Correlation between the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) Scores and the Stability Metrics in Patients with Knee Osteoarthritis

ABSTRACT

Aims: The aim of the present study was to assess the correlation between the stability metrics related to the center of pressure excursion measurements and the WOMAC questionnaire scores.

Method and Materials: Fourteen patients with moderate knee osteoarthritis and fourteen healthy age-matched individuals were participated to stand with open and closed eyes, and on firm and rocking support on a force platform. The WOMAC questionnaire was obtained from the patient group. One-way ANOVA was utilized to determine the effects of knee osteoarthritis, vision, and support on postural stability metrics. Spearman’s correlation was also used to indicate the correlation between the stability metrics and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) sub scores.

Findings: The anterior-posterior variability of the center of pressure was significantly greater in patients (2.7 mm, p=.003). Elimination of the visual feedback and the rocking support affected the sway area and the AP (p<.001), and the ML variability (p<.024). The pain subscore of the WOMAC questionnaire was negatively and strongly correlated to the AP total mean velocity (open-eyes: r=-.466, closed-eyes: r=-.779). The pain was positively and strongly correlated to the AP variability (open-eyes: r=.796, closed-eyes: r=.744). Patients with knee osteoarthritis showed more postural instabilities.

Conclusion: The instability in the anterior-posterior was more eminent than in the lateral direction. The pain was the most role-playing factor in the destabilization of the posture among the patients with knee osteoarthritis but may be disregarded in physically-difficult conditions of standing.

Keywords: Knee Osteoarthritis; Postural Control; WOMAC Questionnaire; Pain; Center of Pressure.

Introduction

Providing stability during standing is the basic locomotion task for other daily activities which is intervened by Knee OsteoArthritis (KOA) [1-3]. The KOA causes to pain and stiffness, declined functional performances, and muscle weakness [4]. The detected instability in the standing of patients with KOA is often quantified by some linear or nonlinear metrics related to the Center of Pressure (CoP). The literature is well documented by studies that showed CoP-related instabilities due to uni/bi-lateral KOA could involve in different tasks and sensory conditions [5-7]. On the other hand, some studies have focused on the functional tests and also the self-administered questionnaires [8-10]. One of the most commonly-used questionnaire is the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) which quantifies the major symptoms like pain, stiffness, and physical performance in different daily tasks and functions [11]. The biomechanical assessments to reveal CoP-related metrics also design tasks that are the fittest ones to daily activities [12-14], or a bit more difficult to provoke hidden neuro-musculo-skeletal reactions [15-17].

The relationship between the biomechanical assessment of stability and the functional self-described scores may unveil the underlying role-playing factors in postural destabilization. However, it has
gained the attention of limited researchers. For instance, Debi et al. (2011) showed a negative correlation between the single-leg stance phase duration and the WOMAC scores [15]. Although Hirata et al. (2013) found that the pain intensity is correlated to the CoP range in the mediolateral direction only in the closed-eyed condition [21], Petrella et al. (2017) indicated that the WOMAC scores in pain and physical performance are negatively correlated to the anterior-posterior displacement and velocity of the CoP movement [18].

According to the challenges that mentioned above, the aim of the present work was to evaluate the possible correlations between the WOMAC scores and the CoP-related metrics of stability for patients with KOA by considering different visual and support conditions. It was hypothesized that worse WOMAC scores are correlated to more sways and variations, and less sway velocities.

Method and Materials

In this cross-sectional study fourteen healthy individuals and fourteen patients with knee osteoarthritis have been participated. The patients had moderate knee osteoarthritis which were diagnosed by the radiographic imaging and it was assured that their K-L index was between grade II and III. Both healthy individuals and patient had no history of lower limb, back surgery or using of prosthesis. Moreover, they had no neurological, muscular, or orthopedic diseases that affect normal posture with an exception to the knee osteoarthritis for the patient group. All participants were informed about the test conditions and procedures and were asked to sign the written informed consent form. All ethical issues were considered in the study and the study procedures were approved by the ethical committee of Tarbiat Modares University (TMU).

For conducting this study, the participants were asked to stand barefoot with crossed arms in four different situations: 1) open eyes on the firm support, 2) open eyes on the rocking support, 3) closed eyes on the firm support, and, 4) closed eyes on the rocking support. The rocking support was a 40 × 55 cm wooden plate that was capable of rotating forth and back (pitch movement) because of three semi-ellipses (minor axis = 26 cm) attached beneath. The rocking plate was supported by a pair of springs (stiffness = 4 kN/m) in the front and rear. These situations were designed due to imposing further challenges on the balance in the knee osteoarthritis patients in a reduced and moving base of support and also in the absence of visual feedback. The order of standing conditions was randomized for each participant. Each situation had three 30-second trials.

