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KINEMATIC ANALYSIS OF THE ANKLE/FOOT COMPLEX MOBILITY OF WOMEN WITH PFP DURING WEIGHT BEARING FUNCTIONAL TESTS

ANÁLISE CINEMÁTICA DA MOBILIDADE DO COMPLEXO TORNOZELO/PÉ DE MULHERES COM DFP DURANTE TESTES FUNCIONAIS DE DESCARGA DE PESO

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Abstract: Patellofemoral pain (PFP) has been frequently associated with abnormalities in the alignment of the lower limbs and trunk, particularly during weight-bearing activities. In this context, proximal and local factors have been widely discussed. Distal factors could also be involved and need to be investigated in more detail. Our objective was to compare the foot kinematics of the ankle/foot complex in women with pronated feet and patellofemoral pain with the kinematics of asymptomatic women during the execution of anterior and lateral step down tests.
Methods: Fifty women were divided into two groups: control (n=16); and patellofemoral pain (n=34). All volunteers were evaluated using three-dimensional motion capture during the forward and lateral step-down tests. For each session, nine repetitions of each clinical test were performed on the most painful limb of the women with PFP and the dominant limb of the women in the control group. The mobility of the ankle/foot complex was measured and the range of motion was calculated for all segments. The two groups were compared using multivariate analysis of variance.
Results: Women in the PFP group exhibited less knee flexion and significantly greater mobility of: the hindfoot in relation to the tibia and the laboratory; the forefoot in relation to the tibia; and the forefoot in relation to the hindfoot.
Conclusion: Women with PFP exhibited greater mobility of the ankle/foot complex during the anterior and lateral step down tests, when compared with asymptomatic women.

Keywords: Pain. Knee. Biomechanical phenomena. Rehabilitation.

Resumo: Introdução: A dor femoropatelar (DFP) tem sido frequentemente associada a anormalidades no alinhamento dos membros inferiores e tronco, principalmente durante atividades de descarga de peso. Nesse contexto, fatores proximais e locais têm sido amplamente discutidos. Fatores distais também podem estar envolvidos e precisam ser investigados com mais detalhes. Nosso objetivo foi comparar a cinemática do complexo tornozelo/pé em mulheres com pés pronados e dor femoropatelar pormeio de cinemática tridimensional de mulheres assintomáticas durante a execução dos testes step down anterior e lateral.
Métodos: Cinquenta mulheres foram divididas em dois grupos: controle (n=16); e dor patelofemoral (n=34). Todos os voluntários foram avaliados usando captura de movimento tridimensional durante os testes step down anterior e lateral. Para cada sessão, foram realizadas nove repetições de cada teste clínico no membro mais doloroso das mulheres com DFP e no membro dominante das mulheres do grupo controle. A mobilidade do complexo tornozelo/pé foi medida e a amplitude de movimento foi calculada para todos os segmentos. Os dois grupos foram comparados por meio de análise multivariada (MANOVA).
Resultados: As mulheres do grupo DFP apresentaram menor flexão do joelho e mobilidade significativamente maior de: retropé em relação à tíbia e ao laboratório; do antepé em relação à tíbia; e do antepé em relação ao retropé.
Conclusão: Mulheres com DFP apresentaram maior mobilidade do complexo tornozelo/pé durante os testes de step down anterior e lateral, quando comparadas com mulheres assintomáticas.

Descritores: Dor. Joelho. Fenômenos biomecânicos. Reabilitação.

