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Association between Lower Extremity Kinematics and Muscle Strength, Pain, Physical Activity Level, and Functional Status in Females with Patellofemoral Pain

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ABSTRACT

Background: Impaired lower extremity kinematics has beenconsidered as a contributing factor to patellofemoral pain (PFP). However, current knowledge about the correlation between lower extremity kinematics and muscle strength is very limited. This study investigated the correlation between lower extremity kinematics and muscle strength, pain, physical activity level, as well as functional status in females with PFP.

Methods: Seventy-five females with PFP participated in this analytical cross-sectional study. Lower extremity kinematics, maximal isometric strength of muscles, pain severity, physical activity level, as well as subjective and objective function were assessed using a motion analysis system, a dynamometer, Visual Analog Scale, the International Physical Activity questionnaire, and the Kujala questionnaire and the step-down test, respectively. The hip and knee kinematics were determined during the initial contact and the initial phase of landing. Pearson's correlation coefficients were calculated to establish the correlation between the variables.

Results: The knee rotation at the initial contact was significantly correlated with quadriceps strength (r=-0.240, P=0.038) and pain severity (r=0.268, P=0.020). Pain was significantly correlated with hamstring (r= -0.310, P=0.007) and quadriceps strength (r=-0.253, P=0.029) and the Kujala score (r=-0.346, P=0.002).

Conclusion: Our findings do not indicate a strong correlation between muscle strength and joint kinematics in females with PFP. An explanation is the presence of various subgroups of people with PFP. Future studies should focus on evaluating the correlation between the risk factors of PFP in subgroups, classified based on biomechanical, psychosocial, and anatomical characteristics.

Introduction

Patellofemoral pain (PFP) is one of the most common causes of knee pain which affects women and men of different ages [1]. PFP is more prevalent in women than in men and in active individuals than in those with low physical activity [1]. In a recent meta-analysis, the annual incidence of PFP was reported to be 22.7% in the general population [2]. Nejati et al. reported a prevalence of 26%, 20% and 16% of PFP among Iranian female climbers, volleyball players, and runners, respectively [3]. In addition to high prevalence and poor prognosis [4, 5], the risk of early knee osteoarthritis [6] has made the disease a serious challenge to the musculoskeletal

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system heath. In a prospective study, Stathopulu et al. showed that 91% of those who had experienced PFP in childhood still complained of knee pain in a 22-year follow-up [4]. Lankhorst et al. also found that more than 50% of patients who received a six-week evidence-based treatment still complained of pain and functional impairment 5 to 8 years after treatment [5].

The exact etiology of PFP is unknown; however, according to biomechanical theory, abnormal patellar kinematics (patellar maltracking) and resultant abnormal stress distribution in the patellofemoral joint (PFJ) play the key role in the development of PFP [7]. Studies suggest that numerous factors such as the hip and knee muscle weakness [2, 7], static and dynamic malalignment of the lower extremity [8, 9], and high physical activity level [2] may contribute to the development of PFP. In this regard, previous studies have focused on the association between quadriceps muscle weakness and PFP and consistently supported their association [10, 11].

Later, it was hypothesized that abnormal patellar kinematics may also be caused by impairment in lower extremity kinematics resulting from the hip muscle weakness [12]. Supporting this assumption, some researchers found an increase in hip internal rotation and adduction in people with PFP compared with healthy people [13, 14]. Although hip muscle weakness has been repeatedly observed in people with PFP [12, 14, 15], there is still insufficient information about the association between the weakness of hip muscles and disturbed lower extremity kinematics in PFP. In this regard, previous reports are contradictory [16-18]. For instance, de Oliveira Silva et al. found no significant correlation between knee kinematics and quadriceps muscle strength during step descent in people with PFP [16]. Nagakawa et al. also observed no significant correlation between the eccentric strength of trunk muscles and trunk and lower extremity kinematics in people with PFP [17]. However, Boling et al. reported a significant correlation between hip muscle strength and changes in trunk and hip kinematics in people with PFP [18]. A likely explanation for the inconsistency between the previous reports is the sex differences in muscle function and lower extremity kinematics [19], which was not considered in some previous studies which included females and males with PFP in a single group [17, 18].

