BIOMECHANICAL CHANGES IN GAIT OF SUBJECTS WITH MEDIAL KNEE OSTEOARTHRITIS

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ABSTRACT

Objective: Demonstrate the presence and magnitude of biomechanical variables during gait in patients with medial knee osteoarthritis (OA) and the relationship with the knee loading. Methods: Gait of 21 subjects diagnosed with medial knee OA was evaluated and compared to the control group. Results: The group with OA showed: Lower gait speed (0.8 ± 0.1 vs. 1.1 ± 0.1m/s), higher peak early (2.6 ± 1.2 vs. 0.3 ± 1.4 Nm/Kg) and late peak of the adduction moment (1.8 ± 0.7 vs. 0.9 ± 0.2 Nm/Kg), higher peak flexor moment (1.6 ± 0.9 vs. 0.6 ± 0.4 Nm/Kg), high dynamic peak varus ($11.5^O \pm 8.3$ vs. $3^O \pm 3.9$), higher peak flexion ($15.6^O \pm 8$ vs. 9.3^O to ± 4.1), with a flexion tendency ($5.5^O \pm 8.5$) in the stance phase, smaller peak of flexion ($58.7^O \pm 13.3$ vs. $67.5^O \pm 4.8$) in the balance phase and higher peaks of external rotation ($25.5^O \pm 12.7$ vs. $0.5^O \pm 22.4$). Conclusion: Patients with medial knee OA show changes in gait with increased external rotation, speed reduction, increased flexor moment and flexion in the stance phase, insufficient for reduction of the load. **Level of Evidence III, Case Control Study.**

Keywords: Knee. Biomechanics. Gait.

INTRODUCTION

Misalignment is one of the main factors that can compromise knee function and predispose to the evolution of osteoarthritis (OA).[1] There is controversy regarding the occurrence and the magnitude of particular biomechanical modifications in the gait of these patients, and also, regarding whether such changes are related to the evolution of OA or to adaptive changes.[2]
In biomechanical evaluations of the knee during gait, the variable studied most often is the external adductor moment. This has been considered the main predictor of knee loading, especially of the medial compartment, with a high degree of reliability[3,4] Several other variables are also studied, such as the knee flexor and extensor moments, the range of motion in flexion-extension, rotation of the lower limb, the spatio-temporal variables, among others, in the search for adaptive and/or evolutionary changes of the disease.[5]
The aim of the present study is to demonstrate the presence and magnitude of these variables and their modifications in patients with medial knee OA, also observing the relations between such modifications and knee loading in the realization of its habitual gait pattern.

MATERIAL AND METHOD

Subjects – Inclusion/exclusion criteria and clinical evaluation
The study was conducted with two groups. Group A: composed of individuals with medial knee OA and Group B: normal individuals, without misalignment and any symptom or sign of knee pathology. The two groups were submitted to gait analysis, carried out at a self-selected speed. The patients from Group A had symptoms and signs of medial compartment overload, associated with varus deformity in varying degrees. In addition to patients with primary varus, patients with single or multiple ligament injury associated with varus deformity primary or secondary to ligament injury were also included in the study. The diagnosis was established with a basis on clinical, radiographic and arthroscopic data. The exclusion criteria were: hip arthrosis, presence of inflammatory arthritis, age over 60 years, limitation of knee extension above 15°, presence of flexion below 90°, varus deformity above 20°, systemic disease, grade IV-V OA according to the Ahlback radiologic classification, and presence of OA in lateral compartment or in patellofemoral compartment, symptomatic, moderate to severe.[6-8]
The complete questionnaire of the Knee Society Score (KSS)

was applied for objective clinical symptomatic evaluation and functional evaluation.[9] This questionnaire objectively assesses pain, range of motion, stability, limitations of range of motion, alignment, limitation of gait distance, limitation for walking up and down stairs and use of walking aid.

