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orthopaedics@physiotherapy.ca

Strength Training: The Use of the Theravital Bicycle Trainer for the Treatment of Gait Dysfunction in Extended Care Patients

John Branten, PT, Dip Geriatric PT
Chantal Leijgraaff, PT
Peter Huijbregts, PT, MSc, MHSc, DPT, OCS, FAAOMPT, FCAMT

** Mr. John Branten is a specialist geriatric physical therapist and team leader for allied health services in the extended care facility "Joachim en Anna" in Nijmegen, the Netherlands.*
** Ms. Chantal Leijgraaff is a staff physical therapist in the extended care facility "Joachim en Anna" in Nijmegen, the Netherlands.*
** Dr. Peter Huijbregts is an Assistant Professor at the University of St. Augustine for Health Sciences in St. Augustine, FL, and a consultant at Shelbourne Physiotherapy in Victoria, BC*

Correspondence Address
Dr. Peter Huijbregts, PT, Shelbourne Physiotherapy, 100B-3200 Shelbourne Street
Victoria, BC V8P 5G8 Canada, (250) 598-9828 (phone) shelbournephysio@telus.net,

Abstract

This article discusses the indications for the Theravital Bicycle Trainer as a therapeutic intervention for extended care residents with active instability of the hip or combined active instability of both the hip and the knee. Data were collected on leg extension strength and gait function. Nineteen patients referred to physical therapy with a diagnosis of gait dysfunction and strength deficits participated in the study; data from 18 patients were used for a retrospective statistical analysis. The Theravital intervention resulted in significant strength gains in both patient groups. Only the hip instability group showed significant improvements in gait function. The Theravital Bicycle Trainer seems to provide an effective therapeutic intervention for elderly patients with gait dysfunction due to hip abductor weakness. Patients with both hip and knee instability likely benefit more from a combination of Theravital training and open kinetic chain knee extensor strengthening. Patients with marked hip abductor weakness also seem to benefit more when open kinetic chain exercises for the hip abductor muscles are added to their therapeutic program. Further research is required to support these recommendations.

Introduction

On average, a healthy 80 year-old has only half the strength of a person aged 40[1]. An extended care resident has again only 60% of the strength of a healthy person of the same age[2]. In an extended care resident with a previous history of multiple falls, the strength of the main leg muscles will have further decreased to 30% of age-related normal levels[2]. Rantanen[3] studied the effect of strength and balance on the quality of gait in 1,002 elderly women: the study showed a strong correlation between gait function and leg muscle strength.

An earlier quasi-experimental study within our facility (one-group pre-test post-test design) investigated the effects of open kinetic chain exercises for the quadriceps muscles as an intervention for improving gait in a population of extended care patients with thigh weakness4. This study lent support to the above-mentioned correlation between leg muscle strength and gait function: over a six-week period mean knee extension strength increased by 139% with concurrent improvement in gait function[4]. This substantial strength gain (with post-intervention values more than double the pre-intervention values) was explained by the often markedly diminished pre-intervention strength values in our study population.

In the discussion section of this earlier study[4], the suggestion was made to strengthen not just the quadriceps muscles but also to include, e.g., the gluteal muscles by way of a therapeutic intervention program consisting of closed kinetic chain exercises. Another suggestion made was to study the effect of strength training on different types of gait dysfunction. The goal of this study is to address both suggestions mentioned above:

1. What is the effect of closed kinetic chain strength training of the major leg extensor muscles, i.e., gluteal and quadriceps muscles?
2. What is the effect of an increase in leg extension strength on different types of gait dysfunction?

In our study, the gait dysfunctions of interest were active instability of the hip and/or the knee. In this study, active instability of the hip was operationally defined as the presence of a Trendelenburg gait pattern; the operational definition for active knee instability was the presence of a ventral giving way of the knee during stance phase.

Leg extension strength was trained with a Theravital Bicycle Trainer (Figure 1). The Theravital is a movement trainer that has a passive as well as an active mode. The cycling motion on the Theravital is a closed kinetic chain exercise. In this study, a closed kinetic chain exercise was operationally defined as a multi-joint movement with a movement structure similar to that of an ADL-function[5], in this case the ADL functions of gait and sit-to-stand transfers.

