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Knee contact forces are not altered in early knee osteoarthritis

S. Meireles ME[a,*], F. De Groote PhD[b], N.D. Reeves PhD[c], S. Verschueren PhD[d], C. Maganaris PhD[e], F. Luyten PhD[f], I. Jonkers PhD[a]

[a] Department of Kinesiology, KU Leuven, Belgium
[b] Department of Mechanical Engineering, KU Leuven, Belgium
[c] School of Healthcare Science, Manchester Metropolitan University, United Kingdom
[d] Department of Rehabilitation Sciences, KU Leuven, Belgium
[e] School of Sport and Exercise Sciences, Liverpool John Moores University, United Kingdom
[f] Department of Development and Regeneration, KU Leuven, Belgium

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ABSTRACT

Objective: This study calculated knee contact forces (KCF) and its relations with knee external knee adduction moments (KAM) and/or flexion moments (KFM) during the stance phase of gait in patients with early osteoarthritis (OA), classified based on early joint degeneration on Magnetic Resonance Imaging (MRI). We aimed at assessing if altered KCF are already present in early structural degeneration.
Design: Three-dimensional motion and ground reaction force data in 59 subjects with medial compartment knee OA ($N = 23$ established OA, $N = 16$ early OA, $N = 20$ controls) were used as input for a musculoskeletal model. KAM and KFM, and KCF were estimated using OpenSim software.
Results: No significant differences were found between controls and subjects with early OA. In early OA patients, KAM significantly explained 69% of the variance associated with the first peaks KCF but only KFM contributed to the second peaks KCF. The multiple correlation, combining KAM and KFM, showed to be higher. However, only 20% of the variance of second peak KCF was explained by both moments in established OA.
Conclusion: KCF are not increased in patients with early OA, suggesting that knee joint overload is more a consequence of further joint degeneration in more advanced stages of OA. Additionally, our results clearly show that KAM is not sufficient to predict joint loading at the end of the stance, where KFM contributes substantially to the loading, especially in early OA.

1. Introduction

Osteoarthritis (OA) is a chronic degenerative and multifactorial [1,2] joint disease that most frequently affects the knee [3]. Patients complain about pain, reduced range of joint movement, muscle weakness, stiffness and instability, which limits physical activities in daily living [4], results in loss of their independence, reduced quality of life and high health-related costs [5].

The cause of OA remains unclear. It is known that biochemical and mechanical factors may contribute to its initiation [6–9]. Indeed, subchondral bone remodeling [10] following mechanical overloading will increase the reactive stresses underneath the cartilage, therefore decreasing the shock absorbing efficiency of cartilage [11] and causing local cartilage lesions [12]. In agreement with this statement, aberrant knee joint loading has been identified as a factor affecting the progression of knee OA [13–15] in more advanced stages of OA [16]: increased medial compartment loading has been associated with more pronounced clinical symptoms and OA severity as assessed by radiography [24,25]. Most studies [17–24] used the knee adduction moments (KAM), i.e. the external knee joint moment in the frontal plane was used as an indirect measure of medial compartment loading during functional activities. Alternatively, musculoskeletal modeling in combination with dynamic motions has been used to calculate knee contact forces. Using this approach, Kumar et al. [26] found

* Corresponding author at: Tervuursevest 101, Gebouw De Nayer, lokaal 02.49 B-3001 Leuven – Heverlee. Tel.: +32 16 37 94 63.
E-mail addresses: susana.meireles@faber.kuleuven.be, susanameiras@gmail.com (S. Meireles), Friedl.DeGroote@mech.kuleuven.be (F. De Groote), N.Reeves@mmu.ac.uk (N.D. Reeves), Sabine.Verschueren@faber.kuleuven.be (S. Verschueren), c.maganaris@ljmu.ac.uk (C. Maganaris), frank.luyten@uz.kuleuven.ac.be (F. Luyten), ilse.jonkers@faber.kuleuven.be (I. Jonkers).

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medial KCF were increased in established OA subjects (K&L ≥ 2) with radiographic signs of joint structural changes. Interestingly, medial compartment loading of the knee was found to be related to a combination of both KAM and knee flexion moment (KFM), therefore questioning the role of KAM as sole indicator of medial compartment knee loading.

More recently, clinical interest is towards identifying OA patients in more early stages of the disease process. Early detection of OA may enable more effective interventions before major structural damage has occurred [29]. The lack of effectiveness in delaying the progression of OA [30] may be mainly caused by a late intervention, when structural deterioration is already advanced [31]. Luyten et al. [27] have proposed a classification criteria for identifying early knee OA patients, which combines knee pain and Kellgren and Lawrence (K&L) radiographic classification (0 or 1) [28] with structural changes detected on Magnetic Resonance Imaging (MRI) or cartilage lesions by arthroscopy.

The role of mechanical loading in these patients where only early signs of joint degeneration are present, is less well explored in literature. Three recent articles have shown that there is no evidence of increased KAM in early stages of knee OA compared to healthy controls [16,25,32]. However, since KAM does not account fully for the internal knee joint loading [26,33], these studies potentially fail to describe the more subtle changes in loading characteristics in the early OA patients where structural degeneration is less pronounced.