Radiographic Evaluation

Panoramic weight-bearing radiographs of the lower limbs were taken for determination of the mechanical axis and anatomic axis of the lower limb. Other radiographs, such as anterior-posterior without support, anterior-posterior with stress, lateral with 30° of knee flexion, tunnel, axial view of the patella and orthostatic panoramic radiograph of the lower limbs, were taken for evaluation of other possible alterations that could exclude the patient from the study.

Equipment and procedures

The biomechanical gait analysis was carried out at the Laboratory of Biomechanics and Rehabilitation of the Musculoskeletal System of Hospital de Clínicas da Universidade Estadual de Campinas - Unicamp. The participants used six ProReflex MCU240 cameras, which emit and capture reflected infrared light, placed on pedestals at a distance of 1.80cm from the ground and positioned with the camera lens focusing on the force platform. Qualisys, Qtrac Capture and Qtrac View software was used, with the AMTI model OR6 - 7 - 1000 force platform employed to capture kinematic and kinetic data. Infrared reflective markers were positioned on the skin using the marker positioning protocol developed at Oxford University and subsequently refined by Lundberg.[10] The patients were asked to walk following their natural gait pattern, at a self-selected speed, along the entire platform, which measured five meters in length. Each patient was submitted to six gait data collection sessions. The three best collections were analyzed then used to generate graphs indicating the variables under analysis by means of the program from the company Qualisys, known as Qgait. The results obtained were standardized according to the patient's weight and height. The graphs were analyzed in terms of format of their outline, and the main peak values were collected throughout the entire gait cycle, finally obtaining the mean values.

The individuals from group A underwent diagnostic arthroscopy with confirmation of the ligament and medial compartment injuries of the knee.

Data analysis

The two groups were compared in terms of the biomechanical gait parameters shown in Table 1.

The spatio-temporal data gathered were: percentage of duration of the stance phase, length of stride, cadence, velocity and period of time of gait cycle. The angles of dynamic varus/valgus of the knee and internal/external rotation of the ankle and foot (toe in, toe out) were obtained with an evaluation of the peaks of these angles in the stance phase. The flexor and extensor peaks were obtained both in the swing phase and in the stance phase. The timing of the angular peaks was determined during gait. As regards the kinetic data, these were evaluated in terms of the peak of adduction, extension and flexion moments, with the obtainment of the timing of these peaks in the gait phase. The standard curve that characterizes the adductor moment is

composed of two peaks, an early peak that occurs in the phase of initial contact, and another late peak that appears in the final stance phase close to propulsion. The gait phase of occurrence of the peaks of moments was also considered. The following names were considered for determination of the gait phases, as shown in Table 2.

Table 1. *Biomechanical gait parameters evaluated.*

	Kinematic		Kinetic	
	Spatio-temporal Gait Data			
Coronal plane	Peak of Varus Angle	PVrA	Mid-Peak of Adductor Moment	MPAM
	Peak of Valgus Angle	PVgA	Early Peak of Adductor Moment	EPAM
			Late Peak of Adductor Moment	LPAM
Sagittal plane	Peak of Extension Angle Stance Phase	PEAst	Peak of Extensor Moment	PEM
	Peak of Extension Angle Swing Phase	PEAsw		
	Peak of Flexion Angle Stance Phase	PFAst	Peak of Flexor Moment	PFM
	Peak of Flexion Angle Swing Phase	PFAsw		
Axial plane	Peak of Internal Rotation Angle	PIRA		
	Peak of External Rotation Angle	PERA		
Location	Location of Angle Peaks in Gait		Location of Moment Peaks in Gait	

Table 2. *Division of the gait phases.*

Gait Phase	Gait Period	Acronym	Cycle Time
Stance Phase	Initial Contact	IC	0 - 5 %
	Loading Response	LR	5 – 16 %
	Midstance	MS	16 – 30 %
	Terminal Stance	TS	30 – 50 %
	Pre-Swing	PS	50 – 64 %
Swing Phase	Initial Swing	IS	64 – 70 %
	Midswing	MS	70 – 80%
	Terminal Swing	TS	80 – 100 %

IC – Initial Contact, LR – Loading Response, MS – Midstance, TS –Terminal Stance, PS – Pre-Swing, IS – Initial Swing, MS – Midswing, TS –Terminal Swing. (Source: Perry J. In: Gait Analysis- Normal and Pathological Function, USA: 1992.).

