



Original Article

The effects of progressive neuromuscular training on postural balance and functionality in elderly patients with knee osteoarthritis: a pilot study

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Abstract. [Purpose] To determine the effects of progressive neuromuscular training on postural balance and functionality in elderly patients with knee osteoarthritis (OA). [Subjects and Methods] Eleven participants between 60 and 75 years of age performed the progressive neuromuscular training for 8 weeks and 4 weeks of follow-up. The area and velocity of the center of pressure were measured on a force platform, and the functionality was measured with a Western Ontario and McMaster Universities Osteoarthritis Index. [Results] The area and velocity (antero-posterior and mediolateral directions) of the center of pressure showed significant differences after 4 and 8 weeks of intervention. Additionally, the global score and some questionnaire dimensions (pain and physical function) showed significant differences after 4 and 8 weeks of intervention. These changes were maintained in all variables at week 4 of follow-up. [Conclusion] The intervention generated improvements in balance and functionality in elderly patients with knee OA. These changes were observed after 4 weeks of training and were maintained 4 weeks after the end of the intervention.

Key words: Proprioception, Balance, Aging

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INTRODUCTION

Osteoarthritis (OA) is the most common joint disease and one of the main causes of functional disability and deterioration in the quality of life¹⁾. OA affects over 27 million people in the United States and is anticipated to be the fourth cause of disability by 2020²⁻⁴⁾. People older than 50 have a prevalence of 35%, which increases to 55% in people over 70 years of age²⁾, with the knee being the most affected joint with an incidence of 240/100,000 people per year⁵⁾.

Knee OA is known to cause more functional limitations for daily activities than any other disease, specifically in rhythm, time, gait velocity, and step distance shortening^{6, 7)}. Studies indicate that these limitations are due to a neuromuscular deficit, characterized by poor proprioceptive capacity and a decrease of muscle strength and balance⁸⁾. Muscle strength training (strengthening), balance, and proprioception have been recommended as standard treatment for knee OA⁹⁾. Progressive and coordinated inclusion of these motor qualities helps restore neuromuscular control and balance, significantly increasing the

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functionality of patients¹⁰). In this context, the term “neuromuscular training” emerges, which is used to describe the progressive combination of proprioceptive, strength, and balance exercises as part of a comprehensive rehabilitation program^{10, 11}). In its early stages, this training includes proprioceptive and strength exercises on stable surfaces without weight support, and it progresses to exercises of proprioception and balance on unstable and weight-bearing surfaces^{10, 12}). According to previous studies, patients with knee OA who receive physical therapy focused on improving neuromuscular control obtain favorable results^{9, 10}). Nevertheless, specific reports about the effectiveness of short-, medium-, and long-term progressive neuromuscular training do not exist^{3, 10}).

To value the functionality of patients with knee OA, the WOMAC questionnaire has been used (from English, *Western Ontario and McMaster Universities Osteoarthritis Index*). This tool measures the pain, stiffness, and physical function of patients with knee OA through a global score and for each of its dimensions¹³). This questionnaire has been widely used for its reliability, validity, and sensibility to evaluate functionality¹⁴). However, it has been reported that this instrument fails to determine changes in motor control and postural balance of the lower limbs¹⁵). One of the universally used methods to value postural balance is a force platform¹⁶). This instrument allows the calculation of the area and velocity of the center of pressure (COP) in the anteroposterior (AP) and mediolateral (ML) directions, which have high reliability, validity, and sensitivity to measure postural balance^{17, 18}). Many authors have shown that individuals who present chronic injuries of the lower limbs present neuromuscular control alteration, which decreases balance in the standing position^{19, 20}). However, there is limited evidence from clinical trials that include elderly patients with knee OA that evaluate balance on a force platform²¹). The majority of trials evaluate proprioception and balance through clinical instruments (e.g. star excursion balance test, WOMAC, unipodal stance) that are not sensitive enough to determine changes in postural balance in the elderly¹⁵).

The purpose of this study was to determine the effect of 8 weeks of progressive neuromuscular training on postural balance and functionality in elderly patients with knee OA. It is hypothesized that elderly patients with knee OA improve postural balance and functionality after progressive neuromuscular training.