For data collection, a 60 x 40-cm force platform (Kistler, type 9286AA, Winterthur, Switzerland) was utilized to measure the excursion of the participants' CoP with a sampling rate of 1200 Hz. In situations where the participants stood on the rocking support, it was placed on the force platform. In addition, the Farsi version of the WOMAC questionnaire was also utilized to assess self-administered pathological concerns about pain, stiffness, and physical functions of the knee (19, 20). The higher score of each part and total (which ranges from 0 to 96) imply worsened cases.

For data analysis, postural assessment of the participants in four test situations included calculation of three linear metrics of Sway Area (SA), Total Mean Velocity (TMV), and Variability (VAR), as well as one nonlinear Fractal Dimension (FD) metric. The SA is the area of an ellipse that encloses at least 95% of the swayed CoP data in the plane of anterior-posterior and

ISSN: 2476-5279: Internatonal Journal of Musculoskeletal Pain Preventon. 2022;7(3): 741-749.
mediolateral directions. The TMV is also the total path length of the CoP in each direction over the total duration time. The variability is the standard deviation of the CoP data in each direction. The FD is also calculated based on Higuchi’s algorithm which considers the absolute slope of the log-log diagram of the path lengths against the measures’ length [21].

To do statistical analysis, one-way Analysis of Variance (ANOVA) was used to assess the statistically-significant effects of the independent parameters of the group (knee osteoarthritis vs. control), vision (open vs. closed eyes), and support (firm vs. rocking) on the dependent postural control parameters extracted from the CoP data. This analysis was done after checking the normality of distribution of the outputs by the Kolmogorov-Smirnov test. Spearman’s correlation test was also utilized to assess how the WOMAC questionnaire scores and stability metrics are correlated to each other. The statistical significance level was considered as 5% for the statistical analyses.

Findings

Totally 14 healthy individuals with age and Body Mass Index (BMI) of [age = 55.4 ± 5.6 year, BMI = 26.7 ± 2.4 kg/m²] and 14 KOA patients with age and BMI of [age = 56.8 ± 6.1 year, BMI = 25.9 ± 3.8 kg/m²] participated in the present study. The total WOMAC score for the patients with knee osteoarthritis was 41.1 ± 12.5. The pain sub-score was 9.1 ± 2.8, the stiffness was 4.0 ± 1.3 and the physical function sub-score was 27.2 ± 12.4.

Figure 1 shows the changes in the sway area among the control and KOA patient groups by removing the visual feedback and reducing the base of support. Sway area of the CoP was significantly increased in the KOA patients only in the open-eyes on the rocking support condition (p = .044, h² = 0.81).

Table 1 presents the mean values of the other stability parameters (i.e. FD, TMV, and VAR) for control and KOA participants with their group’s statistical comparison in four standing tasks. Merely the anterior-posterior variability of the patients on the rocking support has been significantly increased (eye-open: 3.2 cm, P = .032, h² = 0.21; eye-closed: 6.1 cm, P = .034, h² = 0.21) rather than the healthy controls. Other parameters were not changed due to knee osteoarthritis. The main and interactive effects of the knee osteoarthritis, vision, and support conditions on the stability parameters in both mediolateral and anterior-posterior directions have been gathered in Table 2. Variability of the CoP in the anterior-posterior direction was significantly increased by the knee osteoarthritis, although the sway area and mediolateral variability were near to be significant. These three stability parameters (i.e. SA, VAR-AP, and VAR-ML) were also significantly increased by the removal of the visual feedback. Reduction of the base of support by standing on the rocking support also increased fractal dimension in the mediolateral direction as well as the sway area and variability in both directions. The interactive effects were not effective on the stability parameters unless the simultaneous vision and support effect increased significantly the sway area, anterior-posterior fractal dimension, and
Table 1) Stability parameters of the participants of both groups with group effect's P-values (if significant with their $h^2$ effect size) in two AP and ML directions for four test conditions.

