Musculoskeletal modelling of gait modification in knee osteoarthritis: stairs ascent and descent

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***Abstract*— Medial compartment knee osteoarthritis (KOA) is a common musculoskeletal disease characterised by pain and functional limitations. Modifications in the foot progression angle and step width have been used as a strategy to reduce the external knee load.**

In this study, a subject-specific musculoskeletal model was implemented to analyse the mechanical efficacy of gait alterations during stairs ascent/descent on knee medial compressive force in a cohort characterised by clinical diagnosis of medial KOA and varus malalignment.

Our findings showed a high variability in response to different gait modifications and did not suggest an overall mechanical efficacy.

***Keywords*— Osteoarthritis, musculoskeletal modelling, compressive force, knee.**

I. Introduction

MEDIAL compartment knee osteoarthritis (KOA) is an irreversible chronic musculoskeletal disorder [1] characterised by high level of pain and disability with an increasing incidence[2]. Subjects with medial KOA show limitations in daily life activities such as walking or stairs ascent/descent [3]. Alterations in the foot progression and step width during level walking have been largely used in the attempt to reduce the external knee moment with the assumption that this also unloads the medial compartment. However, the mechanical effect of these gait modification during other activity of the daily living such as stairs ascent/descent is still unclear. Moreover, subject-specific musculoskeletal models allow accurate estimation of the Medial Compressive Force (MCF) [4] which is a more direct indicator of the joint load.

Therefore, the aim of this study was to investigate the effect of gait alterations on the impulse and max peak of the knee MCF during stairs ascent/descent in a cohort characterised by clinical diagnosis of medial KOA.

II. Methods

A. Population and Gait Analysis

Six volunteers with a clinical diagnosis of medial KOA (age 63.2 ± 6 years, BMI 30.7 ± 2.9 $Kg \cdot m^{-2}$) were recruited through NHS Greater Glasgow and Clyde. Ethical approval was granted for this study by the NHS Ethical Committee.

Full lower limbs three-dimensional kinematic data from 22 markers were recorded using a 14 Qualisys Oqus camera system sampling at 120 Hz. Two Kistler platforms embedded in the middle of stairs were used to collect ground reaction forces. The symptomatic leg only, or the most affected for patients with bilateral KOA, was included in the analysis.

Each participant performed 4 stairs ascent/descent conditions: a) standardised sports training shoes only (SO), b) SO with toes turned inward ('Toe in'), c) SO with toes turned outward ('Toe out'), d) SO with wider foot position ('Wide'). All stairs trials were performed at a self-selected speed. Participants did not use handrail and executed the task with one foot hitting each step of the stairs.

B. Musculoskeletal modelling

An anatomically scaled model adapted from [4], based on the Twente Lower Extremity data set, was used to estimate the MCF with an inverse dynamic analysis. Joint compressive forces were estimated in the tibial coordinate system following the procedure presented in [5].

C. Data Analysis

The impulse and max peak of the MCF for each condition were used to evaluate the mechanical effect of the gait modifications. Data were corrected for body weight and presented as %BW. The average speed of the four pelvis markers was used to estimate the task speed during the stairs cycle,

III. Results and Discussion

As shown in Table I, the impulse of the MCF during the stair ascent task did not change significantly for most of the conditions. There was an overall increment with the exception on 2 out of 6 subjects. KOA1 showed a slight reduction of the impulse for all the conditions. KOA5 had a minimum reduction with the Toe In and Toe Out condition with respect to the SO. An Opposite effect was observed for KOA3 with a net rise up to 25% for the Toe In condition (Fig. 1).

TABLE I

Stair Ascent Knee MCF Impulse [BW·s], (Max Peak [BW])

	KOA1	KOA2	KOA3	KOA4	KOA5	KOA6
SO	1.04 (2.97)	1.12 (2.29)	0.96 (2.00)	1.11 (2.35)	1.58 (1.67)	1.50 (2.14)
Toe In	1.01 (3.01)	1.12 (2.44)	1.20 (2.15)	1.28 (2.22)	1.55 (1.87)	1.55 (2.17)
Toe Out	1.01 (2.97)	1.12 (2.28)	1.17 (1.94)	1.22 (2.37)	1.55 (1.71)	1.54 (2.23)
Wide	0.99 (2.91)	1.15 (2.23)	1.04 (1.95)	1.15 (2.35)	1.69 (1.88)	1.55 (2.43)

The three gait modifications had a limited effect on the max peak of the MCF with an exception for KOA5 who responded with an increment up to 12% for both the Toe In and the Wide conditions.

