on a stool, transferring, standing with feet together, and standing to sitting unsupported. Each item was scored from 0 to 4. The maximum score is 56. Higher BBS scores indicate better balance. BBS is valid and reliable for patients with stroke [19].

Stroke-Specific Quality of Life Scale

SS-QLS includes 49 items. The major items are energy, family roles, language, mobility, mood, personality, self-care, social roles, thinking, upper-limb function, vision, and work/productivity. Each item is scored from 1 to 5. Higher scores show better functioning [20].

Functional Ambulation Category

The FAC classifies ambulation of patients into six levels:

0. Nonfunctional, ambulates only with parallel bars.
1. Ambulates with continuous manual contact of one person.
2. Ambulates with light touch of one person.
3. Ambulates without touch but with supervision.
4. Ambulates independently on level surfaces, but not on stairs.
5. Ambulates independently on stairs and unlevel surfaces [21].

Stair-Climbing Test

The SCT is a tool used for assessing ascending and descending stairs. A four-step ascend and descend was used, and duration to finish a set was recorded. Lower values of SCT show better performance [22].

Statistical Analysis

The data was analyzed with SPSS for Windows (IBM; Armonk, New York). A Shapiro-Wilk test was used to determine whether the continuous variables were normally distributed. Descriptive statistics are shown as mean ± standard deviation or median (minimum, maximum).

The comparison of the means and medians of the groups was completed with a Student *t*-test. Categorical variables were analyzed by Pearson chi-square or Fisher exact tests. A Wilcoxon signed rank test was used if there was a significant difference before and after the treatment in the groups. A *p*-value of <0.05 was considered statistically significant.

RESULTS

Demographic and clinical features of the groups are shown in **Table 1**. The groups were similar with respect to age, sex, BMI, paretic side, Brunnstrom stages, FAC, time poststroke, and MAS (all $p > 0.05$). By contrast, there was a significant difference between the groups for stroke etiology ($p = 0.03$). In the KT group, 8 patients had thromboembolic stroke and 4 patients hemorrhagic stroke, and in the control group, 12 patients had thromboembolic stroke.

Paretic side peak torque (PT) values of each group before and after treatment are shown in **Table 2**. Compared with baseline, PT levels increased significantly in both groups after treatment (all $p < 0.05$). However, change levels were significantly higher in the KT group than in the control group at 60 °/s AV in extension ($p = 0.04$) and 60 and 180 °/s AVs in flexion (both $p = 0.02$).

Nonparetic side PT values of each group before and after treatment are shown in **Table 3**. Although PT values increased significantly in both groups (all $p < 0.05$), the change levels were more prominent in the KT group at 60 and 180 °/s AVs in extension ($p = 0.03$ and $p = 0.04$, respectively).

Gait, balance, mobility, quality of life, and functional parameters of the groups are shown in **Table 4**. Compared with baseline, all values increased significantly in both groups (all $p < 0.05$); however, the change levels between the groups did not reach significance ($p > 0.05$). For side effects, a temporary skin reaction was seen in only one patient during the last application.

Table 1.
Clinical and demographic features of study subjects. Data presented as mean ± standard deviation or *n* (%).

Variable	Kinesio Tape (*N* = 12)	Control (*N* = 12)	*p*-Value
Age, yr	48.8 ± 12.9	50.9 ± 12.7	0.70
Sex (M/F)	5/7	7/5	0.41
BMI (kg/m^2)	25.7 ± 4.1	26.4 ± 2.2	0.17
Time Poststroke, mo	6.9 ± 5.3	3.8 ± 2.1	0.09
Etiology			
Thromboembolism	8 (67)	12 (100)	**0.03**
Hemorrhagia	4 (13)	0 (0)	
Paretic Side			
Right	6 (50)	8 (67)	0.25
Left	6 (50)	4 (33)	
Brunnstrom (LL)			
Grade 4	5 (41.7)	5 (41.7)	>0.999
Grade 5	5 (41.7)	5 (41.7)	
Grade 6	2 (16.7)	2 (16.7)	
MAS	0.5 ± 0.5	0.5 ± 0.5	>0.999
FAC	3.3 ± 0.5	3.7 ± 0.5	0.60

Note: Bold *p*-value shows significance.
BMI = body mass index, F = female, LL = lower limb, M = male, MAS = Modified Ashworth Scale, FAC = Functional Ambulation Category.