In addition to muscle weakness, other factors such as pain, functional ability, and physical activity level may also influence movement strategies and joint kinematics in people with PFP [16]. Pain and fear of pain can lead to the adoption of compensatory motion patterns to avoid pain [16]. Reduced physical activity and functional impairments and the resultant reduction of physical fitness may influence the lower extremity joint kinematics [20]. Therefore, a thorough understanding of the relationship between these factors and lower extremity kinematics in people with PFP requires a simultaneous assessment of the relationship between these factors. However, there is a scarcity of studies considering the association between pain intensity, functional status, physical activity level, and muscle strength with three-dimensional lower extremity kinematics in a study. Among them, Almeida et al. investigating the association between pain, function and two-dimensional lower extremity kinematics, reported a significant correlation between pain severity and dynamic knee valgus angle in women with PFP [20]. Understanding the correlation between lower extremity kinematics and muscle strength can be a useful guide for developing more specific preventive and treatment strategies for PFP.

Accordingly, this study aimed to investigate the correlation of lower extremity kinematics with muscle strength, pain, function and physical activity level in women with PFP during a jump-landing task.

Methods

Using simple non-probability sampling, 75 women (30.32±6.34) with patellofemoral pain who met eligibility criteria were selected for participation in this analytical cross-sectional study. The demographic profile of the participants is shown in Table 1. The patients were chosen from among those who were referred by orthopedic surgeons to physiotherapy clinics with patellofemoral pain diagnosis for treatment. An experienced physiotherapist screened participants according to the inclusion and exclusion criteria.

Table 1: Participants Characteristics (mean and standard deviation)

Variable	Mean	SD
Age $_{(year)}$	30.32	6.34
Height $_{(cm)}$	160.82	5.70
Weight $_{(kg)}$	61.00	9.05
VAS score $_{(0-100)}$	68.25	18.89
Time passed since diagnosis $_{(month)}$	49.42	41.23
Physical Activity level $_{(METs\ per\ week)}$	4135.83	2703.19
The Kujala scale $_{(0-100)}$	65.40	11.34

VAS: Visual Analog Scale; SD: Standard Deviation

The inclusion criteria were an age range of 18-40 years, minimum pain intensity of 30 out of 100 based on a 100-mm visual analogue scale (VAS) [18], complaint of anterior knee pain in the last three months, pain in performing at least two or more functional activities including step ascent and descent, running, squatting, prolonged sitting, pain on palpation of patellar facets [18], and pain in quadriceps isometric contraction at 60° of knee flexion. The exclusion criteria were the presence of meniscus or ligamentous pathology; patellar and tibiofemoral instability; patellar, iliotibial band and Pes anserinus tendinopathies; apparent knee effusion; history of traumatic patellar dislocation; pain in the hip joint, sacroiliac and lumbar spine [18]; Osgood-Schlatter or Larsen Johansson syndrome; previous history of knee surgery, and pregnancy [18]. In addition, participants with moderate and severe trunk and lower extremity structural and postural malalignments identified by clinical observation, and those with neurological conditions affecting movement were excluded. The participants enrolled in the study after signing an informed consent including information about the study objectives and methods. This research received approval from the Ethics Committee of the university (IR.AJUMS.REC.1394-490). All tests were carried out at the Musculoskeletal Rehabilitation Research Center of Ahvaz Jundishapur University of Medical Sciences.

Data Collection

Pain

Pain intensity was measured using a 100-point VAS, indicating zero as "no pain" and 100 as "the worst imaginable pain". The participants were asked to report their mean pain intensity in the past week.

Physical Activity Level

The Global Physical Activity Questionnaire (GPAQ) developed by the World Health Organization (WHO) was used to determine the activity level of the participants. The questionnaire determines the intensity and duration of a person's physical activity in five domains of work-related activities, recreational activities, transportation, household-related activities and sedentary behaviors (sitting times) during the day, hour, and minute. Using the GPAQ, the total energy expenditure of each person was calculated based on the Metabolic Equivalent of Task (METs) per week. Vasheghani Farahani et al. have reported acceptable validity and reliability of the Persian version of the questionnaire with ICC> 0.7 [21].