SUBJECTS AND METHODS

The sample included 11 participants (3 males and 8 females) diagnosed with OA belonging to the rehabilitation community center of Pehenuhue, Chile. The inclusion criteria were: (a) diagnosis of unilateral knee OA, (b) participants between 60 and 75 years of age, and (c) independent gait. The exclusion criteria were: (a) presents other injuries and/or lower limb surgery, (b) diagnosed with secondary OA, (c) individuals without medical treatment for OA, (d) the presence of peripheral neuropathy, (e) drug consumption that affects the functions of the nervous system, and (f) the presence of dementia or other neurological disorders¹³). The clinical files of the subjects diagnosed with knee OA were reviewed, and the subjects were contacted by telephone to invite them to participate in the progressive neuromuscular training program. From a total of 24 patients who accepted, 11 met the eligibility criteria, with base characteristics of 69.5 ± 1.6 years of age, 70.3 ± 7.4 kg weight, 167 ± 6 cm height, and physical activity/sports 2.9 ± 0.5 times a week. Due to the small number of individuals who agreed to participate, it was not possible to design a trial that included a control group. All participants in the study read and signed an informed consent form according to the Ethical Committee of Santo Tomás University and the Helsinki Declaration.

The training consisted of three sessions per week with duration of 45 minutes per session. This intervention was organized into three progressive stages. The first stage consisted of exercises without discharge of body weight on the lower extremities, which were executed between weeks 0 to 2 of the intervention. The second stage consisted of exercises with discharge of body weight on stable surfaces, which were executed between weeks 3 to 4 of the intervention. Finally, the third stage included exercises with discharge of body weight on unstable surfaces, which were executed between weeks 5 to 8 of the intervention (Table 1). The training was supervised by a physical therapist, and each exercise was planned based on pre-established volumes and intensities, which were modified according to the clinical conditions of each participant (Table 2).

Table 1. Description of exercises according to modality and intervention week

Weeks	Modality	Exercises program
0 to 2	Exercises without discharge of body weight	<ul style="list-style-type: none"> ·Gluteus medius and gluteus maximus muscle strengthening. ·Inclinations in anterior and lateral directions. ·Quadriceps isometric strengthening exercise. ·Quadriceps eccentric control exercise.
2 to 4	Exercises with discharge of body weight on stable surfaces	<ul style="list-style-type: none"> ·Up and down step exercise in anteroposterior and lateral directions. ·Walking in anterior and posterior directions with eyes opened and eyes closed. ·Walking in lateral direction with eyes opened and eyes closed. ·Standing on one extremity. ·Inclinations in anterior and lateral directions with eyes opened and eyes closed.
4 to 8	Exercises with discharge of body weight on unstable surfaces	<ul style="list-style-type: none"> ·Up and down on Bosu exercise. ·Plantar flexion on minitrampoline. ·Standing on one extremity on Bosu. ·Standing on one extremity on minitrampoline.

