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

Sergio Sazo-Rodríguez, PT, MS1, 2), Guillermo Méndez-Rebolledo, PT, MS1, 3)*, Eduardo Guzmán-Muñoz, PT, MS1), Paulo Rubio-Palma, PT4)

1) Escuela de Kinesiología, Facultad de Salud, Universidad Santo Tomás, Chile
2) Exercise Science Laboratory, School of Kinesiology, Faculty of Medicine, Universidad Finis Terrae, Chile
3) Human Motor Control Laboratory, Department of Human Movement Science, Faculty of Health Sciences, Universidad de Talca: Av. Lircay, sn, Talca, Chile
4) CESFAM Pencahue, Ilustre Municipalidad de Pencahue, Chile

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 (This article was submitted Mar. 24, 2017, and was accepted Apr. 27, 2017)

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 shortening6, 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...
functionality of patients. 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. 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. According to previous studies, patients with knee OA who receive physical therapy focused on improving neuromuscular control obtain favorable results. Nevertheless, specific reports about the effectiveness of short-, medium-, and long-term progressive neuromuscular training do not exist.

To value the functionality of patients with knee OA, the WOMAC questionnaire has been used. This questionnaire has been widely used for its reliability, validity, and sensitivity to evaluate functionality. However, it has been reported that this instrument fails to determine changes in postural balance and functionality of the lower limbs. One of the universally used methods to value postural balance is a force platform. 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.

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. However, there is limited evidence from clinical trials that include elderly patients with knee OA that evaluate balance on a force platform. 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 elderly.

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 Pencahue, 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 disorders. 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 2 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).
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

| 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 performed 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 held. |
| 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 performed 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 performed 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.               |
An alpha of 0.05 was considered for all analyses. In addition, Partial eta-squared ($\eta_p^2$) was used to determine the effect size. A $\eta_p^2$ 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; $\eta_p^2=0.80$); AP velocity in eyes opened (df=3; F=9.19; p=0.006; $\eta_p^2=0.77$); ML velocity in eyes opened (df=3; F=9.15; p=0.006; $\eta_p^2=0.77$); AP velocity in eyes closed (df=3; F=8.92; p=0.006; $\eta_p^2=0.77$); ML velocity in eyes closed (df=3; F=38.31; p=0.000; $\eta_p^2=0.79$); global score of the WOMAC questionnaire (df=3; F=29.11; p=0.000; $\eta_p^2=0.91$); and score in the dimensions of pain (df=3; F=35.64; p=0.000; $\eta_p^2=0.93$), stiffness (df=3; F=5.95; p=0.020; $\eta_p^2=0.69$), and physical function (df=3; F=13.29; p=0.002; $\eta_p^2=0.83$) 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 [25, 26]. 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 displacement [7]. 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 balance [18]. 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...
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 balance. Häkkinen et al. indicate that elderly patients who train their strength progressively and present a period of inactivity lose between 9 to 12% of strength. Chen et al. indicate that there is a positive correlation between proprioceptive deficit and decreased strength. 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

| Area (mm²) | Eyes opened Mean Dif | 95% CI of Dif | Eyes closed 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 12a | 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 |

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

| WOMAC Questionnaire | Mean Dif | 95% CI of Dif |
|---------------------|----------|---------------|
| Global | 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 |

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 OA. 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. For this reason, training has a therapeutic potential by improving trophism and muscular strength, favoring the decrease of pain in these participants.

Neuromuscular training has been reported to provide clinically relevant improvements of up to 20% in physical function and pain. 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 tool.

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 I 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 time. 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 measurements, which allows to decrease the probability of committing a type I 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.

