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Impact of 3D unload orthosis on tibiofemoral contact forces in relation to adduction moment and contact locations

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1. Introduction

Knee osteoarthritis (OA) is a chronic disease characterized by joint cartilage damage which is a major health issue in today's society. Valgus knee orthoses are recommended to improve the quality of life of OA patients and to postpone the arthroplasty. Tibiofemoral (TF) contact forces are important parameters for the follow up of OA progression and the assessment of the orthosis efficiency (Yan et al. 2022).

A reduction of the medial contact forces has been reported using musculoskeletal models but the mechanical action of orthosis was not modelled or simplified to an external adduction moment (Yan et al. 2022). Musculoskeletal models have also shown that medial contact force in OA patients is correlated with inter-segmental moments and contact point locations (Dumas et al. 2020; Amiri et al. 2023).

Using a musculoskeletal model with a personalised modelling of the orthosis mechanical action, this study aims to investigate how wearing an orthosis impacts the medial contact forces and its correlations with internal knee adduction moments and contact point locations.

2. Methods

2.1. Experimental set up

Sixteen patients diagnosed with severe medial OA wore a personalised 3D printed orthosis (Evoke, OssKin) for four weeks prior to the test. The orthosis applies a correction of 4 mm knee medial displacement and 5° knee abduction angle. All patients completed the consent form approved by the institutional Ethics Committees. Low dose biplane x-rays (EOS) were acquired in five weight-bearing squat postures (0°, 15°, 30°, 45°, 70° knee flexion) with and without wearing the orthosis. Two inertial Sensors (Noraxon, Inc) were placed in the sagittal plane of the shank and the thigh to control the knee flexion/extension angle in real-time. An AMTI force platform (ORS-6)

was fixed inside the EOS cabinet to measure the forces and moments under the studied foot. A platform was designed to isolate the ground reaction forces under the contralateral foot, while both feet were maintained at the same level.

2.2. Musculoskeletal modelling

A five-segment lower limb model with 5 joint degrees of freedom and 43 muscles lines of action was used in this study. Bone segments and muscles have been scaled to subject anthropometry and positioned in 3D using the biplane x-ray images. Hip joint centre, TF contact point locations (Zeighami et al. 2017), and patellar tendon insertion and tendon length were personalised using the bones 3D reconstructions.

This study used a newly developed method to personalise loads applied by the orthosis on the lower limb. The 3D orthosis forces and moments were computed from the soft tissue stiffness of each segment (K_{ij}^i, K_{ij}^j), where $i=2,3$ stand for shank and thigh, $j=1,2,3$ for spatial directions and r,t for rotation and translation mechanical action (Shafiei and Behzadipour 2020):

$$\begin{cases} F_j^i \\ M_j^i \end{cases} = \begin{cases} K_{ij}^i * (u - u_0) \\ K_{ij}^j * (\vartheta - \vartheta_0) \end{cases} \quad (1)$$

where $(u_0, \vartheta_0) = (-4 \text{ mm}, -5^\circ)$ is the correction values applied at standing posture and (u, ϑ) is the orthosis movement relative to the bone measured in the biplane x-rays of other postures. In order to ensure static orthosis equilibrium, forces and moments on each space axis has been modified as follow:

$$\begin{cases} |F_j| \\ |M_j| \end{cases} = \begin{cases} |(F_j^3 - F_j^2)/2| \\ |(M_j^3 - M_j^2)/2| \end{cases} \quad (2)$$