Table 2. Description and prescription of exercises program

Exercise	Description	Prescription
Lower limb muscle stretching	Stretching of lower limb muscles: quadriceps, hamstrings, gluteus, triceps surae, and tibialis anterior.	3 repetitions with duration of 30 seconds per muscle.
Gluteus medius and gluteus maximus strengthening	Patient in lateral decubitus position with knees flexed at 90 degrees. The extremity placed on top of the other must perform abduction movements plus external rotation.	3 sets of 10 repetitions performed only with the weight of the segment. As sessions proceed, elastic bands are used to increase resistance.
Quadriceps isometric strengthening exercise	Patient in Fowler position performs an isometric quadriceps contraction.	3 sets of 10 repetitions. 6 seconds of contraction and 6 seconds of rest between repetitions.
Quadriceps eccentric control exercise	Patient in sitting position with feet resting on the surface. Locate the extremity, alternately, in 45 degrees of knee flexion. Subsequently, it returns to the original position slowly and controlled.	3 sets of 10 repetitions with opened eyes and then with closed eyes only with the weight of the segment. As sessions proceed, elastic bands are used to increase resistance.
Up and down step exercise in anteroposterior and lateral directions	Patient in standing position proceeds to go up and down on a step in anteroposterior and lateral directions.	3 sets of 10 repetitions in each direction. As the sessions progress, series and repetitions are increased.
Walking to anteroposterior direction	Patient in standing position crosses their lower extremities while walking forward (with eyes closed) and then back (with eyes open) a distance of 10 meters.	2 sets of 5 repetitions. As sessions progress, series and repetitions are increased.
Walking to lateral direction.	Patient walking in lateral direction to right and left for a distance of 10 meters.	2 sets of 5 repetitions. As sessions progress, series and repetitions are increased.
Standing on one extremity.	Patient in standing position, with his hands on waist, flex hip and knee of one limb for as long as possible. It is performs with eyes opened and eyes closed.	2 sets of 5 repetitions for a time of 5 seconds per repetition. As sessions progress, series increases and the time is hold.
Inclinations in anterior and lateral directions with eyes opened and eyes closed.	Patient in standing position performs hip extension with extended knee of one of his lower limbs while hold the balance with trunk flexion and arms abduction. Then he performs a hip abduction with extended knee while hold the balance with trunk inclination toward the contralateral side.	2 sets of 5 repetitions per limb. As sessions progress, series and repetitions are increased.
Up and down on Bosu exercise.	Patient in standing position proceeds to up and down in anteroposterior direction on a bosu with hands on a wall.	3 sets of 10 repetitions. As sessions progress, series and repetitions are increased. The progression is to perform the exercise without hands support
Plantar flexion on a minitrampoline.	Patient in standing position proceeds to hold the balance on a minitrampoline and tries to stand on tiptoe.	3 sets of 10 repetitions. As sessions progress, series and repetitions are increased.
Standing on one extremity on bosu.	Patient in standing position, with his hands on waist, flex hip and knee of one limb for as long as possible. It is performs with eyes opened and eyes closed on a bosu.	3 sets of 10 repetitions. The progression is performing the exercise without hands support on a wall.
Standing on one extremity on minitrampoline.	Patient in standing position, with his hands on waist, flex hip and knee of one limb for as long as possible. It is performs with eyes opened and eyes closed on a minitrampoline.	3 sets of 10 repetitions. The progression is performing the exercise without hands support on a wall.

The total duration of the intervention was 8 weeks.

All evaluations (postural balance and WOMAC questionnaire) were performed in the Human Motor Control Laboratory of the Universidad de Talca, Chile. The time of the evaluations was between 9:00 h and 12:00 h between October 2015 and January 2016. These measurements were performed on week 0 (before the intervention), week 4, and week 8. Four weeks after finalizing the training (week 12), a follow-up evaluation was performed.

The balance measurements were performed on a force platform AMTI model OR6-7 (Advanced Mechanical Technology

Inc., Watertown, MA, USA) with the size of 46.4 × 50.8 cm mounted and leveled on the floor. In addition, AMTI Net Force software (Advanced Mechanical Technology Inc., Watertown, MA, USA) was used to acquire the signal. The data were filtered using a low-pass FIR with a frequency cut-off of 75 Hz and a sampling rate of 200 Hz. Participants were instructed to keep a bipedal position as still as possible, with arms relaxed and feet with one similar to shoulder width. Balance was measured in the eyes opened and eyes closed phases, each lasting 30 seconds. In each condition, three trials were performed and averaged to obtain COP variables: area (cm²), velocity in ML direction (cm/s), and velocity in AP direction (cm/s).

The WOMAC questionnaire is a self-administered instrument (individual and personal) with a total of 24 items, which uses a Likert-type response scale with five options (0=none; 1=mild; 2=moderate; 3=severe; and 4=very severe). The items of the questionnaire are distributed in three dimensions: 1) pain (5 items); 2) stiffness (2 items); and 3) physical function (17 items). Each dimension was explained in detail to the participants, as well as the format of the answers. After the application of the questionnaire, the points obtained were added and standardized from 0 to 100 (from best to worst). The final scores and each dimension of the questionnaire were standardized.