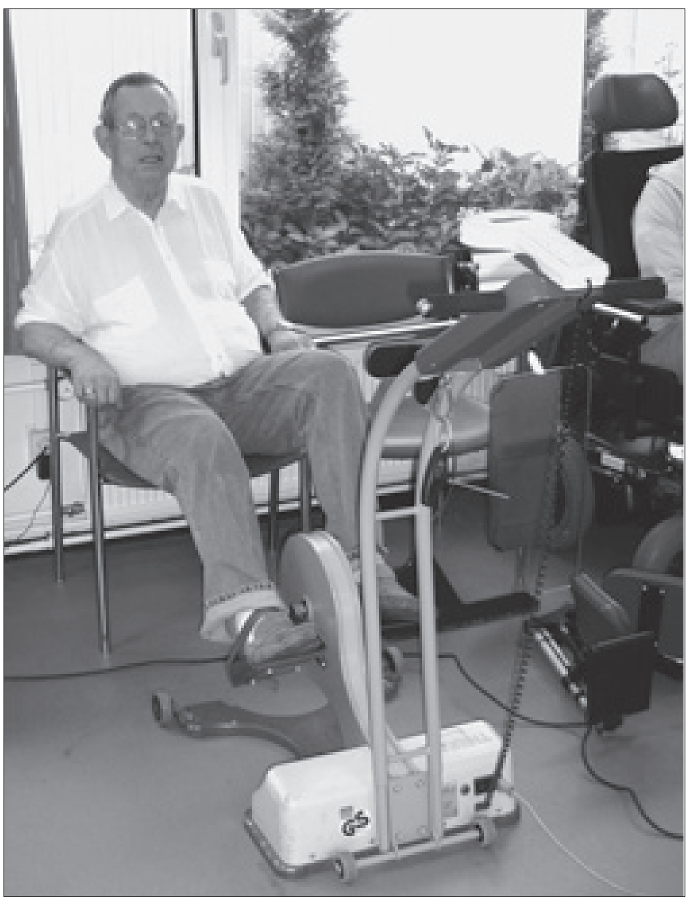

Figure 1. *Man exercising on Theravital Bicycle Trainer.*

Material and Methods

For this study, we used the active mode of the Theravital Bicycle Trainer: the patient was seated in a (wheel) chair and performed a cycling motion against an electronically adjustable resistance. This resistance is adjustable in 15 equally incremental steps. The Theravital Bicycle Trainer allows for closed kinetic chain strength training of the leg muscles, even for patients who have great difficulty with or are unable to ambulate.

The exercise protocol called for three training sessions a week. Every session consisted of three sets of 10 revolutions on the Theravital Bicycle Trainer at a 10-repetition maximum (RM) resistance[5]. The therapist adjusted the resistance such that correct form could no longer be maintained on the ninth or tenth revolution, i.e., the patient started making compensatory movements and/or the movement speed decreased. Every new session started with the 10 RM load established during the previous training session. The resistance was adjusted up to the next higher setting if loss of correct form was not evident at the ninth or tenth revolution. Patients rested a few minutes between sets. The resistance level was considered optimal if it resulted in loss of correct form as defined above on the ninth or tenth revolution of a subsequent set. This protocol was chosen because it has proven effective for strength training in elderly patients[4,6].

Treatment outcome was measured with the Functional Ambulation Categories (FAC) tool (Table 1). Before and after a training session the patient walked some distance with the therapist or the patient did an assisted transfer. This provided the FAC score for that session. The FAC tool documents the assistance needed or, conversely, the degree of independence during gait. Resistance used on the Theravital exercise protocol, FAC score, and relevant information, e.g., the use of assistive devices for gait was recorded for every exercise session. Informed patient consent was obtained for a retrospective data collection and analysis of data collected during all exercise sessions. The institutional review board was consulted regarding this study. They deemed a formal review of the study unnecessary. For data collection we chose a period during which the patients were able to exercise for a few consecutive weeks without interruptions as a result of pathology (absence due to illness). The initial and final data were collected and analyzed for every participating patient.

Subjects

The study population was a sample of convenience: all extended care residents referred for physical therapy during a four-month period with a diagnosis of gait dysfunction and strength deficits (manual muscle test of knee extensors or hip abductors ≤ 4/5) were exercised according to the protocol described above. The physical therapist indicated on the intake form if the gait dysfunction was the result of:

- An active instability of the knee (defined as ventral giving way of the knee during the stance phase of gait)

- An active instability of the hip (defined by the presence of a Trendelenburg gait pattern)
- An active instability of both joints

Patients with lower extremity impairments that made strength training on the movement trainer difficult, e.g. pain due to heel ulcer or degenerative joint disease of the knee were excluded from the study.