Statistical analysis

The SPSS 14 program was used for statistical analysis, employing the Mann-Whitney test with p-value of significance < 0.01 for comparison between the groups.

RESULTS

The evaluation of the characteristics of the groups is summarized in Table 3. There was no significant difference between the groups in the comparison of these data. Table 4 summarizes the results of the KSS and Functional KSS.

As concerns associated ligament injuries, 12 individuals had a previous history of trauma associated with varus deformities and medial OA. Twelve had an anterior cruciate ligament (ACL) injury, while four presented an ACL injury in addition to a posterior cruciate ligament (PCL) injury, and posterior-lateral corner (PLC) injury. One patient had an ACL injury in addition to a PCL injury.

During the arthroscopy it could be seen that all the patients had medial compartment OA; moreover, the ligament injuries diagnosed previously by the clinical evaluation were confirmed.

Table 3. *Characteristics of the Individuals.*

	N		Age (years)	BMI (kg/m2)	Male	Female
	Right	Left				
Group A	10	11	46.0	26.2	20	1
Group B	8	8	37.2	25.5	15	1

Table 4. *KSS Results.*

	KSS > 60	KSS < 60	Functional KSS			
			Excellent	Good	Unsatisfactory	Poor
Group A	2	19	2	3	8	8
Group B	16	0	16	0	0	0

KSS – Knee Society Score

SPATIO-TEMPORAL FACTORS

Table 5 shows the results of the spatio-temporal factors for the two groups.

Table 5. *Comparison between the groups for spatio-temporal factors.*

	Stance Phase (% of cycle)	Step Length* (m)	Cadence* (steps/min.)	Velocity* (m/s)	Cycle Time* (sec.)
Group A	64	1.1	87	0.8	1.4
Group B	62	1.3	99	1.1	1.2

*$p < 0.01$

Kinematics

Figure 1 reveals the angular peak values. Figures 2, 3 and 4 demonstrate the angular graphic distribution in the three spatial planes over the course of the gait cycle.
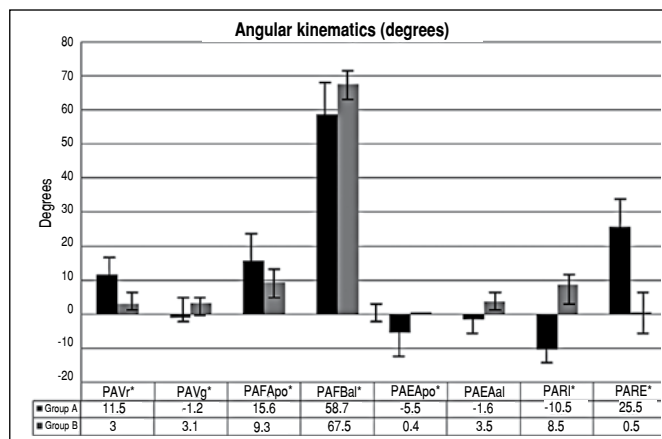

Figure 1. *Peaks of angular knee kinematics* $*p < 0.01$.
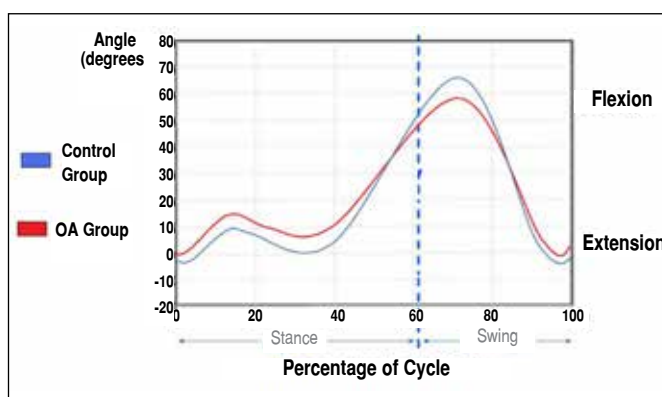
	PAVr*	PAVg*	PAFApo*	PAFBal*	PAEApo*	PAEAal	PARI*	PARE*
Group A	11.5	-1.2	15.6	58.7	-5.5	-1.6	-10.5	25.5
Group B	3	3.1	9.3	67.5	0.4	3.5	8.5	0.5