|                     | Anterior - Posterior | Medio - Lateral |
|---------------------|----------------------|-----------------|
|                     | Control   | KOA    | p-value | Control   | KOA    | p-value |
| Open eyes – Firm support |          |        |         |          |        |         |
| FD                  | 1.49 (.09) | 1.48 (.07) | .625     | 1.54 (.14) | 1.51 (.15) | .576     |
| TMV                 | .11 (.06)  | .11 (.04)  | .928      | .13 (.05)  | .15 (.05)  | .451     |
| VAR                 | 4.97 (1.80) | 6.71 (3.96) | .177     | 3.17 (2.00) | 5.89 (5.55) | .142     |
| Open eyes – Rocking support |          |        |         |          |        |         |
| FD                  | 1.56 (.06) | 1.53 (.08) | .250     | 1.68 (.07) | 1.54 (.13) | .986     |
| TMV                 | .10 (.04)  | .11 (.04)  | .477      | .14 (.05)  | .15 (.05)  | .362     |
| VAR                 | 10.16 (2.66) | 13.40 (3.81) | *.032 (.21) | 5.46 (2.00) | 6.13 (1.91) | .441     |
| Closed eyes – Firm support |          |        |         |          |        |         |
| FD                  | 1.55 (.06) | 1.56 (.10) | .856     | 1.56 (.12) | 1.54 (.13) | .758     |
| TMV                 | .10 (.04)  | .10 (.03)  | .918      | .13 (.05)  | .15 (.05)  | .514     |
| VAR                 | 6.13 (1.50) | 5.94 (1.31) | .757     | 3.54 (2.04) | 3.50 (1.36) | .957     |
| Closed eyes – Rocking support |          |        |         |          |        |         |
| FD                  | 1.53 (.07) | 1.48 (.08) | .116     | 1.67 (.08) | 1.60 (.31) | .429     |
| TMV                 | .10 (.06)  | .13 (.05)  | .928      | .15 (.05)  | .17 (.08)  | .525     |
| VAR                 | 21.88 (6.83) | 27.98 (5.70) | *.034 (.21) | 9.03 (3.78) | 9.34 (4.45) | .863     |

* Significant effects of the knee osteoarthritis ($p < .05$).

FD: Fractal Dimension, TMV: Total Mean Velocity, VAR: Variability and KOA: Knee OsteoArthritis

Table 2) The main and interactive effects of the knee osteoarthritis (KOA), vision and support conditions on stability parameters of sway area (SA), fractal dimension (DF), total mean velocity (TMV) and variability (VAR).

|                     | SA   | Anterior-posterior | Mediolateral |
|---------------------|------|--------------------|--------------|
|                     |      | FD | TMV | VAR | FD | TMV | VAR |
| Knee Osteoarthritis | .077 $a$ | .139 | .809 | .003 $b$ | .323 | .144 | .057 $c$ |
| Vision              | < .001 | .317 | .323 | < .001 | .746 | .541 | .024 $d$ |
| Support             | < .001 | .723 | .203 | < .001 | < .001 | .239 | < .001 |
| KOA × Vision        | .327 | .905 | .794 | .884 | .662 | .932 | .531 |
| KOA × Support       | .229 | .255 | .798 | .143 | .847 | .875 | .799 |
| Vision × Support    | < .001 | .100 | < .001 | .303 | .591 | < .001 |
| KOA × Vision × Support | .228 | .547 | .654 | .596 | .466 | .997 | .282 |

The $h^2$ effect sizes are $a = .030, b = .084, c = .034, d = .048$. 

ISSN: 2476-5279: International Journal of Musculoskeletal Pain Preventon. 2022;7(3): 741-749.
variability in both directions of the CoP excursions.

In order to investigate the relationship between the quantitative stability parameters and the self-reported clinical scale of the knee osteoarthritis, Table 3 presents the Spearman’s correlation coefficients of the SA, FD, TMV and VAR, and the total score, pain, stiffness, and physical functions sub-scales. The pain subscale was the mostly-correlated clinical factor to the stability metrics. Among the standing tasks, the highest correlations were observed in the easier tasks i.e. standing on a firm support. While the eyes were open, the pain was highly and significantly correlated to the TMV and VAR in the anterior-posterior direction and the FD of both directions of the CoP excursions. In regard to the stability metrics, the FD in the mediolateral direction has revealed more correlations to the clinical scales.