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Introduction

Patellofemoral pain (PFP) is linked to a process of anterior knee pain and is most prevalent among women aged between 18 and 35 years, regardless of whether they engage in physical activity or not.[6,7,18,21] The complaint has often been correlated with abnormalities in the alignment of the trunk and lower limbs, particularly during weight-bearing activities.[7,23,29,45] This misalignment reduces the contact area between the patella and the femur and consequently increases the pressure exerted on the retropatellar cartilage, causing the algic process[29] Despite the fact that the etiology of this pain is not well-known, it is clear that local (knee region), proximal (hip and trunk) and distal (ankle and foot)[30,47] factors are directly associated with the PFP. Proximal and local factors have been widely discussed in the literature, whereas distal factors still require further investigation.[5,47]

Concerning these distal factors, a static measurement is capable of assessing the posture of the foot in an orthostatic position. The Foot Posture Index (FPI) assesses three anatomical planes and provides a score, which ranges from -12 to 12, with the following classifications: values between 0 and 5 are considered normal; values between 6 and 9 are classified as pronated; values between 10 and 12 are considered hyper-pronated; and negative values represent supinated feet.[35] This index is important as it provides a quick and easy method of assessing the feet. However, it only provides a static measure of alignment.[40]

Studies that assessed the three-dimensional kinematics of the lower limb and trunk of individuals with patellofemoral pain during different weight-bearing activities have reported excessive ipsilateral trunk lean, pelvic drop, adduction and medial rotation of the hip, abduction of the knee and pronation of the hindfoot.[6,8, 11,36,45] In addition, several theoretical studies have correlated the kinematics of the hindfoot with the kinematics of the hip in women suffering from patellofemoral pain,[5,6,22] reporting delays in the peak and increase of foot eversion (at the time of the initial contact during gait) and increases in the medial rotation of the tibia, leading to the development of patellofemoral pain. .

Witvrouw et al.[47] reported that the influence of hindfoot eversion on the knee of women with PFP remains unknown. Although there is a probable increase in the medial rotation of the tibia among these individuals, no studies have assessed this phenomenon using a mutli-segmetal model to compare women with pronated feet and PFP with a control group during a functional test. This type of investigation could provide significant data, since multi-segmental kinematic models enable us to assess the ankle/foot complex in more detail.[38,44]

Multi-segmental kinematic models enable more detailed assessments of the foot.[19,25,38] It was recently demonstrated that the Oxford Foot Model is reproducible for the anterior and lateral step down tests.[20] These functional tests involve a high muscular demand and seek to assess the dynamic alignment of the lower limbs and trunk, as well as the dynamic stability of the knee, thereby guiding the treatment of women with knee pain and analyzing the results obtained during rehabilitation programs.[13,27,33]

Given the importance of understanding the correlation between biomechanical abnormalities in the ankle/foot complex and patellofemoral pain, the aim of the present study was to compare the foot kinematics of women with patellofemoral pain and pronated feet with the kinematics of asymptomatic women during the execution of anterior and lateral step down tests.

Materials and methods

Participants

This cross-sectional study contained a convenience consecutive sample of 16 assintomatic women (control group, CG), and 34 patellofemoral pain women (patellofemoral pain group, PFPG)

The women in the PFPG scored between 6 and 9 on the Foot Posture Index (FPI), characterizing their feet as pronated.[35] Studies indicate that the clinical measurement of the Foot Posture Index has moderate to high reliability in assessing the adult population[17,35] experienced anterior knee pain for at least three months, with the symptoms increasing during at least two of the following activities: climbing and descending stairs; squatting; kneeling down; jumping; sitting for long periods; isometric resistance of the quadriceps at 60° of knee flexion and palpation of the lateral or medial aspect of the patella. These activities were labeled anterior knee pain provokers by Thomee and colegues[43]

The following exclusion criteria were applied: a history of lower limb surgery; recurrent patellar dislocation or chronic instability; meniscal and/or ligament injuries; and length discrepancies of more than 1 cm between the lower limbs using a measuring tape. The volunteers from CG were recruited from university.