Table 2.
Paretic side peak torque (PT) values before and after treatment and change levels between groups. Data presented as mean ± standard deviation.

Isokinetic Parameter	PT Before Treatment	PT After Treatment	Change Level	*p*-Value
Knee Extension 60°/s AV				
KT	46.8 ± 20.8	65.7 ± 25.5	18.9 ± 15.5	**0.04**
Control	40.0 ± 26.2	47.7 ± 29.5	7.7 ± 4.8	
Knee Flexion 60°/s AV				
KT	19.0 ± 11.0	29.5 ± 16.3	6.4 ± 1.8	**0.02**
Control	12.1 ± 8.0	14.4 ± 9.6	1.9 ± 0.5	
Knee Extension 180°/s AV				
KT	33.8 ± 11.3	40.7 ± 16.9	10.3 ± 8.1	0.06
Control	25.5 ± 7.0	29.7 ± 7.3	4.4 ± 1.6	
Knee Flexion 180°/s AV				
KT	11.9 ± 3.3	18.7 ± 7.1	8.0 ± 5.7	**0.02**
Control	14.7 ± 9.5	19.9 ± 8.0	3.5 ± 1.8	

Note: *p*-value shows comparison of change levels after treatment between groups; bold *p*-values show significance.
AV = angular velocity, KT = Kinesio Tape.

DISCUSSION

In this study, we aimed to elucidate, for the first time in the literature (to the best of our knowledge), whether bilateral KT application to quadriceps muscles is effective on isokinetic and functional parameters in patients with stroke. The most significant result of our study was that KT increased muscle strength on both the paretic and nonparetic sides, while functional parameters did not improve.

Kase et al. have reported that KT increases muscle activation through the following two mechanisms [1]. First, KT stimulates the cutaneous receptors by tactile stimulation, and second, KT increases the subcutaneous space and blood flow, both of which result in muscle activation. In the literature, there are several studies showing the effects of KT on muscle strength [2–11]; however, these studies have conflicting results. While some of the studies reported improvement in muscle strength [9,11], others found adverse outcomes [3–8].

Table 3.
Nonparetic side peak torque (PT) values before and after treatment and change levels between groups. Data presented as mean ± standard deviation.

Isokinetic Parameter	PT Before Treatment	PT After Treatment	Change Level	*p*-Value
Knee Extension 60°/s AV				
KT	64.1 ± 26.5	82.5 ± 32.7	17.7 ± 10.0	**0.03**
Control	64.9 ± 28.0	73.9 ± 27.3	8.9 ± 5.4	
Knee Flexion 60°/s AV				
KT	37.0 ± 26.1	43.0 ± 26.3	6.0 ± 5.2	0.60
Control	24.6 ± 13.5	31.5 ± 14.5	6.9 ± 2.4	
Knee Extension 180°/s AV				
KT	44.2 ± 22.2	56.8 ± 26.6	12.5 ± 9.0	**0.04**
Control	40.2 ± 22.9	46.0 ± 23.9	5.8 ± 2.5	
Knee Flexion 180°/s AV				
KT	21.6 ± 15.0	28.0 ± 17.2	6.4 ± 4.4	0.19
Control	15.0 ± 4.6	19.5 ± 6.2	4.4 ± 2.4	

Note: *p*-value shows comparison of change levels after treatment between groups; bold *p*-values show significance.
AV = angular velocity, KT = Kinesio Tape.

Table 4.
Gait, balance, mobility, and quality of life values before and after treatment and change levels between groups. Data presented as mean ± standard deviation.

Variable	Before Treatment	After Treatment	Change Level	*p*-Value
FIM (Motor)				
KT	56.3 ± 12.0	63.6 ± 10.9	7.3 ± 2.4	0.93
Control	70.2 ± 6.0	78.1 ± 5.2	7.4 ± 1.8	
SS-QLS				
KT	158.9 ± 23.6	170.9 ± 22.1	3.4 ± 1.0	0.44
Control	149.0 ± 18.8	161.2 ± 19.3	2.2 ± 0.6	
10MWT				
KT	15.7 ± 3.8	12.1 ± 2.6	1.5 ± 0.5	0.29
Control	18.1 ± 6.4	15.3 ± 5.3	1.8 ± 0.5	
6MWT				
KT	284.0 ± 73.5	309.8 ± 68.9	19.5 ± 8.9	0.60
Control	211.6 ± 85.4	233.7 ± 84.0	9.1 ± 2.6	
SCT				
KT	14.0 ± 3.0	11.6 ± 3.0	2.3 ± 1.0	0.65
Control	17.5 ± 9.7	15.5 ± 7.9	2.0 ± 2.1	
TUG				
KT	15.5 ± 3.3	12.3 ± 2.7	1.3 ± 0.4	0.21
Control	17.5 ± 8.3	15.2 ± 6.7	1.9 ± 0.5	
BBS				
KT	30.2 ± 8.0	35.1 ± 7.8	4.9 ± 3.3	0.51
Control	46.5 ± 4.5	50.8 ± 3.4	4.1 ± 1.9	
RMI				
KT	9.4 ± 3.1	11.5 ± 3.8	1.9 ± 1.1	0.06
Control	11.2 ± 1.6	12.3 ± 1.1	1.0 ± 0.9	