Figure 2. *Angular variation of the knee in the sagittal plane.*
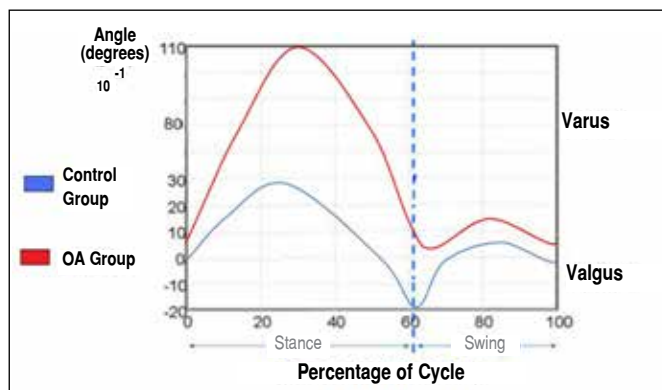

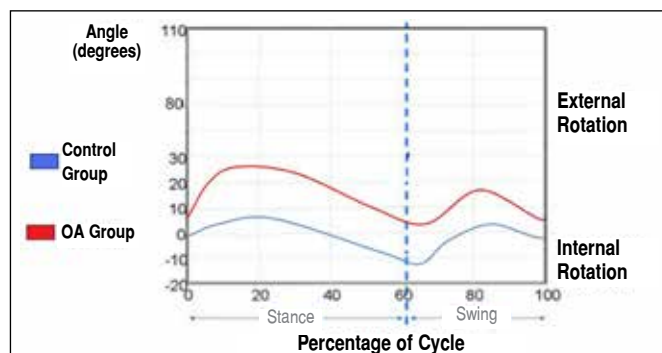**Figure 3.** *Angular variation of the knee in the frontal plane.*

Figure 4. *Angular variation of the foot in the axial plane.*

Location of the Angle Peaks

It can be observed that both group A and group B presented the location of the angle peaks in the same gait phases. PVrA (peak of varus angle) occurred in the midstance phase while individuals from group A presented a slight tendency for its occurrence at the end in the midstance phase and start of terminal stance (p=0.013). PVgA (peak of valgus angle) occurred at the end of the terminal stance in toe off. In the stance phase, PFAst (peak of flexion angle in stance) and PEAst (peak of extension angle in stance) occurred in their habitual locations, loading response phase and midstance, respectively. In the swing phase, PFAst (peak of flexion angle in stance) and PEAst (peak of extension angle in stance) appeared in precisely the same location, midstance and terminal stance, respectively. (Figure 5)
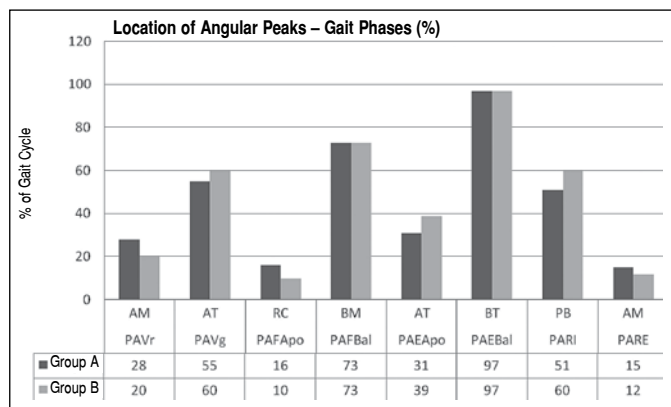
Figure 5. *Location of angular knee peaks in gait.*

KINETIC

Peak of Knee Moments

Figure 6 shows the peaks of the articular moments in the three planes. Figures 7 and 8 reveal the graphic distribution of the moments throughout the gait cycle.