The current study is therefore the first study to evaluate whether knee loading as assessed by KCF, is different in subjects with early medial knee OA compared to healthy subjects and subjects with established medial knee OA. It is hypothesized that in the presence of early signs of structural degeneration as present in early OA subjects, knee loading is increased compared to healthy subjects but to a lesser extent than in established OA subjects. If so, this would confirm that biomechanical overloading is a contributing factor to the progression of OA from the very early onset of the disease. Furthermore, if subjects with early OA present increased knee loading will confirm KCF to be a more sensitive biomarker than KAM in detecting alterations in knee loading in early stages of OA, allowing evaluation of treatment effect even in early stages of the disease process and allowing for earlier interventions.

Furthermore, this study evaluates the contribution of altered frontal and sagittal plane moments to the observed changes in knee loading for subjects in different stages of the disease process. It is hypothesized that in early OA patients, presenting limited structural degeneration, frontal plane moments will contribute less to the observed changes in knee loading compared to established OA. If so, alterations in mechanical knee loading, associated with different levels of joint degeneration, relate to alterations in multidimensional joint loading, with KAM being a more important contributor compared to KFM in patients with established knee OA will be confirmed.

2. Methods

2.1. Participants

Fifty-nine participants (all women, mean age of 65 years) were recruited for this study and were separated into three groups based on a previously published classification [27] control subjects ($n = 20$), early medial knee OA ($n = 16$), and established medial knee OA ($n = 23$) patients. Subject characteristics are listed in Table 1. All procedures were approved by the local ethical committee of Biomedical Science, KU Leuven, Belgium. Written informed consent was obtained from each subject.

Early medial knee OA was diagnosed based on novel classification criteria of Luyten et al. [27], including fulfillment of three criteria, namely knee pain, a K&L [28] grade 0, 1 or 2^- (osteophytes only) and structural changes observed on MRI.

Established medial knee OA was diagnosed based on slightly adapted American College of Rheumatology classification criteria [34], including knee pain, stiffness less than 30 min and crepitus, together with structural changes defined as presence of minimum grade 2^+ (osteophytes and joint space narrowing) on K&L scale for at least the medial compartment on radiography.

A control group was also analyzed, which included asymptomatic healthy subjects with no history of knee OA or other pathology involving any lower extremity joints, and with a radiological score of 0 or 1 according to K&L score.

Participants were excluded if they had a prior significant trauma or surgery in lower limbs and/or low back, if they suffered from a neurological disease affecting coordination and/or balance during gait and/or a musculoskeletal disorders other than knee OA in one of the limbs during the last six months prior to testing.

For symptomatic patients with unilateral knee OA ($n = 9$), only data of the affected knee were analyzed. For those with bilateral knee OA and with large asymmetry in severity ($n = 7$), the most affected side was selected for further analysis. For all other subjects ($n = 23$), both legs were analyzed.

2.2. Gait analysis

An active 3D motion analysis system (Krypton, Metris) recorded the 3D position of 27 LEDs attached to the subjects according to an extended (5 technical clusters and 12 LEDs on 6 anatomical landmarks) Helen Hayes protocol at a sampling frequency of 100 Hz (Fig. 1 - Supplementary Material).

Table 1
Characteristics of the groups: control (C0), early OA (E1) and established OA (E2).

	Control ($n = 20$)	Early OA ($n = 16$)	Established OA ($n = 23$)	p	p (C0-E1)	p (C0- E2)	p (E1- E2)
Age, years	64.6 ± 8.7	64.9 ± 6.0	65.6 ± 7.2	0.910	0.999	0.965	0.989
Body mass, kg	65.0 ± 8.0	70.5 ± 14.0	73.2 ± 12.8	0.079	0.417	0.076	0.860
Gait speed, m/s	1.23 ± 0.20	1.29 ± 0.19	1.21 ± 0.14	0.338	0.659	0.963	0.373
Stance Duration, s	0.63 ± 0.07	0.63 ± 0.06	0.64 ± 0.06	0.096	0.871	0.366	0.105
Timing of the peaks KCF, % Stance	29.1 ± 2.0	28.4 ± 2.1	29.3 ± 2.2	0.400	0.716	0.971	0.448
	82.9 ± 2.6	83.0 ± 4. 9	80.2 ± 5.7	0.095	1.000	0.174	0.189
Single Support Duration, % Stance	61.7 ± 3.9	61.2 ± 2.8	60.1 ± 4.2	0.041*	0.832	0.040*	0.287
Knee Alignment,°	−.03 ± 2.15	0.37 ± 3.31	2.77 ± 4.30	0.020*	0.965	0.022*	0.067
No. of legs	36	30	32		–	–	–
KL grade (no. of legs)	0(24)	0(8)	2^+(22)		–	–	–
	1(12)	1&1$^+$ (22)	3&3$^+$ (5)				
			4(4)				

Values are the mean ± Standard Deviation (SD). ANOVA with Gabriel post hoc test. Significant difference $p < 0.05$ are indicated with *.
Positive values indicate varus alignment and negative values indicate valgus alignment.