**Discussion**

The present study was aimed to investigate the postural control of the patients with knee osteoarthritis and its relationship to the clinical features of the WOMAC...
questionnaire. It was indicated that patients with KOA have instabilities in the anterior-posterior direction which is significantly related to the WOMAC pain score. The variability of the CoP in the anterior-posterior direction was the main measure in the discrimination of the effects of knee osteoarthritis. The variability, that is the standard deviation of the CoP excursions during the standing tasks, is a measure to elucidate the neuromuscular control of posture [22], whose increase balance instabilities. One reason behind the significant increase in the anterior-posterior CoP variability may be related to the impaired proprioception of the patients with KOA [8, 23]. Keeping the variability in a normal range for the individuals even during a quiet standing task is associated with the use of sensory feedback information [24, 25], mainly from the somatosensory which are shown to be not accurate enough in these patients [8, 23]. In addition, another reason for greater CoP variability among the patients with KOA rather than the healthy control people may be the painfulness of their osteoarthritic knee. It was stated that the pain, per se, is an explanatory factor for more postural sways in patients with KOA [8]. The pain also caused more muscle recruitments [26]. Although Masui et al. (2006) stated that the postural sways are more related to the radiographic Kellgren-Lawrence grades than the pain [27], Lyttinen et al. (2010) showed opposed outcomes [28].

The elimination of visual feedback and support conditions also increased the CoP sway variability. Truszczyńska-Baszak et al. (2020) reported that the visual cues make no difference in the postural instabilities of the patients with severe KOA [29]. However, Hirata et al. (2013) showed that the existing vision is important for maintaining the balance in severe KOA patients [2]. The support condition also increased the variability of the AP CoP. Ivanenko et al. (1997) showed the difficulty of standing on an unstable platform even for the healthy controls [16, 30, 31]. The difficulty in standing for such a condition has originated from the narrow horizontal beam of the base of support where the semi-ellipses of the platform contact the ground. The body should keep the center of gravity inside this narrowed area. These endeavors led to a remarkable increase in the variability of the CoP sway in comparison with the firmed support condition.

The variability in the mediolateral direction was also discriminative for the main effects unless the role of the knee osteoarthritis was near to significant. The elimination of vision and unstable support conditions were also significantly increased the variability in the mediolateral direction. Since the patients in this research were all unilaterally suffered from the KOA, it was expected to have more significant effects in the mediolateral direction due to the unloading of the involved leg as reported by Hinman et al. (2002) who stated more instabilities in the mediolateral direction in the patients [5]; but pairwise comparisons in this study (shown in Table 1) reflected opposite outcomes. The excursion of the CoP in the mediolateral direction is, in general, the result of contractions between the gluteus medius muscles (hip abductors). Duffell et al. (2014) showed that the electromyographic activity of the gluteus medius of the unaffected side is considerably more than the controls unlike the KOA affected side [32].

Total mean velocity was not changed because of any independent variables in this study. This metric is the averaged velocity of the CoP movement i.e. the total path traveled in the force platform divided by the total time which is the same for all cases. The direction of the velocity or other nonlinear metrics based on the velocity of the CoP might differ between the groups since it is
more related to the activation of muscles. Fractal dimension had roughly the same condition against the independent variables of the study. This nonlinear metric measures the fine variations of a signal but only could detect the role of support condition in the ML direction. Ashtiani and Azghani (2017) used this metric to show the effective role of the cognitive loads while standing after rotational perturbations. They indicated that the elimination of vision does not change the fine fluctuations of the individuals’ center of mass movements [33].

The correlation between the WOMAC scores and the postural indices of stability confirmed the adverse effects of the painful knee on balance maintenance in accordance with the previous studies [2, 15, 18]. The variability of the AP CoP was significantly and positively correlated to the WOMAC pain score to imply more sense of pain in the knee with osteoarthritis cause higher variability in the posture disregarding the presence of visual feedback. However, standing on the unstable platform reduced this correlation. This meant that when the balance is jeopardized by the rocking support, the pain is not the priority of the Central Nervous System (CNS). Roughly none of the correlation coefficients between the WOMAC scores and postural balance is significant for the rocking support conditions (see Table 3). In other words, standing in a physically-difficult condition vanished the correlations between pathological and postural concerns. Total mean velocity was also significantly negatively correlated to the WOMAC pain score indicating that more painful knee causes slower CoP movements again in the standing on firm support lonely. The literature also has reported the negative correlation between the AP velocity and the WOMAC pain score [18]. Furthermore, Robon et al. (2000) showed that the gait velocity for the patients with knee osteoarthritis is significantly less than the aged-matched control subjects and this is a kind of compensatory mechanism to reduce joint forces [34]. This information implies that the patients with KOA ignored the pain sensation while standing on the rocking support.