REFERENCES

1. Carmona L: Proyecto EPISER 2000: Prevalencia de enfermedades reumáticas en la población española. Metodología, resultados del reclutamiento y características de la población. Rev Esp Reumatol, 2001, 28: 18–25.
2. Nelson AE, Allen KD, Golightly YM, et al.: A systematic review of recommendations and guidelines for the management of osteoarthritis: the chronic osteoarthritis management initiative of the U.S. bone and joint initiative. Semin Arthritis Rheum, 2014, 43: 701–712. [Medline] [CrossRef]
3. Smith TO, King JJ, Hing CB: The effectiveness of proprioceptive-based exercise for osteoarthritis of the knee: a systematic review and meta-analysis. Rheumatol Int, 2012, 32: 3339–3351. [Medline] [CrossRef]
4. Uthman OA, van der Windt DA, Jordan JL, et al.: Exercise for lower limb osteoarthritis: systematic review incorporating trial sequential analysis and network meta-analysis. Br J Sports Med, 2014, 48: 1579–1579. [Medline] [CrossRef]
5. Bijlsma JW, Berenbaum F, Lafeber FP: Osteoarthritis: an update with relevance for clinical practice. Lancet, 2011, 377: 2115–2126. [Medline] [CrossRef]
6. Knopp J, Steultjens MP, van der Leeden M, et al.: Proprioception in knee osteoarthritis: a narrative review. Osteoarthritis Cartilage, 2011, 19: 381–388. [Medline] [CrossRef]
7. Sharma L, Pai YC, Holtkamp K, et al.: Is knee joint proprioception worse in the arthritic knee versus the unaffected knee in unilateral knee osteoarthritis? Arthritis Rheum, 1997, 40: 1518–1525. [Medline] [CrossRef]
8. Takacs J, Carpenter MG, Garland SJ, et al.: The role of neuromuscular changes in aging and knee osteoarthritis on dynamic postural control. Aging Dis, 2013, 4: 84–99. [Medline]
9. Beckwée D, Vaes P, Cnudde M, et al.: Osteoarthritis of the knee: why does exercise work? A qualitative study of the literature. Ageing Res Rev, 2013, 12: 226–236. [Medline] [CrossRef]
10. Diracoglu D, Aydin R, Baskent A, et al.: Effects of kinesthesia and balance exercises in knee osteoarthritis. J Clin Rheumatol, 2005, 11: 303–310. [Medline] [CrossRef]
11. Lim CW, Delahunt E, King E: Neuromuscular training for chronic ankle instability. Phys Ther, 2012, 92: 987–991. [Medline] [CrossRef]
12. Hurley MV, Scott DK: Improvements in quadriceps sensorimotor function and disability of patients with knee osteoarthritis following a clinically practicable exercise regime. Br J Rheumatol, 1998, 37: 1181–1187. [Medline] [CrossRef]
13. Liao CD, Liou TH, Huang YY, et al.: Effects of balance training on functional outcome after total knee replacement in patients with knee osteoarthritis: a randomized controlled trial. Clin Rehabil, 2013, 27: 697–709. [Medline] [CrossRef]
14. Jinks C, Jordan K, Croft P: Measuring the population impact of knee pain and disability with the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Pain, 2002, 100: 55–64. [Medline] [CrossRef]
15. Fitzgerald GK, Fiva SR, Gil AB, et al.: Agility and perturbation training techniques in exercise therapy for reducing pain and improving function in people with knee osteoarthritis: a randomized clinical trial. Phys Ther, 2011, 91: 452–469. [Medline] [CrossRef]
16. Lord SR, Clark RD, Webster JW: Postural stability and associated physiological factors in a population of aged persons. J Gerontol, 1991, 46: M69–M76. [Medline] [CrossRef]
25) Ageberg E, Roos EM: Neuromuscular exercise as treatment of degenerative knee disease. Exerc Sport Sci Rev, 2015, 43: 14–22. [Medline] [CrossRef]

24) Kim HS, Yun DH, Yoo SD, et al.: Balance control and knee osteoarthritis severity. Ann Rehabil Med, 2011, 35: 701–709. [Medline] [CrossRef]

21) Petrella M, Neves TM, Reis JG, et al.: Postural control parameters in elderly female fallers and non-fallers diagnosed or not with knee osteoarthritis. Rev Bras Reumatol, 2012, 52: 512–517. [Medline] [CrossRef]

20) Hertel J: Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. J Athl Train, 2002, 37: 364–375. [Medline]

23) Bennell KL, Wrigley TV, Hunt MA, et al.: Update on the role of muscle in the genesis and management of knee osteoarthritis. Rheum Dis Clin North Am, 2013, 39: 145–176. [Medline] [CrossRef]

22) Cohen J: Statistical power analysis for the behavioural sciences. Hillside: Lawrence Earbaum Associates, 1988.