In total, 19 patients and six therapists participated in this study. The group of 19 patients consisted of 10 patients with an active instability of the hip (hip group), eight patients with active instability of hips and knees (hip/knee group), and only one patient with an active instability of just the knee. This "group" was not analyzed for this study due to its limited group size.

Statistical Analysis

We used a paired t-test to determine the level of statistical significance for the strength gain (defined as an increase in Theravital resistance as used in the study protocol) in the two groups. We used an analysis of variance (ANOVA) to compare the strength gain between both groups. We also compared both groups after correction for possible relevant co-factors by way of an analysis of covariance (ANCOVA). Spearman's $\rho(\rho_s)$ was used to express the correlation between leg extension strength and gait function. The Wilcoxon Rank Correlation Coefficient was used to determine the level of statistical significance for improvements in gait function as measured with the FAC-scores. For this study, we set the level of statistical significance at P=0.05.

Results

The large number of different medical diagnoses in our study population (Table 2) was partly the reason for the large variation in pre- and post-intervention strength and FAC-score. The method of data collection used in this study also produced a large variation in the number of days patients participated in the study (min. 21, max. 70 days) (Table 2).

The study showed increased extension strength of the leg as evidenced by an increased resistance on the Theravital Trainer and improved gait in both the hip/knee and the hip group. The strength gain was statistically significant in both the hip/knee and the hip group, P=0.001 and P=0.004, respectively. Figure 2 shows that the strength gain was greater in the hip group than in the hip/knee group. This difference in strength gain becomes even more obvious when reviewing the weekly strength increase as documented in Table 2: the average weekly strength increase of the patients in the hip group was almost three times the size of that of the patients in the hip/knee group. The ANOVA also documented a statistically significant difference between the strength gain in the hip group as compared to the hip/knee group (3.162; 95% confidence interval (CI): 0.871-5.454; P=0.01).

There was a clear difference in pre-intervention strength between the hip and the hip/knee group: the patients in the hip group started off in this study with relatively low levels of strength. This pre-intervention strength difference could explain the greater strength gains for the patients in the hip group. Higher levels of pre-intervention strength may have resulted in more of a ceiling effect for the patients in the hip/knee group. In addition, there was a difference in the number of days that both groups participated in the study. This difference may also have affected the outcomes. Statistical analysis using an ANCOVA proved that these assumptions were not substantiated. Even after correction for the above-mentioned co-variables (number of days and pre-intervention strength) the strength gains for the hip group were significantly (and to an almost similar

Table 1. FAC score. Low scores describe the amount of assistance required; high scores describe level of independence

ACTIVITY	NUMERICAL SCORE
Patient is unable to ambulate independently or needs assistance from more than one person with ambulation.	FAC=0
Patient needs continuous assistance from one person to maintain weight bearing and balance during ambulation.	FAC=1
Patient needs almost continuous assistance from one person to maintain balance or coordination during ambulation.	FAC=2
Patient needs supervision (verbal feedback or occasional physical assistance) from one person. Physical contact is needed only occasionally. Independent ambulation is (as yet) considered unsafe.	FAC=3
Patient can ambulate independently on level surfaces, but needs assistance on unlevel surfaces, e.g. stairs, inclines, or non-paved surfaces.	FAC=4
Patient can ambulate independently irrespective of surface, i.e., on stairs, inclines, or other unlevel surfaces.	FAC=5

Active hip instability group

nr	age	diagnosis	Resistance at start of interven-tion	Resistance at end of interven-tion	Absolute increase in resis-tance[1]	% in-crease per week	FAC at start	FAC at end	Absolute increase FAC[2]	Number of days
2	92	Femoral neck fracture	7	7	0	0	2	3	1	42
6	95	Femoral neck fracture	2	12	10	19,7	0	4	4	69
11	81	Femoral neck fracture	2,5	9	6.5	24	3	4	1	42
12	81	Decreased ac-tivity level	10	14	4	8,9	4	4	0	28
13	88	Femoral neck fracture	5,5	10	4.5	7,8	1,5	4	2.5	56
14	86	Decreased ac-tivity level	7,5	15	7.5	9,1	3	4	1	56
16	89	Femoral neck fracture	3	10	7	12,9	0	0	0	70
17	84	Decreased ac-tivity level	5	9,5	4.5	23,9	3	4	1	21
18	83	Gait dysfunc-tion	2	7	5	23,3	1	3	2	42
19	79	Decreased ac-tivity level	6	13	7	29,7	3	4	1	20
mean	85,8		5,05	10,65		15,93	2,05	3,4		44,6
SD	4,92		2,54	2,63		9,01	1,31	1,20		17,20

