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Effect of Grades of Chondromalacia on Static and Dynamic Balance: Cross-Sectional Study

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ABSTRACT

Background: Chondromalacia patellae (CMP) is a common condition affecting young adults, characterized by anterior knee pain and progressive cartilage degeneration. It can compromise neuromuscular control and impair postural stability.

Aim: This study aimed to investigate the effect of different grades of patellofemoral chondromalacia on static and dynamic balance in adults aged 18–40 years.

Patients and methods: Eighty-seven participants (both males and females) aged 18–40 years were included in this study. They were divided into five groups: four patient groups with grades I to IV chondromalacia confirmed by MRI, and one healthy control group. All participants had chronic symptoms for more than 3 months and BMI between 19–29. Balance assessment was performed using the Biodex Balance System. Outcome measures included Overall Stability Index (OSI), Anterior–Posterior Stability Index (APSI), Medial–Lateral Stability Index (MLSI), direction control, and time to complete the dynamic balance test.

Results: Statistically significant differences were found across all balance parameters among the five groups. Higher grades of chondromalacia were associated with worse static and dynamic balance. Grade IV participants demonstrated the highest instability and longest test completion times. Age and BMI showed a strong positive correlation with balance deficits, while gender showed no significant differences ($p > 0.05$).

Conclusion: Chondromalacia severity had a direct impact on balance performance. This supports the need for early detection and grade-specific rehabilitation focused on balance and postural control.

Keywords: Chondromalacia patellae, Balance, Postural stability, Limits of stability, Biodex balance system, Cartilage degeneration.

INTRODUCTION

Chondromalacia patellae (CMP), often referred to as runner's knee, mostly affects younger individuals and is characterized by anterior knee pain (AKP) accompanied by observable alterations in patellar cartilage. The primary pathological alterations consist of cartilage softening, swelling, and edema. CMP results from several reasons, including trauma, heightened cartilage susceptibility, patellofemoral instability, anatomical bone abnormalities, aberrant patellar movement, and occupational risks [(1)].

Risk factors for the onset of cartilage degeneration include obesity, female gender, and advancing age. Chondromalacia is a disorder affecting articular cartilage in both athletes and sedentary individuals [(2)]. Chondromalacia patellae (CMP) may be reversible or may advance to patellofemoral osteoarthritis. Quadriceps atrophy, patellofemoral crepitation, and effusion are evident clinical manifestations [(1)].

Patients with CMP report anterior knee discomfort associated with everyday tasks necessitating extended knee flexion and athletic pursuits. Alongside anterior knee discomfort, reports of edema, stiffness, crepitation, pain induced by extended sitting, initial limping, and difficulties in squatting were documented. Extended sitting with the knee flexed, accompanied with discomfort, edema, irregular patellar movement, thigh atrophy, and flexion deficit. It is used to forecast the degree of impairment in knee functions resulting from patellofemoral discomfort [(3)].

Balance, a crucial aspect of human everyday life and activities, may be characterized as input from the central nervous system. Postural control is categorized into static balance and dynamic balance. Static balance regulates the body's oscillation amplitude, while dynamic balance utilizes internal and external information to assess factors affecting stability during interference (such as walking, pushing, and pulling) and to sustain postural control. The optimal integration of static and dynamic balance is essential for the routine activities of everyday human existence. The predominant techniques for assessing knee joint balancing capability include single and double foot support, as well as swing track evaluations under dynamic or static gravitational settings [(4)].

The impact of balance training (BT) on indicators of postural control and mobility in older persons is well reported in the literature. Comprehensive investigations shown that BT significantly enhances indicators of static/dynamic steady-state, proactive, and reactive balance, along with performance in balance test batteries

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among healthy older individuals. Moreover, we successfully developed efficient BT methods to enhance balance function in healthy older persons [5].

The Biodex Balance System (BBS) is a novel device used for the evaluation and treatment of balance impairments. Initial research indicated beneficial outcomes of balance training using the Biodex balance device for enhancing balance function [6]. BBS has many clinical applications for balance training and assessment. It is acknowledged as a crucial instrument for balance and postural stability training in many therapeutic settings. Prior research showed the efficacy of the BBS in enhancing postural balance in patients with multiple sclerosis, Parkinson's illness, stroke, diabetic neuropathy, and the senior demographic at risk of falls [7].