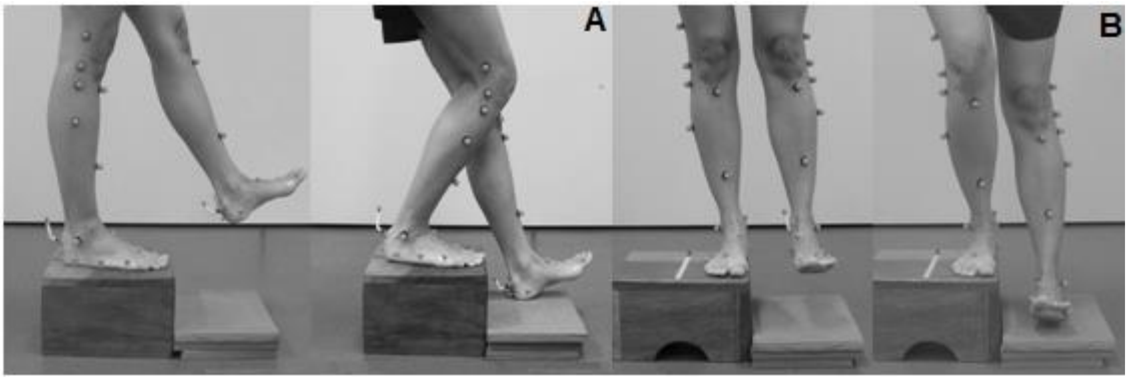
Pain intensity was measured using the Numerical Pain Rating Scale (NPRS)[15]. The participants were requested to classify the intensity of their pain in the previous 15 days.

Procedures

The placement of markers was performed in accordance with the Oxford Foot Model (OFM) protocol.[39] For each test session, thirty-six retro-reflective spherical markers of 9 mm were fixed in place using double-sided tape, as described by Stebbins et al[39]. The alignment of the markers was determined by a laser level prior to fixation[22]. The examiner had acquired clinical experience and had previously studied the placement of markers for the OFM model. This was necessary in order to minimize the possibility of differences in the palpation of anatomical structures and in the placement of the markers. Subsequently, the volunteers performed warm-up exercises and familiarized themselves with the tests that would be carried out on a step (18 cm high, 30 cm long and 30 cm deep).

To perform the anterior step down test, the tested limb was positioned close to the anterior edge of the step and the non-tested limb was suspended immediately in front of the step, assuming hip flexion, knee extension and maximal ankle dorsiflexion. To perform the lateral step down test, the tested limb was positioned close to the lateral edge of the step and the non-tested limb was suspended immediately beside the step, assuming hip and knee extension and maximal ankle dorsiflexion (Figure 1).

Figure 1 - Representation of the adjustments of the patient to perform the single leg step down anterior test (A) and the lateral step down test (B)



Source: Personal archieve.

For both tasks, the volunteers were requested to squat slowly (over the course of two seconds) until the heel of the non-tested limb touched the ground, and then return immediately to the initial position (again over two seconds). In order to standardize the test, the participants were requested to begin from maximal extension and squat until they reached approximately 60° of knee flexion in the support leg, while the contralateral foot touched the ground simultaneously. Adjustments related to the height of the volunteers were made using EVA blocks and the measure was made with a manual goniometer. The task was repeated nine times, with intervals between attempts. The volunteers were asked if they were ready to perform the test again before beginning the next attempt. All the tasks were made in the limptomatica limb. In case of bilateral pain, the most painfull knee was evaluated.

The Vicon® (Vicon Motion System Ltd., Oxford Metrics, UK) system was used to acquire kinematic data. This system involved eight infrared cameras with a frequency of 120 frames per second. Vicon Nexus software (version 1.8.5) was used to acquire and process the data.

Data processing

The markers were reconstructed, named and processed using Vicon-Nexus 1.8.5® software. A Woltring filter with a cutoff frequency of 8 Hz was used to reduce the noise caused by possible movements during the cycle prior to the application of the OFM model. After the reconstruction and labeling of the markers, the movement cycles were recorded using maximal extension and maximal knee flexion as indicators of the start and end of the cycle, respectively. The end of the squat was used as the point of reference.