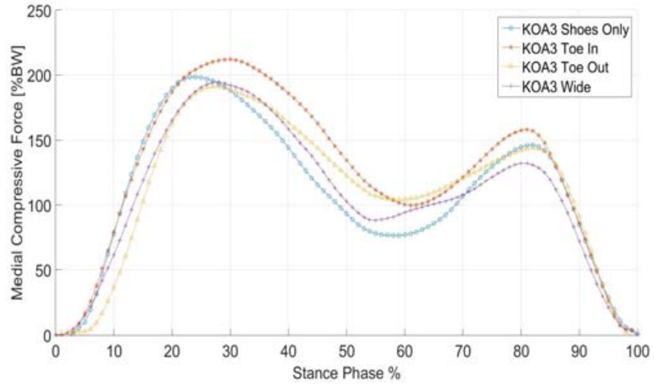

Figure 1: Medial Compressive Force for KOA3 during stairs ascent

Overall our results on the stairs ascent did not suggest a consistent mechanical effect for any of the three selected gait modifications on the medial condyle knee compressive force.

TABLE II

	Stair Descent Knee MCF Impulse [BW·s], (Max Peak [BW])					
	KOA1	KOA2	KOA3	KOA4	KOA5	KOA6
SO	1.33 (3.36)	1.29 (3.18)	1.31 (2.56)	1.33 (3.18)	2.08 (2.35)	1.59 (2.44)
Toe In	1.32 (4.20)	1.23 (3.37)	1.47 (2.46)	1.63 (3.09)	3.35 (2.27)	1.32 (1.75)
Toe Out	1.14 (3.58)	1.33 (3.29)	1.31 (2.38)	1.55 (3.49)	2.75 (2.76)	1.53 (2.25)
Wide	1.06 (3.46)	1.34 (3.25)	1.24 (2.55)	1.38 (3.25)	2.52 (2.73)	1.51 (2.34)

Table II shows high variability and an inconsistent response trend during the stairs descent. As shown in Fig 2, KOA6 responded positively to the three gait modifications with a reduction of both the impulse and the max peak of the MCF with the greater reduction during the Toe In condition. The impulse of the MCF decreased significantly for KOA1 while the max peak of the MCF increased. KOA4 and KOA5 showed the largest increase in the impulse of the MCF.

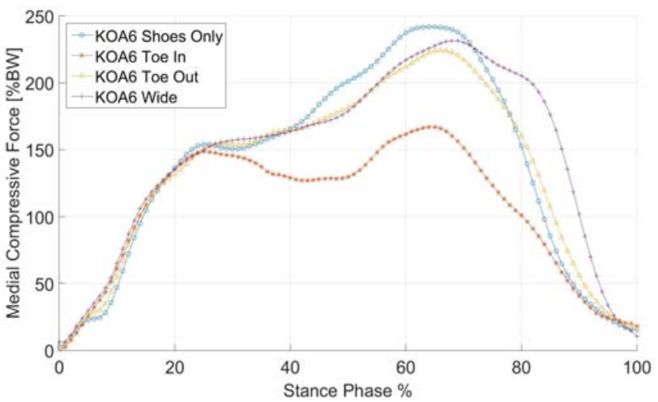

Figure 2: Medial Compressive Force for KOA6 during stairs descent

Walking speed was mostly constant during the stairs ascent trials (Table III). The relative variations between the three gait modifications with respect to the SO were limited below the 10% with the only exception for the Toe In condition for KOA4 and KOA6.

TABLE III

	Walking speed for Stair Ascent (Descent) [m/s]					
	KOA1	KOA2	KOA3	KOA4	KOA5	KOA6
SO	0.69 (0.54)	0.70 (0.58)	0.56 (0.43)	0.69 (0.57)	0.41 (0.29)	0.54 (0.31)
Toe In	0.69 (0.57)	0.72 (0.56)	0.54 (0.41)	0.59 (0.40)	0.41 (0.18)	0.46 (0.29)
Toe Out	0.69 (0.60)	0.76 (0.60)	0.50 (0.40)	0.61 (0.47)	0.42 (0.22)	0.50 (0.30)
Wide	0.72 (0.63)	0.68 (0.55)	0.51 (0.44)	0.65 (0.52)	0.40 (0.25)	0.50 (0.33)

For the stairs descent trials, the walking speed was lower. Overall, Toe in condition was characterised by a reduction of the walking speed. For this task, the speed alteration was less evident particularly for both Toe Out and Wide conditions with respect to SO. These findings suggest that an outward change in foot posting angle or a wider step may not alter patient's ability during stairs descent.

Overall, it was not possible to identify a response trend for both MCF impulse and max peak for any of the analysed gait modification.

This inconsistency could be associated with the difficulty of the analysed tasks. Stairs ascent/descent is indeed a complex task which requires a high neuromuscular, cognitive and motor function.

IV. CONCLUSION

Our results do not support the biomechanical efficacy of gait modification on the reduction of the MCF during the stairs ascent/descent. However, some subject may respond positively to a gait retraining.

Further analysis based on an extended dataset is necessary to better understand the mechanical effect of gait modification during stairs tasks. Results from this study may suggest that the best strategy of gait modification should be tailored on a subject-specific level.

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