The peak knee moments occur in similar locations. In group A, EPAM (early peak of adduction moment) occurs in the loading response phase while in group B, EPAM appeared at the start of midstance. Considering its variation, it can be said that both occur in the same phase (p=0.19). LPAM (late peak of adduction moment) occurred at the end of midstance and start of pre-swing in both groups, as was the case with PEM (peak extensor moment). PFM (peak flexor moment) occurred in the loading response phase. (Figure 9)
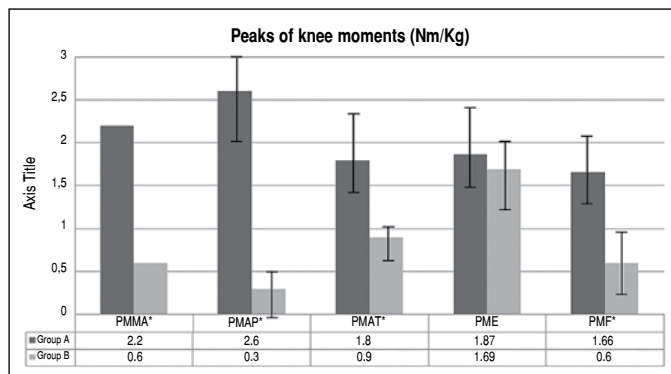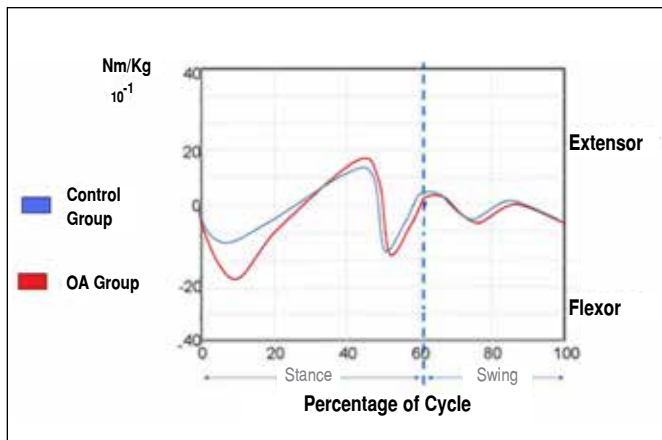
Figure 6. *Peaks of knee moments. *p<0.01.*

Figure 7. *Joint moment of the knee sagittal plane.*
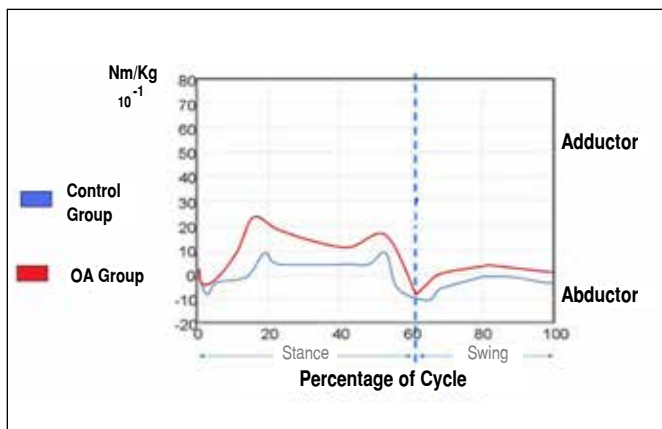
Figure 8. *Joint moment of the knee frontal plane.*
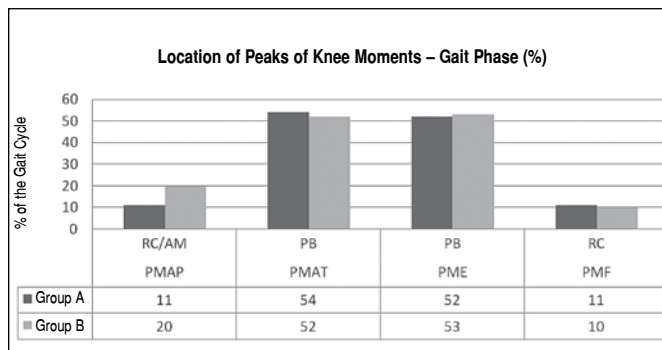
Figure 9. *Location of peaks of knee moments in gait.*