The program SPSS version 15.0 was used to perform the statistical analysis of the data. The distribution and homogeneity of variance of the data were determined through the Shapiro-Wilk test and Levene test, respectively. A one-way repeated measure ANOVA with a time factor (four levels) was performed to determine the effect of the intervention protocol on the WOMAC variables (global score and score of the dimensions of pain, stiffness, and physical function), area, and velocity in AP and ML direction of the COP. A t-test corrected by Bonferroni was used to compare the differences between weeks of the intervention. An alpha of 0.05 was considered for all analyses. In addition, Partial eta-squared (η^2) for ANOVA was used to examine the effect size. A η^2 less than 0.06 was classified as “small,” 0.07–0.14 as “moderate,” and greater than 0.14 as “large”²².

RESULTS

Repeated measures ANOVA revealed a significant main effect of the time factor on the following variables: area in eyes opened (df=3; F=11.10; p=0.003; η^2 =0.80); AP velocity in eyes opened (df=3; F=9.19; p=0.006; η^2 =0.77); ML velocity in eyes opened (df=3; F=9.15; p=0.006; η^2 =0.77); AP velocity in eyes closed (df=3; F=8.92; p=0.006; η^2 =0.77); ML velocity in eyes closed (df=3; F=38.31; p=0.000; η^2 =0.79); global score of the WOMAC questionnaire (df=3; F=29.11; p=0.000; η^2 =0.91); and score in the dimensions of pain (df=3; F=35.64; p=0.000; η^2 =0.93), stiffness (df=3; F=5.95; p=0.020; η^2 =0.69), and physical function (df=3; F=13.29; p=0.002; η^2 =0.83) of the WOMAC Questionnaire. On the contrary, the repeated measures ANOVA revealed no significant main effect of the time factor on the remaining variables. The multiple pairwise comparisons between weeks are observed in Table 3 for COP variables and in Table 4 for the WOMAC Questionnaire.

DISCUSSION

The results of this study showed that neuromuscular training of 8 weeks improved postural balance and functionality in elderly patients with knee OA, due to the significant decrease of COP variables (area and velocity) and the WOMAC Questionnaire score. These improvements were observed within 4 weeks of the intervention and maintained their effects 4 weeks after the end of the training.

The postural balance deficit in patients with knee OA may be attributed to alterations in the tissues surrounding the articulations (tendons, ligaments, capsules, etc.) together with the weakness of the hamstrings and abductors of the hip^{23, 24}. These alterations may be potentiated by the decrease of the excitability of quadriceps motor units—caused by factors such as joint pain, swelling, and laxity—provoking poor voluntary activation, a proprioceptive deficit, and a decrease of neuromuscular control^{8, 25–27}. According to prior investigations, COP variables that present more deterioration are area and velocity in the ML direction, due to deficits in neuromuscular and central nervous system control. This implies that the alterations evidenced in the ML plane^{28, 29} may be related to the weakness of the hip abductors and the AP plane because of knee extensor weakness.

The literature reports that improved postural control is related to lower COP sway, specifically within a smaller area of displacement¹⁷. In addition, it shows that the area and velocity of the COP are what best represent the behavior of postural sway, with velocity being the most reliable to evaluate postural balance¹⁸. Our study shows that these changes of velocity in the COP occur in both the AP and ML planes. Neuromuscular training possibly improves segmental alignment of the limb, sensorimotor control, and joint stability^{30, 31}, optimizing the execution of functional tasks in favor of synchronization and coordination in the activation of lower limb muscle groups during knee movements^{10, 25, 32, 33}. Against these findings, it is inferred that the intervention could provoke a better neuromuscular response in charge of AP (ankle and knee muscles) and ML (ankle and hip muscles) stability.

In the eyes closed phase, an increase in COP sway was observed, possibly because of visual input inhibition provoking greater postural instability^{34, 35}. The eyes closed COP evaluation is a more demanding test compared to the eyes opened evaluation, which is why our training plan contemplates the execution of eyes closed exercises with the purpose of promoting postural control through somatosensory and vestibular inputs. Thus, it is inferred that the neuromuscular training favored the re-education of postural balance, generating a significant impact on somatosensory and muscle response, helping the elderly patients use their balance control strategies more efficiently.