Functional Assessment

The Persian version of the Kujala anterior knee pain scale determined the self-reported functional ability of each participant [22]. The Kujala is a valid and reliable self-report questionnaire containing 13 items that assess subjective symptoms and functional limitations associated with anterior knee pain [22]. This questionnaire scores functional ability from zero to 100, with zero indicating the severe functional disability and 100 representing no functional limitation. The step-down test was used for reliable objective evaluation of functional ability [23]. To do the test, the participants stood on a 20 cm-height stair with involved (or more involved) leg, while maintaining the uninvolved (or less involved) leg along the involved leg with the knee in extension and hands on the pelvis. They then stepped down from the stair with the uninvolved leg so that the heel would touch the ground (without applying weight) and subsequently returned to the initial condition. The frequency of performing this task within 30 seconds was recorded as a functional test score.

Muscle Strength Testing

The muscle strength of quadriceps, hamstring, hip abductors, and external hip rotators was evaluated by a fixed dynamometer (Isometric push-pull, Danesh Salar Iranian Company, Tehran, Iran). Omidi et al. (2017) reported excellent intra-rater reliability of ICC=0.86 for the dynamometer [24]. The strength of each muscle group was measured in the standard clinical positions [24] (Figure 1). The quadriceps strength was measured in the sitting position with the knee in 60 degrees of flexion.

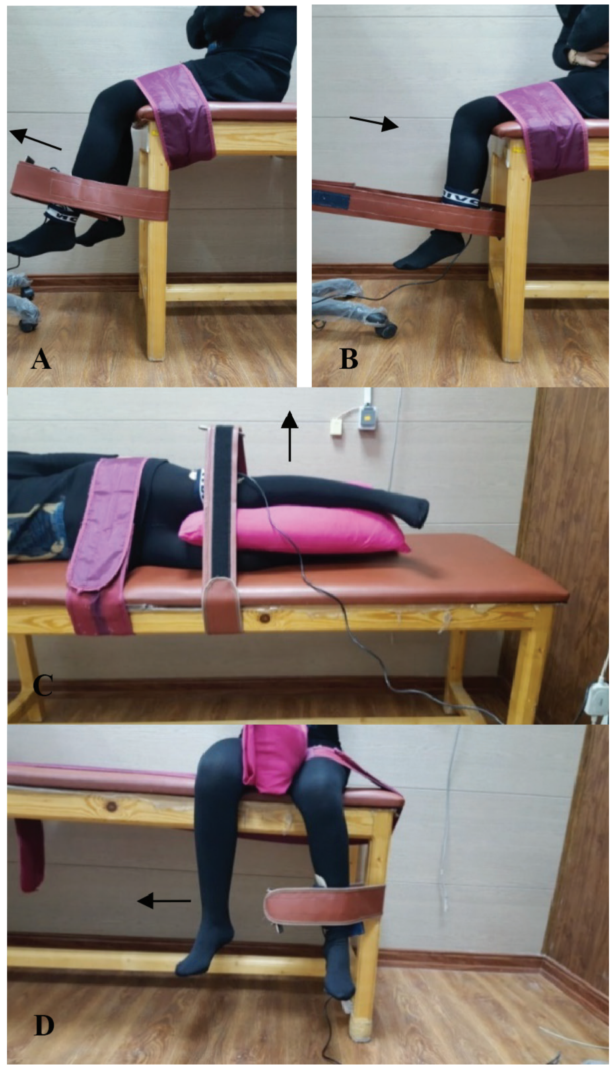

Figure 1: Participant positions for the Maximal Isometric Muscle Strength Testing: A) Quadriceps strength testing, B) hamstring strength testing, C) Hip abductor strength testing, D) Hip external rotators strength testing; the arrow shows the direction of force.

The dynamometer was fixed to the distal tibia, 5 cm above the ankle joint (Figure 1A). The hamstring muscle strength was also evaluated in a sitting position, with the hip and knee in 90 degrees of flexion (Figure 1B). To evaluate the hip abduction strength, the participants lay on the opposite side with a pillow between the two thighs to keep the hip joint in the neutral position, with the pelvic fixed to the bed using a Velcro strap. The dynamometer was fixed to the distal femur, above the lateral condyle of the test leg. Next, the subject was asked to use their maximal effort to abduct the limb (Figure 1C). To assess the strength of the hip external rotators, the person sat on the edge of the examination bed with the knee and thigh in 90 degrees of flexion, where the thigh was fixed to the bed in a neutral position, and a foam roll was placed between the two knees to avoid hip adduction. In this position, the dynamometer was stabilized above the medial ankle. The person was asked to use their maximal effort to move the ankle inward (Figure 1D).

