Gait & Posture 58 (2017) 333–339

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Review article

Factors influencing knee adduction moment measurement: A systematic review and meta-regression analysis

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ARTICLE INFO

Keywords:
Knee adduction moment
Footwear
Meta-regression
Knee osteoarthritis
Walking speed

ABSTRACT

The external knee adduction moment has been identified as a key biomarker in biomechanics research, with associations with this variable and degenerative diseases such as knee osteoarthritis. Heterogeneity in participant characteristics and the protocols used to measure this variable may however complicate its interpretation. Previous reviews have focused on interventions or did not control for potential moderator variables in their analysis. In this meta-regression analysis, we aimed to determine the influence of factors including the cohort type, footwear, and walking speed on the measurement of knee adduction moment. We performed a systematic review of the literature, identifying articles that used the Plug-in-Gait inverse dynamics model to calculate the knee adduction moment during level walking, and used a mixed effect model to determine the effect of the previously described factors on the measurement. Results for 861 individuals were described in 19 articles. Walking speed had the largest influence on knee adduction moment ($p < 0.001$), and participants with medial knee osteoarthritis had an increased knee adduction moment ($p = 0.008$) compared to healthy subjects. Footwear was found to have a significant overall effect ($p = 0.024$). Participants tested barefoot or wearing their own shoes had lower adduction moments than those tested in footwear provided by the researchers. Overall, the moderators accounted for 60% of the heterogeneity in the results. These results support the hypothesis that an increased knee adduction moment is associated with medial compartment knee osteoarthritis, and that footwear choice can influence the results. Gait speed has the largest effect on knee adduction moment measurement and should be carefully controlled for in studies investigating this variable.

1. Introduction

Mechanical loading plays an important role in the health and disease of the knee [1,2]. There are many biomechanical variables related to knee function that can be directly or indirectly measured, but perhaps the most commonly explored is the external knee adduction moment (KAM). Research has suggested that elevated KAM is associated with medial knee osteoarthritis and its progression, with a proposed mechanism of increased stress in the medial compartment leading to aberrant wear on the soft tissues [3]. There is some debate over this finding, with systematic reviews of the literature finding inconsistent evidence for elevated KAMs in patients with medial knee osteoarthritis compared to healthy controls [4,5].

Direct measurement of knee kinetics is challenging, with significant ethical and methodological obstacles. Studies using instrumented knee implants have provided unprecedented insights into knee loading [6], however these implants have only been used in a small number of people, and are only possible in those requiring knee arthroplasty. Therefore, the most common approach is to estimate the external adduction loads at the knee via motion capture assessment of body kinematics combined with ground reaction force measurements, allowing inverse dynamic methods to be performed [7]. This approach has generally been found to generate reproducible measurements of KAM [8,9].

When designing a study that involves the measurement of KAM, researchers are faced with a range of methodological decisions at the data collection, processing, and analysis stages. During data collection, for example, footwear choice can influence knee mechanics [10]. Indeed, this is the basis of many conservative intervention strategies for knee OA [11]. While asking the participants to walk barefoot removes any external influence of footwear on gait mechanics, in most cases this is likely not representative of how the majority of activities of daily living are undertaken. Standardized footwear can be provided, however the effect of walking in unfamiliar shoes may influence gait. Subjects can be tested in their own shoes, but often a subject will use diverse shoe types for different activities and occasions, the properties of the

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http://dx.doi.org/10.1016/j.gaitpost.2017.08.025
Received 13 April 2017; Received in revised form 7 August 2017; Accepted 19 August 2017

shoe may change with use, leading to a fairly heterogenous sample in terms of footwear. Beyond this, participant characteristics including gait speed have been suggested to influence the measurement of KAM [12]. When processing the data, the analytical definition of the knee joint center, including the reference frame used, can all have an effect on the results [13], making it difficult to compare between studies. Many more decisions are required when planning such a study, and in many cases, there is no established consensus to answer to these questions, and a choice must be made based on the aims of the study along with pragmatic considerations.

Previous systematic reviews involving the measurement of KAM have focused on interventions or did not directly control for potential confounding factors related to the protocol used. In this systematic review of the literature, we used a meta-regression approach to determine if participant characteristics, footwear (barefoot, own, or standardized), and walking speed had a significant effect on the results reported by studies measuring KAM.

2. Methods

2.1. Search strategy

Titles and abstracts containing the search term "knee adduction moment" with related Medical Subject Headings (MeSH) were identified from the Pubmed database using the RISmed package [14] running on R version 3.3.1 [15] on 2016/10/12. Reference lists were also reviewed for additional relevant literature. The code and results from the literature search can be found in the code and results from the literature search can be found at https://github.com/Telfer/KAM_MetaRegression.