Finally, the ranges of motion were calculated, based on the movements performed during the nine tests for each lower limb on the three planes. These values were calculated for the following segments: hindfoot in relation to the laboratory (HFTLF); hindfoot in relation to the tibia (HFTBA); forefoot in relation to the tibia (FFTBA); forefoot in relation to the hindfoot (FFHFA) and knee on the sagittal plane.

Statistical analysis

The demographic characteristics and the range of motion data were tested in terms of normality using the Shapiro Wilk test. The independent t-test was used to compare the characteristics of the sample. The kinematic variables were compared between the groups using multivariate analysis of the variance tests (MANOVA). The homogeneity of the covariance matrices was assessed by Box's M test. When the F value was significant, the Bonferroni post hoc test was used to identify the differences. The significance was set as 5 % ($P \leq 0.05$). Cohen´s d effect was calculated and defined as follows: < 0.2 = trivial; 0.2 to 0.5 = small; 0.5-0.8 = medium; and > 0.8 = large.[28] All of the comparisons were conducted using version 15.0 of SPSS software (SPSS Inc., Chicago, IL).

Results

With the numbers of subjects in this study, significant differences could be detected. Table 1 displays the comparative demographic data between the groups of volunteers.

Table 1 - Comparative demographic data between the groups of volunteers

	CG	PFPG
Height (m)	1.63 ± 6.2	1.58 ± 5.8
Mass (kg)	55.6 ± 6.1	57.2 ± 6.8
Age	24.6 ± 4.0	26.5 ± 8.2
FPI	7.5 ± 1.7	8.03 ± 3.2
VAS	0	5.7 ± 1.6
AKPS	100	66.7 ± 10

Abbreviations: CG: Control Group; PFPG: Patellofemoral pain group; VAS: Visual analogue scale.

The women in the PFP group exhibited greater mobility in all of the segments analyzed in both tests, with significant differences recorded between the groups. Table 2 displays the comparisons of the mean results for the two groups in the anterior and lateral step down tests.

Table 2 – Comparison of kinematic variables between control and patellofemoral pain group during anterior and lateral step down tests

	STEP DOWN ANTERIOR			STEP DOWN LATERAL		
	Control	**Pain**		**Control**	**Pain**	
Sagittal Plane	**Mean ± SD**	**Mean ± SD**	**ES§**	**Mean ± SD**	**Mean ± SD**	**ES§**
Knee (Flexion)*	59.42 (55.0-63.7)	55.75 (52.8-58.6)	0.4	53.47 ± (50.7-56.2)	48.65 (46.6-50.6)	0.8
HFTFL (Plantar Flexion)*	7.86 (6.0-9.6)	11.33 (10.0-12.6)	0.9	6.40 (4.9-7.8)	7.87 (6.7-8.9)	0.4
HFTBA (Dorsiflexion)*	22.97 (20.1-25.8)	39.15 (36.8-41.4)	2.6	21.69 (19.3-23.9)	36.41 (34.3-38.4)	2.7
FFTBA (Dorsiflexion)*	30.86 (28.0-33.6)	48.78 (46.2-51.3)	2.7	30.10 (27.8-32.3)	42.72 (40.5-44.8)	2.3
FFHFA (Dorsiflexion)*	8.15 (6.3-9.9)	12.89 (11.5-14.1)	1.3	8.17 (6.5-9.8)	10.56 (9.2-11.8)	0.6
Frontal Plane						
HFTFL (Eversion)*	1.63 (1.0-2.1)	19.73 (16.8-22.6)	2.9	1.33 (0.7-1.9)	13.64 (11.3-15.9)	2.4
HFTBA (Eversion)*	17.6 (13.9-21.2)	32.82 (28.3-37.2)	1.4	19.20 (15.7-22.6)	33.45 (28.5-38.3)	1.2
FFTBA (Pronation)*	17.16 (13.7-20.6)	33.68 (28.8-38.5)	1.4	18.36 (15.0-21.7)	35.93 (31.0-40.8)	1.5
FFHFA (Pronation)*	2.82 (2.0-3.5)	10.65 (8.4-12.8)	1.6	2.16 (1.4-2.9)	10.55 (8.2-12.8)	1.7
Transverse Plane						
HFTFL (External Rotation)*	4.33 (3.1-5.5)	8.54 (7.1-9.9)	1.2	5.15 (3.7-6.5)	8.9 (7.5-10.2)	1.0
HFTBA (External Rotation)*	11.67 (9.3-13.9)	23.76 (19.8-27.6)	1.3	11.14 (8.8-13.4)	24.01 (20.3-27.6)	1.5
FFTBA (Abduction)*	13.27 (10.5-16.0)	23.96 (20.7-27.1)	1.3	13.12 (10.3-15.8)	24.28 (21.4-27.0)	1.6
FFHFA (Abduction)*	2.7 (2.0-3.3)	9.11 (7.6-10.6)	1.9	2.63 (1.7-3.4)	9.05 (7.2-10.8)	1.6