DISCUSSION

Some studies show changes in several kinetic and kinematic factors in individuals with OA, and among these studies, there are surveys that reveal these changes in individuals with medial knee OA.[2,11] According to Borjesson et al.,[12] the spatio-temporal variables of gait are those most directly influenced by the severity of the pathology or of the treatment applied.

Besides the altered spatio-temporal factors, patients with various degrees of OA adopt different gait patterns to unload the knee. In most of the related studies, when loading comparisons (adductor moment) are made between individuals with less

severe OA and control groups, the adductor moment appears elevated. This pattern may differ in patients with moderate or severe OA, who present loading values similar to the control group. These phenomena can be explained by the existence of some adaptive mechanisms observed in the gait of these individuals.[13,14]

In the spatio-temporal results of this survey, we found a slight increase of the stance phase between the groups, yet without significant difference (p=0.131). The other parameters appeared significantly changed in the group of patients with OA. The gait velocity demonstrated greater reduction in the group with OA, about 27% (p<0.001), while the step length appeared reduced in about 15% (p<0.001). This study was produced with individuals who present the pathology with a lower level of radiological severity, yet with important symptoms demonstrated by the low KSS score, where it is possible to infer that the variation of the spatio-temporal values starts in individuals with only slight radiological impairment, yet with important functional symptoms.

It remains controversial whether any of these variables, particularly the reduction in velocity, occur due to adaptive mechanisms.[2] Various studies diverge on the relation between severity of OA and gait velocity. According to Kaufman et al.[15] this relationship occurs in such a way that patients with OA perform strategies to maintain gait velocity and step length, and patients with more severe OA tend to have greater joint stiffness to avoid the action of external articular moments, regardless of the gait velocity. Kirtley et al.[14] demonstrated that speed reduction is part of a strategy for reduction of articular moments and that there is a strong connection between velocity and moment in the sagittal plane, more specifically related to the flexor moment. Mundermann et al.[16] declared that patients with OA, more effectively in those with more severe pathology, reduce velocity for reduction of the adductor moment. However, Ueda et al.,[17] when assessing healthy individuals studied in five velocity categories, affirmed that gait speed reduction is not sufficient for reduction of the adductor moment during gait, and that only an increase in speed significantly increased the adductor moment.

In studies that have made a direct correlation between articular moments of the knee and velocity, some results draw our attention. A negative correlation was found between peak adductor moment in the terminal stance phase (terminal peak) and gait velocity by Thorp et al.[18] Moreover, the relation between adductor moment and velocity can assume different relations depending on how the wave is analyzed. According to Robbins and Maly[19] velocity reduction is related to the reduction of the peak adductor moment, to the detriment of the increase in the wave impulse (magnitude and duration), which would maintain the joint overload for a longer period of time. The same study informs that the increase in velocity is directly related to the increase of the adductor moment, corroborating Ueda's results. In the present study, we observed that the group of patients with OA exhibited lower self-selected speed than the control group, yet with the maintenance of the stance phase. With no increase of the stance phase, the limb load incidence time is the same as the healthy group. This means that there is no increase in the impulse of the loading waves (articular moments), even with velocity reduction, demonstrating that velocity reduction

can be viewed as an adaptive and/or evolutionary mechanism that modifies knee loading in some ways.