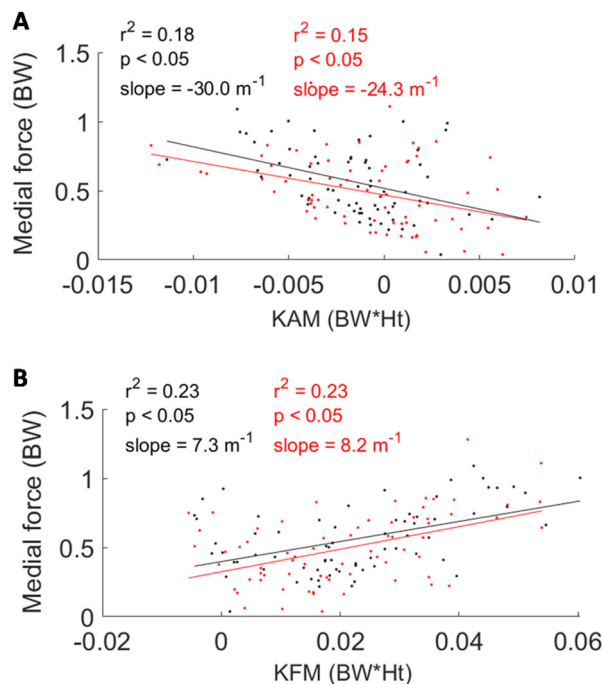
For all of the static squat postures, internal knee adduction and flexion moments (KAM and KFM) and contact forces were calculated *via* inverse dynamics and static optimisation including subject-specific contact point locations (Dumas et al. 2020). The Mann-Whitney statistical test has been performed to study the effect of wearing or not the orthosis on TF contact forces. Linear regression tests have been performed to study the relation between the evolutions of medial force, internal KAM, internal KFM and contact points locations.

3. Results and discussion

Regarding TF contact forces, a major increase of lateral contact force of 26.4% in standing posture and a general but not significant decrease in medial force in all postures were found with the orthosis (Table 1).

Table 1. Average variation (in %) of TF contact forces while wearing orthosis.

	0°	15°	30°	45°	70°
Medial	-9.1	-15.2	-15.2	-12.9	-6.6
Lateral	+26.4	-6.2	-3.9	-3.6	+0.7
Total	+1.3	-10.8	-9.1	-7.3	-2.3

**Figure 1.** Correlations between medial contact force and internal KAM (A) and internal KFM (B), with (red) and without (black) the orthosis.

Correlations were observed between the medial contact force and the KAM parameters ($r^2 = 0.18$ and $r^2 = 0.15$ with and without orthosis, respectively) and the KFM parameters ($r^2 = 0.23$ both with and without orthosis) (Figure 1) indicating that modelling the orthosis does not impact the relationships identified in the literature for OA patients (Dumas et al. 2020; Amiri et al. 2023). Given the slopes of the correlations, to reduce the medial contact force, the internal KAM should be increased (external KAM reduced) and the internal KFM should be decreased (external KFM increased). No correlations have been found between the medial contact force and the contact point locations neither with or without the orthosis. The literature (Dumas et al. 2020) showed that medial contact forces could be reduced if the contact points are more medial. However, contact points seem already located more medially in OA patients (Zeighami et al. 2017) compared to healthy subjects, and this may not necessarily be the goal to achieve with the orthosis. Besides, it has been observed that the displacement of contact

point locations remains close to 0 mm for many patients and postures.

This study reports on the unloading mechanism of the medial compartment of the knee when wearing the orthosis, as previously observed by Yan et al. (2022), and confirmed these observations with the inclusion of the orthosis into the numerical approach. In this study, the orthosis was assumed to be rigid, and the slippage was neglected. The soft tissue stiffness was obtained from the literature (Shafiei and Behzadipour 2020) and was not subject-specific. All these modelling assumptions result in the computation of orthosis loads that can compromise orthosis equilibrium. That is why a control step was implemented in this study.

4. Conclusions

This study evaluates the impact of 3D knee unload orthosis using biplane radiography and musculoskeletal modelling including customized loads applied by the orthosis. Medial contact forces are reduced as the internal adduction moments increased and the internal flexion moments decreased.

Future investigations should now focus on evaluating the orthosis performances on dynamic activities such as walking.

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KEYWORDS Osteoarthritis; musculoskeletal modelling; knee brace; tibiofemoral contact forces

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