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Calculation of external knee adduction moments: A comparison of an inverse dynamics approach and a simplified lever-arm approach

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ABSTRACT

Background: The external knee adduction moment (EKAM) is often studied in knee osteoarthritis research. This study compared EKAMs between two methods of calculation: a method that only requires ground reaction force and knee position data (i.e. lever-arm), and an inverse dynamics link-segment method.
Methods: Sixteen participants walked while wearing a control shoe with and without a six millimeter lateral wedge insole. Peak EKAMs between the lever-arm and inverse dynamics methods were compared for the control condition, and the %change in moment induced by the lateral wedge was compared between methods.
Results: When comparing EKAMs between methods, no correlation was found ($r = 0.24$, $p = 0.36$); peak EKAMs with the lever-arm method (26.0 Nm) were significantly lower than EKAMs with the inverse dynamics method (40.2 Nm, p b 0.001); and Bland–Altman plots showed poor agreement between methods. When assessing the %change in moment with a lateral wedge, a moderate correlation was found ($r = 0.55$, $p = 0.03$) between methods; Bland–Altman plots showed moderate agreement between methods; and the lever-arm method (−6.4%) was not significantly different from the inverse dynamics method (−11.4%, $p = 0.09$); however, the two methods produced opposite results 31% of the time.
Conclusion: The lever-arm method cannot estimate peak EKAMs, and can only approximate the %change in moment induced by a lateral wedge; however, the error rate was 31%. Therefore, the lever-arm method is not recommended for use in its current form.
Clinical relevance: This study may help guide the development of a fast and simple method for determining EKAMs for individuals with knee osteoarthritis.

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1. Introduction

The external knee adduction moment (EKAM) is often used as a surrogate for medial compartment load in knee osteoarthritis research [24]. This practice is supported, in part, since it has been shown that EKAM magnitude is correlated with osteoarthritis severity and osteoarthritis disease progression [2,27]. Consequently, numerous osteoarthritis studies have made the EKAM a focus. For instance, researchers have attempted to reduce the EKAM using footwear, surgical, gait or other device interventions, in an attempt to slow the progression of osteoarthritis [4,12,18,30]. Other studies have used this moment with musculoskeletal models, and in vivo force sensors to estimate the actual load on the medial tibiofemoral compartment [1,20]. Most commonly, the EKAM is studied as an outcome in footwear orthotics studies, where patients with knee osteoarthritis are provided with a laterally wedged insole to reduce the EKAM with the intent of improving symptoms associated with knee osteoarthritis.

Typically, the EKAM is calculated using an inverse dynamics (ID) approach, where Newton–Euler equations are used to solve for resultant moments at the knee [18,26,29,31]. This approach can be considered the gold-standard in terms of estimating the magnitude of the EKAM as it uses three dimensional kinematics and kinetics data from the foot/ankle and shank/knee, and body segment inertial parameters as inputs, and can be used with an embedded segment coordinate system [25,31]. While this approach is useful in research settings where precise estimations of EKAM magnitude are desired, it is a complicated and expensive procedure to utilize in regular clinical practice, which prevents clinicians from knowing whether a lateral wedge intervention may be beneficial to their patient.

Often, a change in the magnitude of the EKAM resulting from a lateral wedge intervention is attributed to alterations in the magnitude of the ground reaction force, or length of the lever arm between the resultant frontal-plane ground reaction force and knee joint center [15,24]. While, the length of the ground reaction force to knee joint center lever arm is not technically part of the EKAM calculation (see [31]),

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reporting of this variable remains prevalent in the literature. A simplified equation for the EKAM can be derived if it is assumed that the ground reaction force and ground reaction force to knee joint center lever arm are the primary variables implicated in EKAM magnitude:

$$EKAM_Y = r_z GRF_x + r_x GRF_z. \quad (1)$$

In this equation, GRF_x corresponds to the mediolateral ground reaction force, GRF_z corresponds to the vertical ground reaction force, r_x corresponds to the mediolateral distance from the ground reaction force center of pressure to the knee joint center, and r_z corresponds to the vertical distance from the ground reaction force center of pressure to the knee joint center.

Some authors have begun to use this simplified calculation of the EKAM [28], which will be described here as the lever-arm method (L-Arm method). This approach has the advantage over the ID method for EKAM calculation in that it is relatively fast to compute, and requires a less extensive data collection in that only the position of the knee joint center relative to the origin of the ground reaction force, and magnitude of the vertical and mediolateral ground reaction forces are required. Therefore, this approach may be of special interest to researchers or clinicians who do not have access to full inverse dynamics setups, or those who desire a rapid estimate of the EKAM and may represent a simplified and clinically useful alternative to the ID method. However, the results obtained from this L-Arm approach, in terms of EKAM magnitude, and change in EKAM magnitude with a biomechanical intervention have not yet been compared against the ID method, which is critical if the method is to be used more widely in biomechanics and clinical practice.