Note: *p*-value shows comparison of change levels between groups.
6MWT = 6-minute walk test, 10MWT = 10-meter walk test, BBS = Berg Balance Scale, FIM = Functional Independence Measure, KT = Kinesio Tape, RMI = Rivermead Mobility Index, SCT = Stair-Climbing Test, SS-QLS = Stroke-Specific Quality of Life Scale, TUG = Timed "Up and Go" test.

Wong et al. evaluated the effects of KT application to quadriceps muscle in nondisabled subjects [5]. Although total work and PT values did not change in their study, time to PT decreased significantly. In a controlled trial by Lins et al., 60 nondisabled patients were randomized into KT, elastic bandage, and control groups [6]. KT was applied to vastus medialis, vastus lateralis, and rectus femoris muscles in the KT group. However no significant differences were found after application in isokinetic, postural balance, or functional parameters. Moreover, in a single-blind, placebo-controlled, crossover study by Vercelli et al., 36 nondisabled subjects were randomized into three groups as follows: KT with stimulation technique, KT with inhibition technique, and sham band [8]. Isokinetic parameters did not change in any of the three groups. Anandkumar et al. randomized 40 patients with knee osteoarthritis into control and KT groups and found that posttest isokinetic parameters and pain scale scores showed statistical improvement [11]. Fratocchi et al. have shown significant improvement in PT values of biceps brachii muscles in the KT group versus the placebo band group [9].

In our study, we enrolled patients with hemiplegia who were in a rehabilitation program, which is different from the previous studies. In addition, we applied KT bilaterally in order to compare the paretic and nonparetic sides. Regarding the time frame, we evaluated long-term effects rather than short-term effects. All isokinetic parameters showed improvement in both groups after the treatment ($p < 0.05$); however, the increases were more prominent in the KT group. Stroke duration was shorter in the control group ($p < 0.05$). We could speculate that paretic muscles have more sensitivity to tactile stimulation and muscle reeducation than nonparetic muscles.

Another important issue in our study was the increase in the flexion parameter. Although we applied KT only to extensor muscles, flexor muscles showed improvement on the paretic side as well. We could attribute this result to the fact that the strengthening in the knee extensors and the mechanical support of KT contribute to better knee control. On the other hand, the increase in isokinetic parameters did not result in improvement of functional parameters and gait. This could have been because muscle strength did not develop enough or because functional parameters are related to several other factors, such as proprioception and balance. Also, KT may need to be applied for longer periods.

As for side effects, a skin reaction was seen only in one patient. It was temporary and seen only during the last application (at the end of the fourth week). We did not find any side effects that could have discontinued rehabilitation, caused discomfort, or affected activities of daily living. We did not use a satisfaction scale in our study. Nonetheless, we received positive feedback from the patients regarding the KT application. For instance, some patients stated that they could feel mechanical support and perform knee extension better. We believe that this can result in better motivation and self-confidence during the rehabilitation process.

LIMITATIONS

First, our sample size could have been larger. Although the groups were similar regarding age, BMI, sex, and functional parameters, stroke patients show heterogeneity. Second, lack of a crossover design and follow-up evaluations are limitations of our study. Third, the selection bias of patients who had high levels of function according to Brunnstrom grading is a limitation as well. However, it would not be possible to perform this study on patients with low levels of functioning.

CONCLUSIONS

In light of our results, KT application to quadriceps muscles in addition to conventional exercises for 4 wk seems to be effective on isokinetic parameters on the paretic and nonparetic side, but not on functional parameters. Crossover and long-term follow-up studies regarding the effects of KT on muscle strength or proprioception are awaited.

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