The strength of each muscle was evaluated three times with one-minute rest interval between the trials [14], with the mean of the three trials being used for data analysis. Each person performed 2-3 familiarization trials before the actual tests. The muscle strength was normalized based on the weight and height of the individuals and the length of the limbs ([muscle strength (kg)×limb length (cm)]÷[height (cm)×weight (kg)])×100). We used the distance between greater trochanter to lateral femoral condyle as a segment length for normalizing hip abductors strength. Also, the distance between lateral femoral condyle to lateral malleoli was used for normalizing the strength of knee flexors and extensors and hip external rotators [24].

Kinematic Data

Kinematic data were recorded using a seven-camera motion analysis system (Qualisys, Model: 2.5.613) with a sampling frequency of 120 Hz while participants performed a jump/landing task. Jump-landing activity is a multipalnar movement that is widely used for evaluation of biomechanical integrity of lower extremity in people at risk of lower limb musculoskeletal injuries. Research suggests a link between disturbed landing kinematics, specifically in the initial phase of landing and knee injuries [25].

Before testing, surface markers were installed bilaterally on the first, second, and fifth metatarsal heads, medial and lateral malleoli, medial and lateral femoral condyles, greater femoral trochanter, anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). Additionally, two pairs of clusters of surface markers were placed on the lateral aspect of the thighs and the shins. An anatomical frame was recorded with the participants standing a 35-cm-height platform, with hands on waist, the hip in the neutral position, and feet shoulder-width apart.

The participants were then asked to jump from the platform as high as possible and land at approximately ½ of their body height away from the box, which was marked on the floor. A successful jump was characterized by jumping off and landing with both feet simultaneously without losing balance. Participants did not receive any instruction about the landing technique ensuring that additional feedback does not affect the landing. The participants performed three test trials with the rest interval of 1 minute between the trials. Prior to data collection, each participant performed 5-minute jogging for a warm-up and 3 familiarization trials of the jump/landing task.

Finally, the kinematic data from the affected or most affected lower extremity was used for analysis [18]. Visual 3D software (C-motion Inc., Kingston, Canada) was used to measure kinematic variables. The variables of interest were the hip and knee joints' angles in the sagittal, frontal and transverse planes at the initial contact of feet with the ground plus the maximum angular values at the initial landing phase. The initial contact was defined as the moment at which the angular velocity of the lateral malleoli marker was zero. The initial landing phase was defined from the initial contact of feet until the knee joint reached the maximum flexion.

Statistical Analysis

The Shapiro-Wilk test assessed the normality of data for each variable tested. Pearson correlation coefficient was used to test the correlation of variables.

Results

The results of the Shapiro-Wilk tests confirmed the normal distribution of each variable (P<0.05). The mean age of the ±participants was 30.32±6.34 years and the mean VAS score for pain was 68.25±18.89. Qualitative ranking of physical activity level showed that most participants had low and moderate levels of activity. Table 1 reports the participants' characteristics in detail.

Table 2 shows the mean maximal isometric strength of muscle groups. There was a significant negative relationship between the quadriceps strength and the internal/external rotation angle of the knee at the initial contact (r=-0.240, P=0.038). There was, however, no significant relationship between other kinematic variables and the strength of lower extremity muscles (P>0.05) (Table 3).

Table 2: Maximal isometric muscle strength (mean and standard deviation)

Muscle	Mean	SD
Quadriceps	4.99	2.27
Hamstring	2.80	1.28
Hip Abductors	5.12	2.19
Hip External Rotators	1.98	0.70

Muscle strength was normalized based on weight, height and limb length

A weak but significant correlation was found between the pain intensity and the knee internal/external rotation angle at the initial contact (r=0.268, P=0.020). Further, a negative significant correlation was observed between pain intensity and the hamstring (r=-0.310, P=0.007), as well as quadriceps (r=-0.253, P=0.029) strength. In addition, a negative significant correlation was found between the pain intensity and the Kujala score (r=-0.346, P=0.002). The step-down score and the level of physical activity had no significant correlation with any of the variables tested (P>0.05) (Table 4).