Using Eq. (1) to calculate the resultant frontal plane load assumes that (1) the angular acceleration and/or the mass moment of inertia of the shank is zero, (2) the EKAM occurs exclusively in the laboratory frontal plane, i.e. not within a defined segment or embedded local joint coordinate system, and (3) the lower leg and foot act as one rigid body, as opposed to separate bodies connected at a joint. Assumption (1) is reasonable, since rotations of the shank in the frontal plane are small, and the mass moments of inertia of the shank are also very small. However, Assumption (2) is violated during walking, where the shank in the sagittal plane is not always oriented perpendicular to the ground, and thus perfect adduction/abduction in the laboratory coordinate system cannot occur for most of stance phase (Fig. 1). Assumption (3) is also violated during gait as the foot pronates during the beginning of stance phase and the ankle muscles produce a frontal plane moment that controls this process. This moment has been shown to directly affect the resultant frontal plane knee moment [22]. Together, these two violated assumptions may contribute towards inaccurate estimations of the resultant EKAM magnitude calculated using the L-Arm approach.

While estimations of raw EKAM magnitude may not be accurate with the L-Arm method, it is possible that the method may be viable for estimating the change in EKAM magnitude between intervention conditions. For example, Hinman et al. [15] have shown that a moderate correlation exists between the magnitude of the ground reaction force to knee joint center lever arm and the EKAM calculated using an ID method when testing a lateral wedge intervention; however direct comparisons of changes in EKAM magnitude between the L-Arm method and ID method have not been performed.

Therefore, it is currently not known how EKAMs calculated using the L-Arm approach compare to the ID method during gait. Moreover, it is not known if the L-Arm can accurately estimate the change in EKAM when a laterally wedged insole is given. This is an important consideration for osteoarthritis management, where a common goal is to reduce frontal plane knee joint load using laterally wedged footwear [24]. Therefore, the purpose of this study was to compare the magnitude of the moments calculated from the L-Arm and ID methods, and also compare the change in moment with the two methods when participants are given a lateral wedge intervention designed to reduce frontal plane knee load. Since the leg and foot are not a solid rigid body, and since the EKAM does not occur exclusively in the frontal plane, it was hypothesized that peak EKAM magnitude during walking calculated using the L-Arm method would be significantly different from, and not be correlated with, peak EKAM magnitude calculated from the ID method. However, since it has been shown that the magnitude of the ground reaction force to knee joint center lever arm is moderately correlated with the peak EKAM, when investigating the percent change in EKAM induced by a lateral wedge footwear intervention, it was hypothesized that the percent change in peak EKAM calculated using the L-Arm method induced by a lateral wedge footwear intervention would not be significantly different from, and would be correlated with, peak EKAM changes determined from the ID method.

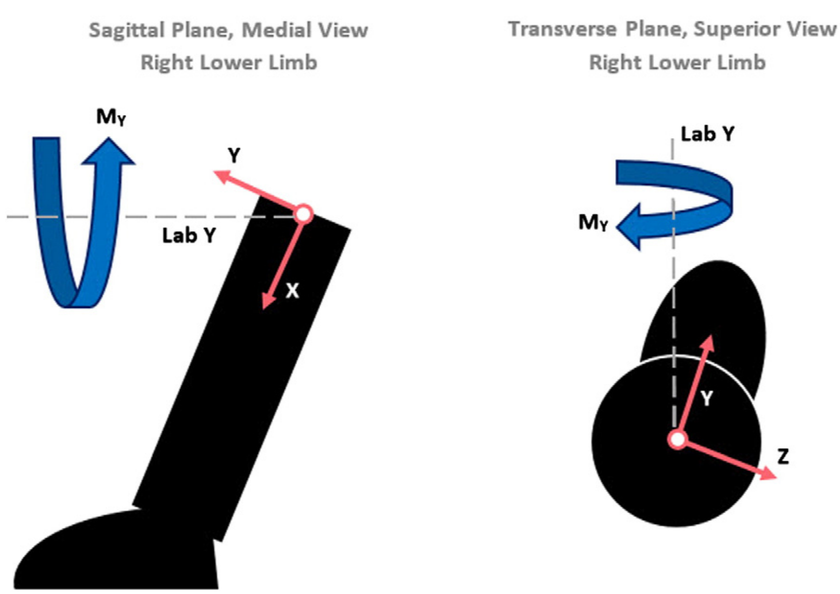

Fig. 1. A schematic diagram showing how the internal knee adduction/abduction axis can be out of plane from the laboratory coordinate system. The external knee adduction moment, shown as M_Y, is calculated in the laboratory coordinate system, and therefore is out of plane with the actual knee adduction/abduction axis.

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