* P<0,01; HFTLF – hindfoot in relation to the laboratory; HFTBA- hindfoot in relation to the tibia; FFTBA – forefoot in relation to the tibia; FFHFA – forefoot in relation to the hindfoot.§ Effect size determined using Cohen d (0.0 to 0.2 - trivial, 0.3 to 0.5 - small, 0.6 to 0.8 - medium, and 0.9 or higher - large)

Discussion

The present study assessed the ankle-foot three-dimensional kinematics of 36 women with PFP and compared them with 16 asymptomatic women (both with pronated feet) during the anterior and lateral step down tests using a multi-segmental foot model. According to the results obtained, the women with PFP exhibited greater joint mobility between the segments of the ankle-foot complex, as well as less knee flexion, than the asymptomatic women during this activity.

Assessments of foot posture are commonly conducted in clinical diagnoses of PFP, although their validity, in terms of providing data about the dynamic function of individuals with PFP, remains unclear. The evidence suggesting that the static posture of the pronated foot is a risk factor for the development of patellofemoral pain is very limited, despite the fact that it is known that the mechanics of movement can be affected by abnormal foot posture and abnormal foot pronation in cases of PFP.[42] A pronated foot, as defined by the FPI, is considered one of the risk factors for the development of multifactorial syndromes, including PFP[12,24] and could be associated with the peak of hindfoot eversion,[6] increases in the contact area, pressure in the midfoot during gait[41] and the orientation of medial forces in the forefoot during the single leg squat.[34] However, prospective studies are required to determine if this relationship is causal ou not.[6,] Neal *et al.*, 2014)

Although there is a consensus[47] that the exact effect of hindfoot eversion on the knee remains obscure, it remains to be seen if individuals with PFP exhibit greater foot mobility and increased medial rotation of the tibia. Barton et al.[3] noted that individuals with PFP exhibit more pronated foot posture and increased general foot mobility, in relation to asymptomatic individuals. Albertini et al[1] reported a greater distribution of plantar pressure in the medial region of the foot while descending and climbing stairs. Conversely, Wilson et al.[46] noted regional differences in the plantar distribution of women with PFP that are not consistent with a reduction in pronation during gait. However, until now, there has not been a kinematic foot measurement that involved a multi-segmental model and effectively analyzed the correlation between the segments in order to compare patients with PFP with a control group during functional tests. A prospective assessment of these measurement is required to determine if they contribute to a better understanding of the mechanical proximal abnormalities found in cases of PFP.

The present study sought to fill this knowledge gap by performing kinematic analysis using a multi-segmental model of the foot and the Oxford Foot Model protocol. Our results confirmed a significantly higher mobility of the ankle/foot complex among individual with PFP, as well as less knee flexion. This could be correlated with attempts to protect and/or compensate for articular pain.[5] These data corroborate the ideas of Barton et al.[3] and Boling et al.,[9,10] who reported that individuals with greater mobility in the ankle/foot complex and an accentuated navicular drop are more likely to develop PFP. Barton et al.[5,6,] correlated delays in the peak and increase of foot eversion during the initial contact of individuals with PFP with an increase in the medial rotation of the tibia during gait, stating that these factors could predispose individuals to the onset of PFP.