Discussion

The purpose of this study was to determine the relationship between kinematic variables and muscle strength, pain intensity, physical activity level as well as functional status in females with PFP. The findings of this study showed no significant relationship between lower extremity kinematics and muscle strength, except for a weak relationship between the Int/Ext knee rotation angle and quadriceps strength. This suggests that muscle strength and impaired kinematics should be considered as independent factors rather than interrelated factors in PFP treatment.

Our results are consistent with the findings of recent studies reporting non-significant relationship between kinematic parameters and muscle strength [16,17]. For instance, de Oliveira Silva et al. reported no significant relationship between quadriceps strength and kinematics

Table 3: Pearson's correlation coefficient, r (p value), for correlation between lower extremity joint angle during Jump/landing task and muscle strength in females with patellofemoral pain

Lower extremity joint angle (°)	Normalized Muscle Strength			
	Quadriceps	Hamstring	Hip abductors	Hip external rotators strength
Hip flexion angle at IC	-0.12 (0.30)	-0.03 (0.76)	0.20 (0.08)	0.03(0.77)
Maximum hip flexion	-0.09 (0.42)	-0.00 (0.97)	0.14 (0.20)	-0.02(0.82)
Hip Abd/Add at IC	0.16 (0.15)	0.06 (0.57)	-0.10 (0.35)	0.21(0.06)
Maximum hip Abd/Add	0.10 (0.36)	-0.06 (0.58)	-0.22 (0.05)	0.10(0.38)
Hip Int/Ext rotation at IC	0.06 (0.57)	-0.12 (0.28)	-0.04 (0.72)	-0.02(0.82)
Maximum hip Int/Ext rotation	0.10 (0.38)	0.19 (0.09)	0.11 (0.33)	0.19(0.10)
Knee flexion at IC	0.09(0.40)	0.13 (0.26)	-0.12 (0.28)	-0.01(0.93)
Maximum knee flexion	0.07 (0.54)	0.03 (0.74)	-0.16 (0.16)	0.06(0.58)
Knee Abd/Add at IC	0.07 (0.50)	-0.07 (0.51)	-0.00 (0.96)	-0.14(0.20)
Maximum knee Abd/Add	-0.01 (0.88)	0.09 (0.41)	-0.03 (0.80)	0.05(0.66)
Knee Int/Ext rotation at IC	-0.24 (0.03)	-0.04 (0.71)	-0.02 (0.86)	0.01(0.92)
Maximum knee Int/Ext rotation	0.10 (0.39)	0.02 (0.82)	-0.03 (0.798)	0.13(0.26)

IC: Initial contact, Int/Ext: Internal/External, Abd/Add: Abduction/Adduction, Significance was set at P<0.05

Table 4: Pearson's correlation coefficient, r (p value), for correlation between lower extremity joint angle during Jump/landing task and muscle strength in females with patellofemoral pain

Lower extremity joint angle (°)	Pain (0-100)	The Kujala score (0-100)	Physical Activity (MET/week)_
Hip flexion angle at IC	0.00 (0.98)	0.00 (0.95)	-0.06 (0.56)
Maximum hip flexion	0.07(0.53)	0.08(0.47)	-0.12(0.27)
Hip Abd/Add at IC	-0.08(0.47)	0.01(0.89)	0.09(0.41)
Maximum hip Abd/Add	0.03(0.76)	-0.11(0.33)	0.00(0.97)
Hip Int/Ext rotation at IC	-0.09(0.43)	-0.06(0.56)	-0.02(0.85)
Maximum hip Int/Ext rotation	-0.22(0.05)	0.03(0.73)	0.05(0.64)
Knee flexion at IC	0.14(0.22)	0.06(0.58)	-0.03(0.73)
Maximum knee flexion	0.06(0.56)	-0.01(0.86)	0.13(0.25)
Knee Abd/Add at IC	0.06(0.57)	-0.08(0.49)	-0.05(0.63)
Maximum knee Abd/Add	-0.06(0.60)	0.00(0.98)	0.16(0.14)
Knee Int/Ext rotation at IC	0.26 (0.02)	-0.08(0.46)	-0.08(0.45)
Maximum knee Int/Ext rotation	0.16(0.14)	0.01(0.91)	0.01(0.91)
Normalized Muscle Strength			
Hip abductor	-0.05(0.61)	-0.06(0.57)	-0.02(0.83)
Hip external rotators	-0.18(0.11)	0.18(0.10)	0.00(0.94)
Quadriceps strength	-0.25(0.02)	0.02(0.83)	0.08 (0.49)
Hamstring strength	-0.31(<0.001)	0.22(0.05)	-0.03(0.74)