2.2. Selection criteria

Two of the authors (ST and ML) reviewed the abstracts for suitability. Full texts were inspected if insufficient detail was presented in the abstract. This review considered English language studies from the earliest available date which reported the external knee adduction moment as measured during gait over level ground. Papers were only eligible if they presented original research, therefore case studies, study protocols, editorials, cadaver and studies based on computational simulations were excluded. Studies reporting on children (< 18 years old) were not eligible for inclusion as knees that were still developing could have a confounding effect on our analysis. Studies based around any type of intervention were included if they reported baseline measurements of KAM. In several instances, data from the same cohort of subjects were reported in several different articles, and in this situation any re-analyses of data from the same participants were excluded. Authors were contacted to confirm details in cases where it was unclear if the same participants had been included in more than one article.

As previously described, the choices made during the processing of gait analysis data can have a significant effect on the results. We limited studies to those using the Plug-in-Gait inverse dynamics analysis software (Vicon Ltd, Oxford, UK) for the calculation of KAM to obtain as homogenized a dataset as possible [16,17]. While small changes to this software have been made over time, the basic calculations and marker model have remained relatively consistent.

2.3. Methodological quality

As this review focused on cross sectional results, an adapted version of a quality index for non-randomized trials previously utilized for literature reviews in this area was used to assess the quality of articles [4,18,19]. Two reviewers (ST and ML) independently performed the quality assessment. Articles that scored less than 50% on the quality index were excluded from the main analysis.

2.4. Data synthesis

From each paper that met the inclusion criteria, two reviewers (ST and ML) extracted demographic details on the study population(s) including age, height, mass and BMI. The primary characteristic of the study population, i.e. if they were healthy controls, or had medial knee osteoarthritis for example, was determined. The walking speed of each group was noted. The footwear, if any, worn by the study participants during gait analysis was extracted. If the participant's own shoes were worn, these were grouped together in a single category. If the researchers provided footwear for the testing, these were again grouped into a single category.

Measurement data associated with the KAM measurement during level walking were extracted. The distinctive "m" or "double hump" shape of the KAM waveform has led researchers to report several discrete variables related to it [20]. We included articles that reported the 1st peak (usually described as the peak value occurring during the first 50% of stance), as this has been strongly associated with disease progression in knee osteoarthritis [21,22]. Alternative analysis strategies such as those based around principal component analysis have been described [23], however to allow synthesis of the data we focused on the 1st peak value as a single discrete variable that lends itself to the meta-regression approach that was proposed for this review. Where required, data points were digitized from figures within the paper. To maximize the number of studies that could be included in the analysis, where data was not directly available in the manuscript, we attempted to contact the authors to obtain this information. Where KAM was presented in units other than%BW*H, we converted to%BW*H using the demographic data provided (see Supplementary materials for further information). %BW*H was the most commonly reported unit for KAM found in these papers, therefore we chose to use this as our standardized unit. Where a repeated measures analysis was carried out for an intervention that was not footwear based, for example if the study was testing the effects of gait retraining [24], we used the control condition, which was the subjects' normal baseline walk.

2.5. Statistical analysis

All analyses were performed in R using the metafor package [25]. Full analysis code and extracted data has been made available at https://github.com/Telfer/KAM_MetaRegression. Cohort groups and footwear types needed to be reported in at least two studies to be included in the analysis. A mixed-effects modeling approach was used to analyze the data, with moderators of cohort type, footwear, and walking speed of participants. A chi-square test of the moderators was performed to determine if there was a significant effect across all moderators, followed by cohort-specific and footwear-specific chi-square tests of moderators. In the case of articles where repeated measures of different footwear conditions were reported, to avoid violation of the independence assumption [26] a separate model with non-standardized footwear repetitions removed was run and the results compared to determine if there was any undue effect.

3. Results

Through the search strategy described above, 556 articles were initially identified. Of these, 277 were found to meet the inclusion criteria based on initial screening. Upon review of the full articles, including quality assessment, a further 258 were excluded. The final analysis included 29 subject cohorts from the remaining 19 articles which reported the 1st peak of the KAM waveform determined via the Plug-in-Gait model. These articles provided data for all the required moderator variables, and met the required quality standards (Fig. 1). Full quality assessment results can be found in the Supplementary materials. Summary results from the included articles are provided in Table 1.

Overall, these studies included data on 29 groups of participants,