This study has faced some limitations. The rocking support was only able to wobble in the pitch direction. Moreover, this study excluded the patients with severe grade of the knee osteoarthritis which might cause diverse effects on the postural outputs.

### Conclusions

Patients with knee osteoarthritis have more postural instabilities than healthy people. Elimination of visual feedback and standing on rocking support caused instability in posture for both healthy and KOA-suffered individuals. The instability in the anterior-posterior was more than in the lateral direction. The pain was the role-playing factor in destabilizing the posture among the patients with knee osteoarthritis. The painful knee was neglected when physical difficulties were imposed on the CNS during the control of posture.

### Acknowledgement

The authors would like to thank Movement Disorders Research laboratory of Tarbiat Modares University, Tehran, Iran.

### Authors Contribution

IH has acquired the data and analyzed them. He has also participated in discussions and writing of the manuscript. MNA has developed the main idea of the study and designed the experiments. He also analyzed the data, helped with discussions, and wrote the manuscript. FB has participated in the development of the main idea, design of experiments, discussions, and writing of the manuscript.

### Conflict of Interest

No conflict of Interest declared by authors.
Correlation between the Western Ontario and ... Hosseini I. et al.

Ethical Permission
This study approved by the ethical committee of Tarbiat Modares University (TMU). The ethical code is IR.MODARES.REC.1398.094.

Funding/Supports
None declared by authors.