IC: Initial contact, Int/Ext: Internal/External, Abd/Add: Abduction/Adduction, Significance was set at P<0.05

of step-descent in 40 people with PFP [16]. Nagakawa et al. found no significant correlation between either the trunk eccentric strength or the frontal plane kinematics of the trunk, hip and knee joints in 30 subjects with PFP during the single-leg squat [17]. In contrast, Boling et al. found a significant relationship only between hip external rotator strength and hip abduction angle in 15 people with PFP [18]. Inconsistency between the results of Boling et al's study and the recent works (including ours) can be explained by the small number of participants in their work. Other factors that may influence the finding of studies investigating the correlation between muscle strength and joint kinematics include sex differences in kinematics and the type of task tested [19]. Studies also suggest that other contributors such as neuromuscular control [26], psychological factors [27], previously learned movement patterns, and compensatory motor mechanisms [28] have significant effects on lower limb kinematics in people with PFP. Further, the interactions of the factors listed and their cumulative effects may cause kinematic changes. For example, in the study by de Oliveira Silva et al., a moderately significant relationship was observed between fear of motion (kinesophobia) and lower extremity kinematics[16].

In our study, the maximum isometric strength of quadriceps and hamstring had a significant negative correlation with the pain intensity. However, there was no significant relationship between the strength of hip joint muscles and pain intensity. In general, the results of studies are inconsistent on the relationship between the pain intensity and the muscle strength in the people with patellofemoral pain [24, 26-29]. For instance, Omidi et al. found no significant correlation between the pain intensity and the strength of hip and knee muscles in subjects with PFP [24], while Nagakawa et al. observed a significant correlation between the strength of hip external rotators and the pain intensity [29]. The same authors reported a moderate correlation, though not significant, between the strength of knee extensors and the pain intensity [29]. Differences in the results of studies may be partially related to the difference in how muscle strength was measured. In the present research and study of Omidi et al., the maximum isometric strength of the muscles was measured, while Nagakawa et al. measured the maximal eccentric torque of muscles. The weak and moderate correlation between the pain and the muscle strength in this research and previous studies can be due to the inhibitory effect of pain on muscular force production capacity. In addition, the fear of pain is a psychological factor that may affect the patient's effort to produce the maximum force. It is possible that pain and fear of pain have a greater influence on muscular force production capacity during eccentric contraction and under dynamic conditions rather than isometric muscle contraction.

In this study, there was a significant correlation between pain and function (the Kujala score), which is consistent with the findings of Long-Rossi et al. [30]. These researchers also reported a moderate correlation between pain and physical function in people with PFP. Recent studies suggest that psychological factors are also involved in PFP [27]. The findings of Maclachlan et al. indicated a correlation between anxiety, depression as well as kinesiophobia, pain and physical function in subjects with PFP [27]. It seems further studies in subgroups of people with PFP based on psychological are necessary for a thorough understanding of the relationship between pain, joint biomechanics, and function.

Study Limitations

This study included only women with a low to moderate activity level. The results from people with high activity level and men can be different. We also included patients with unilateral and bilateral PFP in the study group and did not evaluate the psychosocial factors in our study. Comparison of landing kinematics in patients with bilateral and unilateral PFP is also warranted. Further studies could also be conducted to understand the correlation between the psychosocial factors plus neuromuscular control and biomechanical factors in individuals with PFP for designing more effective treatment plans.

Conclusion

Our findings suggest no strong correlation between lower extremity kinematics and muscle strength, pain intensity, physical activity and function in women with PFP. Future studies should consider the mutual role and the cumulative effects of potential risk factors on lower extremity biomechanics in people with PFP and the role of risk factors in subgroups of patients with distinct mechanical and psychological characteristics.

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