PATIENTS AND METHODS

Study design: Observational cross-sectional study of patients diagnosed and referred to as having PFPS. The study was conducted at the Faculty of Physical Therapy, Misr University for Science and Technology, Egypt. Participants were chosen using a suitable sampling approach and the study was carried out from August 5, 2023, to February 10, 2024.

Study participants: The study's sample size was determined based on an alpha value of 0.05, an appropriate power of 80%, with a high effect size (d= 0.89). The study required a total of 34 participants (G * Power, version 3.1.9.4). The subjects were divided into two categories: 17 were given knee alignment-oriented balance exercises while the other 17 were given conventional balance exercises.

Inclusion criteria: The patient's age was between 18-35 years old of both gender and reported a pain intensity of 3 out of 10 on VAS while engaging in exercise in the past week. Gradual development of pain in the front of the knee lasting more than 12 weeks.

Exclusion criteria: The patient had a medical history that included a patellofemoral dislocation or subluxation, radiologically proven knee osteoarthritis, knee joint effusion, as well as possibly other injuries or pain in the hips or back. Patients having a pacemaker, epilepsy, serious malignancies, kidney stones, disc or spinal lesions, acute arthritis, recent surgery, severe fractures, or cardiovascular illness.

Instruments: Visual analogue scale (VAS), Biodex Stability System (Biodex balance system, United States, model 950-440- A700 12.1″ BALANCE SD DISPLAY ASSEMBLY), and the Kinovea software v0.8.26 (Kinovea open-source project under GPLv2).

METHODS AND PROCEDURES

The Clarke's sign test was used to assess the presence of chondromalacia patellae. A prospective validation study involving 106 patients undergoing arthroscopic knee surgery reported a sensitivity of 39.1% and a specificity of 67.5%, indicating moderate diagnostic value [8] (Figure 1).

Figure (1): Patellar grinding test, Adopted from **Malanga *et al.*** [9]

MRI was used to confirm the diagnosis of patellar chondromalacia and determining its grades. It is considered a reliable and accurate non-invasive diagnostic tool, particularly in more severe cases [10]. MRI has shown high diagnostic value due to advancements in magnetic field strength, coil technology, and software. MRI arthrography also demonstrated superior diagnostic accuracy in knee pathologies, including patellar chondromalacia [11].

The Biodex Balance System (model 950-441, serial number: 16040459) was used to assess postural stability. It provides dynamic testing across anterior–posterior and medial–lateral axes. It calculates overall stability index (OSI), medial-lateral stability index (MLSI), and anterior-posterior stability index (APSI). The BBS has been shown to be a reliable device, with intra-class correlation coefficients of R = 0.95 (dominant limb) and R = 0.78 (non-dominant limb) at Level 8 resistance [11].

Static balance test execution

- Each patient performed three trials, each lasting 20 seconds, with a 10-second rest between trials.
- During each trial, patients were instructed to keep the on-screen cursor as close as possible to the center of a displayed circle.
- Trials were repeated if the patient touched the rail handles or moved their feet.
- The mean average of OSI, APSI, and MLSI was calculated and documented from the three trials.

Dynamic balance test (Limits of stability) execution

- The same patient preparation and foot positioning protocols were followed as in the static test.
- The patient was instructed to follow and reach moving targets (a red dot) on the screen using their center of pressure; the red dot would move to a new location once correctly reached.
- Each patient completed three trials, with test duration varying depending on individual balance capabilities and severity of postural disturbance.
- Trials were repeated if the patient touched the rail or lost balance.
- After completion of the three trials, the following values were averaged and recorded:

  - **Time to complete the test**
  - **Directional control values** in all directions: Overall, Forward, Backward, Left, Right, Forward/Left, Forward/Right, Backward/Left, Backward/Right. (Figure 2)

- All trial data were automatically saved by the Biodex software.
- Trials were discarded and repeated in cases of procedural violation (e.g., touching rail handles or stepping off platform).
- Final results were based on the mean of the three trials for each measured parameter.