[1]paired t-test, p< .000
[2]Wilcoxon Matched Pairs Signed Rank Correlation Coefficient, p=0.012
SD = standard deviation

Active hip and knee instability group

nr	age	diagnosis	Resistance at start of interven-tion	Resistance at end of interven-tion	Absolute increase in resis-tance[3]	% in-crease per week	FAC at start	FAC at end	Absolute increase FAC[4]	Number of days
1	89	Decreased activity level	8	13	5	5	4	4	0	70
4	79	Femoral neck fracture	2	3	1	7,5	0	0	0	42
5	79	CVA	6	8	2	3,3	2	3	1	63
7	88	Decreased activity level	5	8	3	10	4	4	0	35
8	85	Gon- and coxarthrosis	8	11	3	3,7	1	4	3	63
9	92	CVA	9	12	3	3,7	3,5	4	0.5	56
10	86	Gon- and coxarthrosis	6	9	4	8,6	3	4	1	35
15	88	Femoral neck fracture	7	6,5	--0.5	-2,4	3	3	0	21
mean	85,75		6,38	8,81		4,93	2,56	3,25		48,13
SD	4,35		2,06	3,02		3,63	1,36	1,30		16,21

[3]paired t-test, p=0.004
[4]Wilcoxon Matched Pairs Signed Rank Correlation Coefficient, non-significant, 0.068
SD = standard deviation

Table 2. Data overview: Effect of Theravital training. Only the hip and hip/knee groups are represented (* non-significant). The paired t-test and the Wilcoxon Matched Pairs Signed Rank Correlation Coefficient are calculated for the pre- and post-intervention differences for resistance and FAC.

extent as before exclusion of said co-variables) better than the strength gains in the hip/knee group (3.176; 95 CI: 0.957-5.395; P=0.008).

As did Rantanen[3] we also found a strong correlation in our small study population between extension strength of the legs and gait function ((s=0.76, P=0.0001). This may in fact provide us with an early clinical prognostic indicator for successful rehabilitation. Further research to substantiate this assumption is required.

The Wilcoxon Rank Correlation Coefficient showed a significant improvement of gait function (as measured with the FAC-score) in the hip group (P=0.01, z=2.5205). However, for the patients in the hip/knee group the improvement in gait was not statistically significant (P=0.0679, z=1.8257) (see Table 2 for further data).

Discussion

The fact that a Trendelenburg gait pattern responded positively to a strength training intervention that mainly seemed to affect the extensor but not the abductor muscles of the hip is somewhat surprising. Possibly strength training of the prime movers also loads these synergistic muscle groups to such an extent that it causes an increase in strength. The effect on the abductor muscles may also be indirect: perhaps the strength training-mediated improvements in gait provided the stimulus for an increase in abductor strength? Fiatarone et al[7] reported a similar phenomenon: open kinetic chain strength training of the quadriceps resulted in an increase in hamstrings strength, a muscle group that functions synergistically to the quadriceps in many closed kinetic chain functions.

To our surprise two patients (from the hip/knee group) started having increasing symptoms of active instability of the knee while participating in the Theravital strength training protocol. Both patients had participated in an open kinetic chain exercise protocol for strengthening the quadriceps prior to this study. Theravital resistance increased and the patients displayed gait patterns with increasing hip stability, yet they had increasing difficulty with rising from a seated position, had more knee flexion during gait, and eventually had problems with the knee giving way during the stance phase of gait. Post-intervention measurements showed a decrease in quadriceps strength despite weeks of Theravital strengthening. We have two different hypotheses to explain this unexpected loss of quadriceps strength:

- During a closed kinetic chain extension activity, such as the leg extension exercise on the Theravital Bicycle Trainer, bi-articular muscles function to transfer energy from proximal to more distal joints5,8. Hip extension as a result of gluteal contraction lengthens the rectus femoris muscle over the hip joint. Even a static contraction of the rectus femoris transforms this muscle to a somewhat rigid connection between the hip and the knee joint: extension of the hip thus leads to extension of the knee. In theory, the mono-articular vasti muscles do not even need to contract for knee extension to occur during a closed kinetic chain activity. These minimal contractile requirements on the knee extensor muscles may provide an insufficient stimulus for increasing (or even maintaining) knee extensor strength.
- A second possible reason for the observed loss of quadriceps strength is the disadvantageous location of the knee extensors within the involved kinetic chain. The Theravital pedals provide a reaction force directed centrally. The line of action of this reaction force runs much closer to the center of rotation of the knee joint than it does to the center of rotation of the hip joint (Figure 3). Even though the Theravital exercise provides resistance to the entire extension chain, this difference in lever arms results in higher demands on the hip joint extensor muscles than on the knee extensor muscles. The Theravital exercise seems to provide sufficient stimulus for strengthening the hip extensors, but this stimulus may be insufficient to increase (or even maintain) quadriceps strength.

The insufficient training stimulus for the quadriceps might explain the smaller strength gains in the hip/knee group: a lag in knee extensor strength gain will negatively affect kinetic chain extension strength gains. A training protocol which includes both open and closed kinetic chain exercises is likely more indicated to improve strength and gait function in patients with both hip and knee instability when walking.

Considering this it is in fact surprising that the increase in FAC-score in the hip/knee group was only slightly smaller than the increase in FAC-score in the hip group. Perhaps the limited group sizes provided too little power for our statistical analysis to show a significant difference in the FAC-score for this group.

Two patients in the hip group made very slow progress during their rehabilitation. These patients had a very marked pre-intervention Trendelenburg gait pattern. Where some patients were able to somewhat stabilize their hip during gait resulting in only a slight drop of the contralateral iliac crest, these two patients were so deficient in hip abductor strength that they were unable to weight bear at all on the affected leg. These two patients participated in the study but seemed to benefit more from a post-study 10 RM open kinetic chain hip abductor strengthening protocol. For patients with marked hip abductor weakness the closed kinetic chain Theravital exercise protocol seems to provide an insufficient stimulus for strength gain in the hip abductor muscles.

This article reaches conclusions with regard to the effectiveness of strength training in elderly patients that are different from those in a recent study by De Vreede et al[9]. These authors compared the effects of a regimen of multiple isolated progressive resistance exercises for a large number of different muscle groups to intensive, functional, ADL-based training in a group of high-functioning elderly subjects with good to excellent age-referenced gait function. In this study the strength training group had significant gains in strength over the functional training group at a 3-month post-test whereas function as measured on an ADL-test increased only in the latter group. At 12 months, strength measures returned to baseline in the strength training group but functional gains in the functional training group were still significant when compared to baseline. De Vreede et al[9] concluded that strength training did not produce functional improvements because isolated strength training was insufficiently specific and did not address "...the complex interplay of cognitive, perceptual and motor functions ... involved in the performance of daily tasks..." In contrast, Buchner et al10 studied the correlation between strength and function in 409 elderly subjects and noted that whereas large changes in physiological capacity (i.e., strength) may have little or no effect on daily function in healthy adults, small changes may produce large effects on performance in frail adults. This may serve to explain the seemingly inconsistent findings of studies researching the effect of strength training on functional improvements in elderly subjects: elderly patients with limited gait function (FAC 0-4) seem to benefit greatly from isolated strength training but high-functioning elderly subjects derive little benefit from this intervention[4,6,7].

Conclusion

Strength training with a Theravital Bicycle Trainer appears to be an effective method for increasing closed kinetic chain leg extension strength for patients with gait dysfunction as a result of hip instability and combined hip and knee instability. Theravital training also resulted in significantly improved gait function for patients with hip instability. Therefore, a 10 RM protocol using the Theravital Bicycle Trainer seems to provide an effective therapeutic intervention for elderly patients with gait dysfunction due to hip abductor weakness. These study results may also apply to other commercially available equipment providing a closed kinetic chain exercise stimulus for strengthening leg extension. Patients with both hip and knee instability likely benefit more from a combination of Theravital training and open kinetic chain knee extensor strengthening. Patients with marked hip abductor weakness also seem to benefit more when open kinetic chain exercises for the hip abductor muscles are added to their therapeutic program. Further research is required to substantiate these recommendations.

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