Neuromuscular training programs applied to patients with knee OA have a minimum of 6 to a maximum of 12 weeks

Table 3. Multiple pairwise comparisons between weeks for center of pressure variables

Area (mm ²)	Eyes opened		Area (mm ²)	Eyes closed	
	Mean Dif	95% CI of Dif		Mean Dif	95% CI of Dif
Week 0–Week 4**	5.74	1.96 a 9.53	Week 0–Week 4	5.97	–0.53 a 12.47
Week 0–Week 8*	5.64	2.11 a 9.1	Week 0–Week 8	6	–0.17 a 12.18
Week 0–Week 12*	4.9	1.00 a 8.79	Week 0–Week 12	5.25	–1.34 a 11.84
Week 4–Week 8	–0.1	–0.56 a 0.35	Week 4–Week 8	0.03	–0.81 a 0.87
Week 4–Week 12	–0.85	–2.23 a 0.54	Week 4–Week 12	0.72	–3.15 a 1.71
Week 8–Week 12	–0.75	–2.00 a 0.51	Week 8–Week 12	–0.75	–3.37 a 1.86
AP Velocity (cm/s)			AP Velocity (cm/s)		
Week 0–Week 4***	0.45	0.06 a 0.40	Week 0–Week 4***	0.58	0.25 a 0.90
Week 0–Week 8**	0.37	0.11 a 0.34	Week 0–Week 8*	0.51	0.07 a 0.95
Week 0–Week 12*	0.32	0.01 a 0.32	Week 0–Week 12	0.37	–0.05 a 0.79
Week 4–Week 8	–0.08	–0.09 a 0.07	Week 4–Week 8	–0.07	–0.42 a 0.29
Week 4–Week 12	–0.13	–0.18 a 0.05	Week 4–Week 12	–0.21	–0.62 a 0.21
Week 8–Week 12	–0.06	–0.15 a 0.03	Week 8–Week 12	–0.14	–0.71 a 0.42
ML Velocity (cm/s)			ML Velocity (cm/s)		
Week 0–Week 4**	0.47	0.16 a 0.79	Week 0–Week 4***	0.56	0.31 a 0.81
Week 0–Week 8**	0.48	0.18 a 0.78	Week 0–Week 8***	0.56	0.31 a 0.80
Week 0–Week 12*	0.42	0.09 a 0.76	Week 0–Week 12***	0.52	0.27 a 0.77
Week 4–Week 8	0.01	–0.04 a 0.05	Week 4–Week 8	–0.01	–0.09 a 0.09
Week 4–Week 12	–0.05	–0.23 a 0.12	Week 4–Week 12	–0.04	–0.20 a 0.13
Week 8–Week 12	–0.06	–0.21 a 0.12	Week 8–Week 12	–0.04	–0.21 a 0.14

Dif: Differences; 95% CI: 95% confidence interval; AP: anteroposterior direction; ML: mediolateral direction

*<0.05; **<0.01; ***<0.001

long^{36, 37}). Our neuromuscular training plan generated positive effects after 4 weeks of intervention, prolonging its effects up to 4 weeks after the intervention. Nevertheless, there were no significant changes in postural balance in subsequent weeks if evaluations are compared (4 vs. 8, 4 vs. 12, and 8 vs. 12). Possibly, these early positive effects are because the first 4 weeks were based on strength training (with and without body weight support), which, according to the evidence, generates neuromuscular adaptations, improvements in the recruitment of motor units, and optimization of sensory responses of joints favoring positive changes in balance³⁸). In addition, these positive changes last between 4 and 8 weeks, where the intervention was focused on balance and proprioception training.

Häkkinen et al. indicate that elderly patients who train their strength progressively and present a period of inactivity lose between 9 to 12% of strength³⁹). Chen et al. indicate that there is a positive correlation between proprioceptive deficit and decreased strength⁴⁰). In this context, the elderly patients of our study showed that in the first 4 weeks the intervention focused on training strength, which generated improvement in strength and indirectly of proprioception and balance, and subsequently the following 4 weeks were focused on training balance and proprioception, which maintained the strength gain and optimized neuromuscular and postural control. In this way, a possible reduction of the force that would negatively impact the postural balance was avoided. Future investigations could compare progressive neuromuscular training and strength training to determine if the balance and functionality improvements are maintained during a follow-up period.