Powers et. al[30] stated that there is evidence of a correlation between hindfoot eversion and rotation of the tibia and hip in cases of PFP. Peak hindfoot eversion has been positively correlated with peak medial rotation of the tibia and hip in cases of PFP, that may contribute to a greater articular load and accentuates the misalignment of the lower limb and joint stress.[4]

Witvrouw et. al[47] confirmed that patients with PFP produce more hindfoot eversion during gait than asymptomatic individuals. This may be due to the increase in hip adduction,[4] as well as the greater medial rotation of the tibia, which may provide a strong link between PFP and distal factors. Silva et al[37] recently showed that hindfoot eversion while climbing stairs has the potential to differentiate women with PFP, although the movement of the hindfoot was analyzed in relation to the laboratory and not in relation to segments of the foot and tibia. Therefore, no prospective studies have identified hindfoot eversion as a predictor of PFP.

The results of these studies confirmed greater dorsiflexion, eversion and pronation, as well as lateral rotation and abduction of the foot, among women with PFP in the two step down tests (lateral and anterior). These movements could be correlated with the reduced mobility of ankle dorsiflexion, although dorsiflexion was also higher in the PFP group.

Limited ankle dorsiflexion has been previously described among individuals with PFP[48] and may lead to compensatory eversion of the calcaneus or increases in the progression angle of the foot in order to decrease the feet center of mass.[14] Conversely, the increase in pronation in subtalar joint may be caused by a limitation in the mobility of ankle dorsiflexion, resulting in an increase in knee valgus during functional activities that demand knee flexion simultaneous to ankle dorsiflexion. [20]

We belive that the higher range of motion of dorsiflexion, pronation, eversion, rotation and abduction found in PFP group can be a strategy to prevent high values of knee flexion, once as higher the knee flexion, its could be painfull during the activity.[16,32]

In this way, if we evaluate the effect size of the variables, we will realize that the sagittal plane was the one that presented the smallest effects, despite the statistical differences presented. In SDA, the lowest effect found was for knee flexion, while in SDL the lowest effects were for knee flexion, plantar flexion and dorsiflexion. We believe that these lower effect size values reforce the idea that lower range of motion of kneeflexion in the PFP group can be compensated by larger ankle range of motion in an attempt to protect the knee joint[10,37]

During weight-bearing activities, the mechanics of the foot are often interpreted in the context of a theoretical correlation between foot pronation and movements on the transverse plane of the knee and hip, which can contribute to PFP, since they do not preserve the arthrokinematics of the knee during flexion and extension. Thus, it is probable that the mechanism observed herein (excessive mobility of the ankle/foot complex) compensates for the limited knee flexion that may occur as a result of the expectation of pain.

However, it is important to stress that the association between foot pronation and the kinematics of the knee has not been consistently reported.[26] A number of studies have not reported increases in foot pronation or hindfoot eversion in individuals with PFP during gait.[31] Similarly, the conclusion that excessive mobility of the ankle/foot complex is a compensatory mechanism must be tested in future studies involving the simultaneous analysis of the kinematics of the trunk and lower limbs of individuals with PFP using multi-segmental models.

This study has some limitations, we think that we evaluated only pronated feet can be one of that, but as the literature affirm that woman wit pronated feet have more risk to develop PFP, we decided to evaluate only this type os feet. The mean clinical implication of this study is that the physiotherapy need to give attention to the foot os PFP woman during the treatment.

Conclusion

Women with PFP exhibit greater mobility in the ankle/foot complex during the anterior and lateral step down tests than asymptomatic women.

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