References
1. Sharma L, Pai Y-C. Impaired proprioception and osteoarthritis. Curr Opin Rheumatol. 1997;9(3):253-8.
2. Hirata RP, Jørgensen TS, Rosager S, Arendt-Nielsen L, Bliddal H, Henriksen M, et al. Altered visual and feet proprioceptive feedbacks during quiet standing increase postural sway in patients with severe knee osteoarthritis. PloS one. 2013;8(8):e71253.
3. Tanaka R, Hirohama K, Ozawa J. Can muscle weakness and disability influence the relationship between pain catastrophizing and pain worsening in patients with knee osteoarthritis? A cross-sectional study. Braz J Phys Ther. 2019;23(3):266-72.
4. Öztürk Ö, Bombaro H, Keçeci T, Algun ZC. Effects of additional action observation to an exercise program in patients with chronic pain due to knee osteoarthritis: A randomized-controlled trial. Musculoskelet Sci Pract. 2021;52:102334.
5. Hinman R, Bennell K, Metcalf B, Crossley K. Balance impairments in individuals with symptomatic knee osteoarthritis: a comparison with matched controls using clinical tests. Rheumatology. 2002;41(12):1388-94.
6. Turcot K, Sagawa Jr Y, Hoffmeyer P, Suvá D, Armand S. Multi-joint postural behavior in patients with knee osteoarthritis. Knee. 2015;22(6):517-21.
7. Pirayeh N, Shaterzadeh-Yazdi M-J, Negahban H, Mehravar M, Mostafaei N, Saki-Malehi A. Examining the diagnostic accuracy of static postural stability measures in differentiating among knee osteoarthritis patients with mild and moderate to severe radiographic signs. Gait Posture. 2018;64; doi: 10.1016/j.gaitpost.2018.04.049.
8. Hassan B, Mockett S, Doherty M. Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. Ann Rheum Dis. 2001;60(6):612-8.
9. Sanchez-Ramirez D, van der Leeden M, Knol D, van der Esch M, Roorda L, Verschueren S, et al. Association of postural control with muscle strength, proprioception, self-reported knee instability and activity limitations in patients with knee osteoarthritis. J Rehabil Med. 2013;45(2):192-7.
10. Amano T, Tanaka S, Ito H, Morikawa S, Uchida S. Quantifying walking ability in Japanese patients with knee osteoarthritis: Standard values derived from a multicenter study. J Orthop Sci. 2018;23(6):1027-31.
11. Bellamy N, Kirwan J, Boers M, Brooks P, Strand V, Tugwell P, et al. Recommendations for a core set of outcome measures for future phase III clinical trials in knee, hip, and hand osteoarthritis. Consensus development at OMERACT III. J Rheumatol. 1997;24(4):799-802.
12. Turcot K, Armand S, Fritschy D, Hoffmeyer P, Suvá D. Sit-to-stand alterations in advanced knee osteoarthritis. Gait Posture. 2012;36(1):68-72.
13. Duffell LD, Guliati V, Southgate DF, McGregor AH. Measuring body weight distribution during sit-to-stand in patients with early knee osteoarthritis. Gait Posture. 2013;38(4):745-50.
14. Anan M, Shinkoda K, Suzuki K, Yagi M, Ibata R, Kito N. Do patients with knee osteoarthritis perform sit-to-stand motion efficiently? Gait Posture. 2015;41(2):488-92.
15. Debi R, Mor A, Segal G, Segal O, Agar D, Debbi E, et al. Correlation between single limb support phase and self-evaluation questionnaires in knee osteoarthritis populations. Disabil Rehabil. 2011;33(13-14):1103-9.
16. Hosseini I, Ashitani MN, Bahrpeyema F. Postural Stability in Patients with Moderate Knee Osteoarthritis: Roles of Visual Feedback and Dynamic Perturbations. J Rehabil Sci Res. 2021;8(4). 10.30476/jrsr.2021.92686.1214
17. Jorge JG, Dionisio VC. Biomechanical analysis during single-leg squat in individuals with knee osteoarthritis. Knee. 2021;28:362-70.
18. Petrella M, Gramani-Say K, Serrão PRMdS, Lessi GC, Barela JA, Carvalho RdP, et al. Measuring postural control during mini-squat posture in men with early knee osteoarthritis. Human Mov Sci. 2017;52:108-16.
19. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes in patients with osteoarthritis of the hip or knee. J Rheumatol. 1988;15(12):1833-40.
20. Eftekhar-Sadat B, Niknejad-Hosseyni SH, Babaei-Ghazani A, Toopchizadeh V, Sadeghi H. Reliability and validity of Persian version of Western Ontario and McMaster Universities Osteoarthritis index in knee osteoarthritis. J Res Clin Med. 2015;3(3):170-7.
21. Higuchi T. Approach to an irregular time series on the basis of the fractal theory. Phys D:
Nonlinear Phenom. 1988;31(2):277-83.  
22. Appiah-Kubi KO, Wright W. Vestibular training promotes adaptation of multisensory integration in postural control. Gait Posture. 2019;73:215-20.  
23. Taglietti M, Bela LFD, Dias JM, Pelegrinelli ARM, Nogueira JF, Júnior JPB, et al. Postural sway, balance confidence, and fear of falling in women with knee osteoarthritis in comparison to matched controls. PM&R. 2017;9(8):774-80.  
24. Horak FB. Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls? Age Ageing. 2006;35(suppl_2):ii7-ii11.  
25. van Beers RJ. Motor learning is optimally tuned to the properties of motor noise. Neuron. 2009;63(3):406-17.  
26. Brucini M, Duranti R, Galletti R, Pantaleo T, Zucchi PL. Pain thresholds and electromyographic features of periarticular muscles in patients with osteoarthritis of the knee. Pain. 1981;10(1):57-66.  
27. Masui T, Hasegawa Y, Yamaguchi J, Kanoh T, Ishiguro N, Suzuki S. Increasing postural sway in rural-community-dwelling elderly persons with knee osteoarthritis. J Orthop Sci. 2006;11(4):353-8.  
28. Lyysinen T, Liikavainio T, Bragge T, Hakkarainen M, Karjalainen PA, Arokoski JP. Postural control and thigh muscle activity in men with knee osteoarthritis. J Electromyogr Kinesiol. 2010;20(6):1066-74.  
29. Truszczyńska-Baszak A, Dadura E, Drzal-Grabiec J, Tarnowski A. Static balance assessment in patients with severe osteoarthritis of the knee. Knee. 2020;27(5):1349-56.  
30. Ivanenko YP, Levik YS, Talis V, Gurfinkel V. Human equilibrium on unstable support: the importance of foot-support interaction. Neurosci Lett. 1997;235(3):109-12.  
31. Oliaei S, Ashtiani MN, Azma K, Saidi S, Azghani MR. Effects of postural and cognitive difficulty levels on the standing of healthy young males on an unstable platform. Acta Neurobiol Exp. 2018;78:60-8.  
32. Duffell LD, Southgate DF, Gulati V, McGregor AH. Balance and gait adaptations in patients with early knee osteoarthritis. Gait Posture. 2014;39(4):1057-61.  
33. Ashtiani MN, Azghani MR. Nonlinear dynamics analysis of the human balance control subjected to physical and sensory perturbations. Acta Neurobiol Exp. 2017;77:168-75.  
34. Robon MJ, Perell KL, Fang M, Guererro E. The relationship between ankle plantar flexor muscle moments and knee compressive forces in subjects with and without pain. Clin Biomech. 2000;15(7):522-7.