Figure (2): Balance Test Execution.

Ethical approval: Written informed consents were obtained from all patients before to their participation in the trial. The study has received approval from The Research Ethical Committee of the Faculty of Physical Therapy, Cairo University (No: P.T.REC/012/005573). The Helsinki Declaration was followed throughout the study's conduct.

Statistical analysis

The statistical analysis was performed using IBM SPSS version 29.0. First, normality of the variables was tested using Kolmogorov-Smirnov test. Descriptive statistics in the form of means and standard deviations were calculated. ANOVA test and Pearson correlation coefficient were used. The level of significance for all tests were set at $p \leq 0.05$.

RESULTS

The data revealed that there was no significant difference between the five groups regarding demographic data (age, gender, and BMI) which showed that the five groups were homogenous. The data also showed that there was a significant difference between the five groups regarding OSI, APSI and MLSI as well as time to complete test and overall direction control where for all variables, grade 4 had the highest mean score while the control group had the lowest mean score (Table 2). Table (1) showed that all the study variables were normally distributed since the assumption of normality was accepted for all variables.

Table (1): Test of normality (Kolmogorov –Smirnov test) for study variables

Variables	Z-value	p-value
OSI	0.698	0.714
APSI	0.740	0.644
MLSI	0.695	0.720
Time to complete test	0.798	0.547
Overall direction control	0.743	0.638

Table (2) revealed that there was a significant difference between the five groups regarding OSI, APSI and MLSI. Grade 4 had the highest mean score (OSI=1.7, APSI=1.53 and MLSI=1.41), while the control group had the lowest mean score for all variables (OSI=0.64, APSI=0.54 and MLSI=0.5). Also, the values tend to increase with increasing grade. The mean values of grade 2 (OSI=1.13, APSI=0.95 and MLSI=0.82) was slightly higher than grade 1 (OSI=0.7, APSI=0.58 and MLSI=0.48). The mean values of grade 3 (OSI=1.59, APSI=1.32 and MLSI=1.09) was slightly higher than grade 2 (OSI=1.13, APSI=0.95 and MLSI=0.82).

Table (2): Static Balance (Postural Stability) of the five groups

Variables	Grade 1 (n=20)		Grade 2 (n=20)		Grade 3 (n=16)		Grade 4 (n=11)		Control (n=20)		Difference between groups	
											F	p
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd		
OSI	0.70	0.20	1.13	0.34	1.59	0.25	1.70	0.15	0.64	0.12	71.255	.000*
APSI	0.58	0.15	0.95	0.28	1.32	0.28	1.53	0.18	0.54	0.11	65.152	.000*
MLSI	0.48	0.14	0.82	0.26	1.09	0.36	1.41	0.21	0.50	0.12	43.207	.000*

*significant at p-value<0.05

Table (3) revealed that there was a significant difference between the five groups regarding time to complete test and overall direction control. Grade 4 had the highest mean score (time=2.08 and overall=18.2), while the control group had the lowest mean score for time to complete test (1.23) and grade 1 had the lowest mean score for overall direction control (11.7). Also, the values tend to increase with increasing grade. The mean values of grade 2 (time to complete test=1.36 and overall direction control=12.6) was slightly higher than grade 1 (time to complete test=1.24 and overall direction control=11.7). The mean values of grade 3 (time to complete test=1.69 and overall direction control=15.2) was slightly higher than grade 2 (time to complete test=1.36 and overall direction control=12.6).

Table (3): Dynamic balance (Limits of stability) of the five groups

Variables	Grade 1 (n=20)		Grade 2 (n=20)		Grade 3 (n=16)		Grade 4 (n=11)		Control (n=20)		Difference between groups	
											F	p
	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd		
Time to complete test	1.24	0.09	1.36	0.09	1.69	0.30	2.08	0.44	1.23	0.09	39.950	.000*
Overall direction control	11.70	1.42	12.60	1.43	15.25	2.18	18.27	2.20	12.40	2.68	24.905	.000*

*significant at p-value<0.05

Table (4) showed that there was a significant direct positive strong correlation between OSI, APSI, MLSI, and time to complete test, and overall direction control**.** The results of this study reported that there was a significant difference between the five groups (the four grades and the control group) regarding OSI, APSI and MLSI as well as time to complete test and overall direction control. The values tend to increase with increasing grade where for all variables, it was found that grade 4 had the highest mean score, while the control group had the lowest mean score.