The neuromuscular training produced significant changes at 4 weeks of intervention in the global score and in the

Table 4. Multiple pairwise comparisons between weeks for WOMAC questionnaire (global and dimensions)

WOMAC Questionnaire		
Global	Mean Dif	95% CI of Dif
Week 0–Week 4***	22.16	12.17 a 32.15
Week 0–Week 8***	33.43	17.84 a 49.02
Week 0–Week 12**	26.47	10.61 a 42.32
Week 4–Week 8*	11.27	0.69 a 21.86
Week 4–Week 12	4.31	–6.29 a 14.90
Week 8–Week 12***	–6.96	–10.46 a –3.47
Stiffness		
Week 0–Week 4	12.5	–6.63 a 31.63
Week 0–Week 8	18.18	–2.75 a 39.11
Week 0–Week 12	11.36	–6.50 a 29.22
Week 4–Week 8	5.68	–12.94 a 24.30
Week 4–Week 12	–1.14	–15.17 a 12.90
Week 8–Week 12*	–6.82	–13.27 a 0.37
Physical function		
Week 0–Week 4***	22.23	9.93 a 34.54
Week 0–Week 8***	32.8	14.37 a 51.22
Week 0–Week 12**	26.38	8.71 a 44.04
Week 4–Week 8	10.56	–1.11 a 22.24
Week 4–Week 12	4.15	–6.62 a 14.91
Week 8–Week 12*	–6.42	–11.50 a –1.33
Pain		
Week 0–Week 4***	22.82	13.53 a 32.11
Week 0–Week 8***	38.73	26.08 a 51.37
Week 0–Week 12***	29.55	14.98 a 44.11
Week 4–Week 8**	15.91	4.47 a 27.35
Week 4–Week 12	6.73	–7.99 a 21.44
Week 8–Week 12**	–9.18	–15.54 a –2.83

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; Dif: differences; 95% CI: 95% confidence interval.

*<0.05; **<0.01; ***<0.001

dimensions of pain, physical function, and stiffness of the WOMAC questionnaire. The explanation is the close relationship between the strength of the quadriceps muscles and the symptomatology manifested in elderly patients with OA⁴¹). OA causes quadriceps weakness, resulting in a lower capacity for shock absorption, altered neuromuscular control, and joint instability of the knee, increasing the probability of damage to joint cartilage integrity^{41, 42}). For this reason, training has a therapeutic potential by improving trophism and muscular strength, favoring the decrease of pain in these participants^{31, 43}). Neuromuscular training has been reported to provide clinically relevant improvements of up to 20% in physical function and pain³⁷). However, it should be taken into account that daily life activities of elderly patients with OA are not so demanding and that this instrument does not evaluate agility and balance to a high demand, which is why training that involves agility and suddenly perturbations will not necessarily show significant changes measured with this tool¹⁵).

Limitations of this study are the convenience selection of the participants and the small sample size, which may increase the likelihood of committing a type 1 error. In the same way, a control group was not included, which allowed the comparison of the neuromuscular training effectiveness against a conventional intervention. A training/rehabilitation program per se improves the functionality and initial postural balance in patients with knee OA. This is due to the learning effect over time⁴⁴). Despite this, we decided not to include a control group because we still do not check the effect of this novel progressive neuromuscular training. In addition, the research design considered a longitudinal data analysis based on repeated measurements⁴⁵), which allows to decrease the probability of committing a type 1 error and to evaluate if there are significant differences between repeated measurements of a dependent variable (e.g. postural balance) influenced by an independent variable (e.g. neuromuscular training). Future research is suggested in which progressive neuromuscular training is compared with strength training to determine 1) the efficiency in time of each one and 2) if the “progressive” characteristic of neuromuscular training is really the differentiating element of this intervention.

In summary, progressive neuromuscular training produces positive effects at 4 weeks of intervention on postural balance and functionality in participants with knee OA. These effects last for 4 weeks after the intervention. It is recommended to compare this novel progressive neuromuscular training against other interventions.

Conflict of interest

The authors declare that they have no conflict of interests.

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