

ON THE BIOMECHANICAL RELATIONSHIP BETWEEN EXTERNAL HIP, KNEE AND ANKLE JOINT MOMENTS AND THE INTERNAL KNEE COMPRESSIVE FORCES

Jonas Stoltze ^{1,*}, J. Rasmussen¹ and M. Skipper Andersen¹

¹Department of Mechanical and Manufacturing Engineering; e-mail: jss@m-tech.aau.dk,

*Ph.D. student

INTRODUCTION

A common approach for treating Knee Osteoarthritis (OA) is using a brace [1], which has the purpose of reducing the internal joint load of the damaged cartilage and meniscus. The reduction is mostly achieved by shifting the load from the medial to the lateral compartment using a valgus brace, and thus the total compressive load remains the same. The aim of this study was to investigate how internal knee joint loads depend on applied external moments during gait. This knowledge can be useful for improving knee braces.

METHODS

Musculoskeletal (MS) models developed in the AnyBody Modelling System (AMS) from a previous study [2] of ten healthy subjects (8 males and 2 females, age: 25.7 ± 1.5 years, height: 180.8 ± 7.4 cm, weight: 76.9 ± 10.4 kg), who performed three gait cycles (GC) each, were used. The models were driven by full-body 3D kinematics based on trajectories from 35 surface mounted reflective markers (29 placed on the skin and three on each shoe) recorded with eight infrared cameras (Oqus 300 series, Qualisys AB, Gothenburg, Sweden) sampling at 250 Hz, and the GRFs were sampled at 2000 Hz using two force plates (Advanced Mechanical Technology, Inc., Watertown, MA, US).

AMS was used to perform inverse dynamic analysis of each gait trial for eight different load cases; normal gait with no external loads (NoExt), applied hip adduction-abduction (HAA), hip flexion-extension (HFE), knee flexion-extension (KFE), knee varus-valgus (VV), ankle plantarflexion-dorsiflexion (PD) and subtalar inversion-eversion (SIE) moments. Additionally, combinations of the three most effective moments during gait, regarding internal knee joint load reduction, were assessed; HFE+KFE, HFE+PD, KFE+PD and FE+VV+PD. All moments were applied in a way that either fully compensated for the muscles, normally responsible for creating the movements (HAA, HFE, KFE, PD and SIE) or counteracting the varus-valgus moment, M_{VV} (VV).

For each load case, the total compressive knee joint load, $F_{c,t}$ and M_{VV} were computed in AMS from which the medial and lateral compressive forces on the condyles, $F_{c,m}$ and $F_{c,l}$ respectively, were found by means of static equilibrium equations in the frontal plane:

$$F_{c,m} = \frac{F_{c,t}L_l - M_{VV}}{L_l + L_m} \quad F_{c,l} = \frac{F_{c,t}L_m + M_{VV}}{L_l + L_m} \quad (1)$$

The medial and lateral moment arms, L_m and L_l respectively, were estimated from the relationships between internal knee geometry and the maximum width of the femoral condyles from medial to lateral sides as reported in [3].

RESULTS AND DISCUSSION

The mean compressive load \pm one standard deviation during stance phase for NoExt and the combined load cases is depicted in Figure 1.

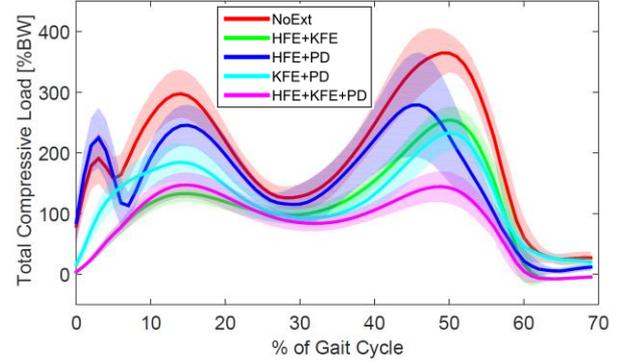


Fig. 1 Knee compressive load during a gait cycle for NoExt and all combined load cases.

A major reduction relative to NoExt was seen when combining HFE, KFE and PD which decreased the mean of the first peak ($\sim 13\%$ GC) and second peak ($\sim 50\%$ GC) with 51.9% and 60% respectively, and the impulse, calculated as the area below the curve, was reduced with 59.4%. Both HFE and KFE significantly reduced the first peak with 22.6% and 43.5% respectively, whereas PD mainly affected the second peak with a reduction of 11.2%, which HFE additionally reduced with 10.6%.

The practical application of combined HFE, KFE and PD moments can be challenging since they each need to be active at different times during the gait cycle. Thus, it might be necessary to limit the brace to two combined moments, and overall HFE+KFE performs best based on having the lowest impulse among the cases with only two loads.

CONCLUSIONS

The results from this study give good indications on the influence of external moments on knee compressive loads, which is valuable information for developing improved knee braces.

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REFERENCES

1. Brooks KS *Osteoarthritic Knee Braces on the Market: A Literature Review* **26**: 2-30, 2014
2. Skals SL, et. al., *Multibody System Dynamics (conditionally accepted)*, 2015
3. Seedhom B, *Dimensions of the knee. Radiographic and autopsy study of sizes required by a knee prosthesis* **31**: 54-58, 1972