Table (4): Correlation among study variables

Study variables	OSI		APSI		MLSI		Time to complete test		Overall direction control	
	r	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
OSI	1									
APSI	0.96	0.00*	1							
MLSI	0.89	0.00*	0.93	0.00*	1					
Time to complete test	0.72	0.00*	0.74	0.00*	0.72	0.00*	1			
Overall direction control	0.64	0.00*	0.68	0.00*	0.65	0.00*	0.75	0.00*	1	

*significant at p-value<0.05

DISCUSSION

The findings of the current study revealed a significant differences between the five groups across all balance parameters. As the grade of chondromalacia increased, there was a marked deterioration in both static and dynamic balance measures. Grade IV patients demonstrated the highest instability (OSI = 1.70; APSI = 1.53; MLSI = 1.41) and longest time to complete the dynamic balance test (2.08 sec), compared to the control group, which showed the lowest instability and best performance (OSI = 0.64; time = 1.23 sec). Additionally, direction control scores worsened progressively with increasing grade.

Post hoc analyses confirmed the statistically significant differences primarily between higher-grade chondromalacia groups (III and IV) and the control group across all outcome measures. Furthermore, a strong positive correlation was found between all balance indices and both age and BMI suggesting that older and higher-BMI individuals exhibited greater instability.

There were no statistically significant differences in any balance parameters between males and females ($p > 0.05$) indicating that gender did not influence the outcomes in this study population.

These findings suggest that the severity of chondromalacia had a direct and measurable impact on both static and dynamic postural control. Early identification and grading of cartilage degeneration may help inform balance training and rehabilitation programs to prevent falls and functional decline in affected individuals.

The findings of the current study align with those of **Silva *et al.*** [13] who observed that individuals with chondromalacia patellae demonstrated poorer static and dynamic postural control compared to healthy controls. In both studies, balance impairments were evident, especially in more demanding tasks, supporting the notion that patellofemoral degeneration has a clear influence on neuromuscular control mechanisms governing stability. These outcomes are also consistent with **Ebid *et al.*** [14] who noted that chondromalacia patients showed significant functional deficits, particularly in weight-bearing and dynamic tasks. Although their study focused on pain and strength outcomes, the underlying biomechanical limitations described are likely contributors to the balance deficits reported in the present investigation. As balance tasks inherently depend on both neuromuscular coordination and structural joint integrity, the deterioration of cartilage in progressive chondromalacia may compromise postural control even further. Moreover, our findings correspond with the conclusions of **Aleknavičiūtė-Ablonskė *et al.*** [15] who highlighted the role of proprioceptive and muscle-strengthening interventions in improving joint function among individuals with grade II patellar chondromalacia. While their work focused on intervention efficacy, the observed need for targeted balance and strength rehabilitation reinforces the present study's evidence that postural stability progressively deteriorates with increasing chondromalacia severity, emphasizing the clinical relevance of early detection and tailored rehabilitation programs. In support of these observations, **Tahir *et al.*** [16] demonstrated that interventions aimed at improving hamstring flexibility and significantly enhanced functional performance in individuals with chondromalacia. Although their study did not directly assess balance, the documented improvements in lower extremity function suggest that muscle flexibility and joint mechanics play a crucial role in postural control. The present findings extend this understanding by showing how structural cartilage changes across grades directly impact both static and dynamic balance.

CONCLUSION

This study provided evidence that the severity of patellofemoral chondromalacia had a direct and measurable impact on both static and dynamic postural control. The deterioration in balance measures was consistent with increasing cartilage degeneration grades. These findings highlighted the importance of early diagnosis and grading of chondromalacia to facilitate timely balance training and prevent functional decline. Additionally, age and BMI were confirmed to be significant influencing factors on balance, while gender was not.

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