27) Turcot K, Sagawa Y Jr, Hoffmeyer P, et al.: Multi-joint postural behavior in patients with knee osteoarthritis. Knee, 2015, 22: 517–521. [Medline] [CrossRef]

28) Ko JH, Newell KM: Aging and the complexity of center of pressure in static and dynamic postural tasks. Neurosci Lett, 2016, 610: 104–109. [Medline] [CrossRef]

29) Wikstrom EA, Fournier KA, McKeon PO: Postural control differs between those with and without chronic ankle instability. Gait Posture, 2010, 32: 145–151. [Medline] [CrossRef]

30) Ageberg E, Link A, Roos EM: Feasibility of neuromuscular training in patients with severe hip or knee OA: the individualized goal-based NEMEX-TJR training program. BMC Musculoskelet Disord, 2010, 11: 126. [Medline] [CrossRef]

31) Roos EM, Herzog W, Block JA, et al.: Muscle weakness, afferent sensory dysfunction and exercise in knee osteoarthritis. Nat Rev Rheumatol, 2011, 7: 57–63. [Medline]

32) Ageberg E, Nilsdotter A, Kosek E, et al.: Effects of neuromuscular training (NEMEX-TJR) on patient-reported outcomes and physical function in severe primary hip or knee osteoarthritis: a controlled before-and-after study. BMC Musculoskelet Disord, 2013, 14: 232. [Medline] [CrossRef]

33) Skou ST, Odgaard A, Rasmussen JO, et al.: Group education and exercise is feasible in knee and hip osteoarthritis. Dan Med J, 2012, 59: A4554. [Medline]

34) Gatica Rojas V, Elgueta Cancino E, Vidal Silva C, et al.: Impacto del entrenamiento del balance a través de realidad virtual en una población de adultos mayores. Int J Morphol, 2010, 28: 303–308. [CrossRef]

35) Masui T, Hasegawa Y, Yamaguchi J, et al.: Increasing postural sway in rural-community-dwelling elderly persons with knee osteoarthritis. J Orthop Sci, 2006, 11: 353–358. [Medline] [CrossRef]

36) Manosalva CC, Verdugo JM, Santis AD, et al.: Efectos del entrenamiento neuromuscular sobre el equilibrio dinámico y actividad muscular en deportistas con inestabilidad funcional de tobillo: un estudio preliminar. CES Movimiento Salud, 2015, 3: 7–15.

37) Villadsen A, Overgaard S, Holsgaard-Larsen A, et al.: Immediate efficacy of neuromuscular exercise in patients with severe osteoarthritis of the hip or knee: a secondary analysis from a randomized controlled trial. J Rheumatol, 2014, 41: 1385–1394. [Medline] [CrossRef]

38) Kordi H, Sohrabi M, Saberi Kakhki A, et al.: The effect of strength training based on process approach intervention on balance of children with developmental coordination disorder. Arch Pediatr, 2016, 114: 526–533. [Medline]

39) Hakkinen K, Airen M, Kallinen M, et al.: Neuromuscular adaptation during prolonged strength training, detraining and re-strength-training in middle-aged and elderly people. Eur J Appl Physiol, 2000, 83: 51–62. [Medline] [CrossRef]

40) Chen Y, Yu Y, He CQ: Correlations between joint proprioception, muscle strength, and functional ability in patients with knee osteoarthritis. Journal of Sichuan University Med Sci Educ, 2015, 46: 880–884.

41) Glass NA, Torner JC, Frey Law LA, et al.: The relationship between quadriiceps muscle weakness and worsening of knee pain in the MOST cohort: a 5-year longitudinal study. Osteoarthritis Cartilage, 2013, 21: 1154–1159. [Medline] [CrossRef]

42) Felson DT, Chaisson CE, Hill CL, et al.: The association of bone marrow lesions with pain in knee osteoarthritis. Ann Intern Med, 2001, 134: 541–549. [Medline] [CrossRef]

43) Segal NA, Torner JC, Felson D, et al.: Effect of thigh strength on incident radiographic and symptomatic knee osteoarthritis in a longitudinal cohort. Arthritis Rheum, 2009, 60: 1210–1217. [Medline] [CrossRef]

44) Reed-Jones R, Carvalho L, Sanderson C, et al.: Examining changes to center of pressure during the first trials of Wii gameplay. Games Health J, 2017, 6: 61–64. [Medline] [CrossRef]

45) Atkinson G: Analysis of repeated measurements in physical therapy research. Phys Ther Sport, 2001, 2: 194–208. [CrossRef]