Another widely discussed adaptive mechanism is external rotation as frontal plane loading reduction factor.[13,14] Ueda et al.[17] related different velocities and rotation angles of the foot. Individuals with gait in external rotation presented high first peaks of adductor moment and low second peaks. An ideal external rotation angle of the foot to significantly reduce the adductor moment would be above 12,4º, which is higher than normal in most people.

One of the explanations for reduction of the adductor moment after external rotation is that besides the change from frontal plane to sagittal plane, there would be the activation of the lateral ischiotibial muscles and relaxation of the medial muscles. The reverse also occurs with the internal rotation movement, increasing the adductor moment.[20] Another explanation found for reduction of the peak adductor moment was given by Jenkyn et al.,[21] in demonstrating that external rotation transfers the axis of a large portion of weight bearing from the frontal plane to the sagittal plane, mechanically characterized by the reduction of the adductor moment and simultaneous increase of the flexor moment.

What we observe is that patients with medial knee OA have a predominant gait pattern in external rotation, represented both by their high peaks of external rotation angles, and by the change of their peaks from internal rotation to external rotation, maintaining values close to 10 degrees, during pre-swing.

In relating the reduction of velocity and increase of external rotation to the peaks of the adductor moment, to verify their relations with loading, we can observe that both peaks of the adductor moment remain high even with such possible adaptations present. LPAM presented lower values than EPAM and less difference than the control group. It seems that LPAM is more sensitive to the modifying factors of gait biomechanics. In spite of the gait in a pattern of external rotation and reduced velocity, patients with medial knee OA continue with high loading levels.

In the sagittal plane, the group with OA presented a higher flexor moment than the control group (p<0.001), which characterizes the kinetic change of adaptation, with transfer of part of the load from the frontal plane to the sagittal plane, as observed by Jenkyn et al.[21] and referred to previously. Kaufman et al.[15] demonstrated that patients with OA exhibit a small knee extensor moment and that gait velocity affects moments more in the sagittal plane. In this study no significant difference was found for the peak of extension moment (p=0.74) between the groups. A limitation of this study resides in the fact that we have some individuals from the tested group with overlapping of medial knee OA and ligament injuries, which could lead to misinterpretation of results.

The exact role of each structure of soft parts responsible for the restriction of the varus tendency, and of the increase in the loading of the medial compartment caused by the unloading of weight during gait in these patients, is still a controversial issue. In reviewing the literature in search of the connection between the soft parts of the knee and their ability to restrict the varus tendency and the consequences of loading brought about by the external adductor moment, we found that the main dynamic restrictor of this tendency is the quadriceps muscle.[22] Now

the role of the ligaments is to provide resistance to the external adductor moment soon after the heel touches the ground and during midstance in gait, primarily by the posterior-lateral complex and secondarily by the anterior cruciate ligament.[23,24] We also saw the need to understand the biomechanical behavior of the knee in individuals with deficient ligament function, yet without other associated abnormalities, to subsequently observe the biomechanical repercussion of these injuries on the individuals from group A, with ligament injuries associated with OA.

In the review of the kinetic studies, we observed that the individuals with deficient anterior cruciate ligament (DACL) and deficient posterior cruciate ligament (DPCL), yet without AO and without misalignment, have reduction of the flexor moment in most of the individuals studied. It is construed as an attempt to avoid the so-called "quadriceps avoidance", a phenomenon that increases tibial translation, especially anterior translation, which increases the sensation of instability.[23]

From the kinematic point of view, most of the patients with deficient anterior cruciate ligament (DACL) without OA and without misalignment present normal range of motion in flexion-extension, increase of external rotation during part of the gait cycle and possible valgus alignment of the knee during the initial stance phase. These phenomena are shown as possible compensatory mechanisms in the attempt to stabilize the joint.[25] Now individuals with deficiency and with isolated PCL injury, with clinically observed ligament lassitude (DPCL), after recovery from the acute phase of the injury and reestablishment of the habitual gait pattern, present few biomechanical and neuromuscular modifications in gait.[26]

In our study we encountered the predominance of external rotation in all the patients from the group with medial knee OA, both in individuals with and without ligament injury. The increase in external rotation appears to take precedence and to be stronger in individuals with DACL and OA of the medial compartment. More detailed studies can demonstrate this relation.

As seen previously, individuals with isolated ACL injury without OA or misalignment present moments of the cycle in valgus, unlike the individuals from Group A with ACL injury, who presented dynamic varus throughout the cycle. This demonstrates that the presence of overload and static misalignment of the knee have greater influence on dynamic alignment than the ligament injury. Individuals with DACL probably present modification of knee loading, which could generate an overload in the medial compartment, increasing the risk of developing OA. This risk multiplies when added to the risk provoked by misalignment, forming a vicious circle.

To further enhance the importance of the studies on the influence of soft parts on knee loading, the instant we observe the change of spatial plane of joint moments in the individuals studied (from the frontal plane to the sagittal plane), there is evidence of the importance of quadriceps use, both in resistance to the varus tendency, and in support to the increase of the flexor moment. It can be inferred that the increase in the flexor moment in the individuals of this study supplants the reduction of the flexor moment found in individuals with DACL and DPCL without OA or misalignment, as demonstrated in literature.

In the kinematic evaluation of the knee, its main plane of action, the sagittal plane, individuals with OA, in general, have their flexion-extension angles decreased.[27] This gait pattern is considered a pattern of greater stiffness, which may represent an attempt at attenuating the load on the knee compartments, or even a consequence of the physiopathological process of all the tissue coating the joint, especially related to the retraction of the capsular and synovial system. The reduction of flexion-extension occurs more intensely in individuals with more severe OA.[28]

In this study, we noticed a difference between the groups in the sagittal plane when we evaluated the peaks of the flexion-extension angles, although with some peculiarities. The individuals with OA presented a higher peak of flexion in the stance phase in comparison to the control group (p<0.001). The opposite happened in the swing phase, where the individuals with OA had lower peaks of flexion than in the control group (p<0.017). The individuals with OA, in stance, maintained the tendency to remain in flexion (5.5°), even at the end of midstance, unlike the patients from the control group, where slight extension occurred (0.4°, p<0.016). In the swing phase, this difference decreases, yet in the individuals with OA the tendency to remain in flexion, although less pronounced (2°), is maintained (p<0.028).

This pattern, of less variation of the flexion-extension values, represents the start of the joint stiffness pattern. This stiffness shows its tendency to continue more in flexion, characterized mainly by the higher flexor peaks of the group with OA in the stance phase.

This tendency for stiffness and flexion gait can also be represented by the reduction of gait velocity and shift of the weight-bearing axis from the frontal plane to the sagittal plane, characterized by the higher peak flexion moment, increasing the tendency for flexion. This stiffness onset pattern also appeared at the extension peaks in stance and in swing.

In the frontal plane, the literature shows that both in normal individuals, and especially in individuals with medial knee OA with varus alignment, there is a tendency to go into knee adduction (varus), yet with intensity around 3 times greater for individuals with the pathology.[27] This is precisely what we observed in this study, the peaks of varus angle of the patients were higher than the control group (p<0.001). The patients with OA presented four times higher varus than the test group, which presented slight dynamic varus. This reinforces the precept that individuals with varus misalignment have elevated degrees of dynamic varus related to elevated adductor moment peak values.

CONCLUSION

Patients with medial knee OA and varus misalignment of the knee are subject to high overload and high angles of dynamic varus in the knee. In these individuals, there is a pattern of gait in external rotation with reduction of velocity as adaptive factors, yet insufficient to reduce weight bearing to normal values.

The highest flexor moment presented demonstrates another adaptive mechanism, transfer of weight bearing from the frontal plane to the sagittal plane. Individuals with medial knee OA have less flexion-extension variation, which characterizes a picture of joint stiffness, with a predominance of flexion. The peaks of angles and peaks of joint moments of the knee occur in the same gait phases, both in normal individuals and in individuals with the pathology, signifying that there are no major changes in the gait pattern.

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