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A comparison of measuring mechanical axis alignment using three-dimensional position capture with skin markers and radiographic measurements in patients with bilateral medial compartment knee osteoarthritis

Annegret Mündermann [a,b,c,*], Chris O. Dyrby [a,b], Thomas P. Andriacchi [a,b,d]

[a] Department of Mechanical Engineering, Stanford University, Stanford, CA, USA
[b] Bone and Joint Center, Palo Alto VA, Palo Alto, CA, USA
[c] School of Physiotherapy, University of Otago, Dunedin, New Zealand
[d] Department of Orthopedic Surgery, Stanford University Medical Center, Stanford, CA, USA

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Abstract

The mechanical axis alignment of the lower extremity is typically measured from frontal plane radiographs of the entire lower extremity during double support standing. The purpose of this study was to test the hypothesis that the mechanical axis alignment can be predicted from skin markers on anatomical landmarks and anthropometric measurements and a stereophotogrammetric system based on significant correlation with the mechanical axis alignment measured from standing radiographs.

Mechanical axis alignment was measured using full-limb radiographs for both knees of 62 patients with bilateral medial compartment knee osteoarthritis (OA). Mechanical axis alignment was also measured using a stereophotogrammetric system with markers on anatomical landmarks and anthropometric measurements to determine joint centers.

The mechanical axis alignment from position capture correlated with that from radiographs ($R^2=0.544$; $P<0.001$). This relationship did not depend on age, gender, BMI, or OA severity. A small but significant difference in the mechanical axis alignment between the two methods was observed (radiograph: 2.6 varus; position capture: 3.8 varus; $P=0.001$). Associations between mechanical axis alignment and OA severity were found for both methods (radiographic: $R^2=0.563$; position capture: $R^2=0.807$).

The proposed method allows the measurement of the mechanical axis alignment without exposure to radiation. This method enables the establishment of the relationship between lower limb alignment and functional variables such as dynamic joint loading in degenerative joint disease and joint injury even in populations who typically do not undergo radiographic examination.

Keywords: Leg alignment; Knee; Osteoarthritis; Varus; Valgus

1. Introduction

Osteoarthritis (OA) is a degenerative joint disease that affects an increasing portion of the elderly population [1–3] with the knee being the most frequent site for OA [4]. Knee OA has a profound effect on the work and social life of patients due to pain, reduced physical functioning, disability, and reduced mobility. Several factors contribute to the severity and rate of progression of the disease including malalignment [5,6], muscle weakness [7], impaired proprioception [8], altered gait patterns [9], and increased joint laxity [10,11]. Static alignment or mechanical axis alignment is frequently used by clinicians to estimate the load distribution at the knee and as evaluation variable during total knee replacement surgery [12,13] with the goal of achieving a neutrally aligned knee.

* Corresponding author. Department of Mechanical Engineering, Durand Building 205, Stanford University, Stanford, CA 94305-4038, USA. Tel.: +1 650 488 4663; fax: +1 650 725 1587.
E-mail address: anne.muendermann@gmail.com (A. Mündermann).

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The mechanical axis alignment is defined as the angle between a line from the center of the femoral head to the center of the femoral intercondylar notch, and a line from the center of the tips of the tibial spines to the ankle talus (Fig. 1) [14]. The mechanical axis alignment of the lower extremity is typically measured from frontal plane radiographs of the entire lower extremity during double support standing. Recently proposed alternative methods for the evaluation of the mechanical axis alignment including other radiographic methods and physical examination that involve the use of inclinometers, calipers or goniometers have been evaluated [15,16] and showed a moderate correlation with the radiographically assessed mechanical axis alignment (R^2-values ranging from 0.102 to 0.640).

During walking, the ground reaction force vector passes medially to the knee joint center causing an external adduction moment (Fig. 2). This represents greater forces transferred through the medial than through the lateral compartment of the knee [17]. Typically for a knee with varus malalignment, the line of action of the ground reaction force likely passes more medially to the knee joint center, thus creating a greater external knee adduction moment during single limb support (Fig. 2). Dynamic alignment or the knee adduction moment during walking is related to the mechanical axis alignment [5] and is a strong predictor for the presence [18], severity [6] and rate of progression [19] of medial compartment knee OA. The knee adduction moment during walking is commonly assessed using gait analysis based on stereophotogrammetric systems. Frequently, anthropometric measurements of patients' lower extremity joint are taken to determine the joint center locations from these skin markers. The use of these anatomical landmarks

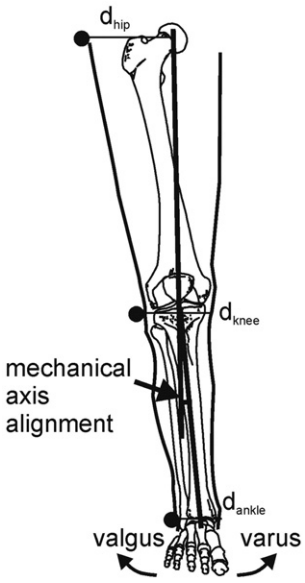

Fig. 1. Mechanical axis alignment was defined as the angle between a line from the center of the femoral head to the center of the femoral intercondylar notch, and a line from the center of the tips of the tibial spines to the ankle talus [14]. Joint centers were determined based on skin markers on the greater trochanter, lateral joint line of the knee and lateral malleolus combined with measured joint correction factors. Positive values indicate varus alignment, and negative values indicate valgus alignment. The limbs were aligned with the laboratory coordinate system for the position capture method.

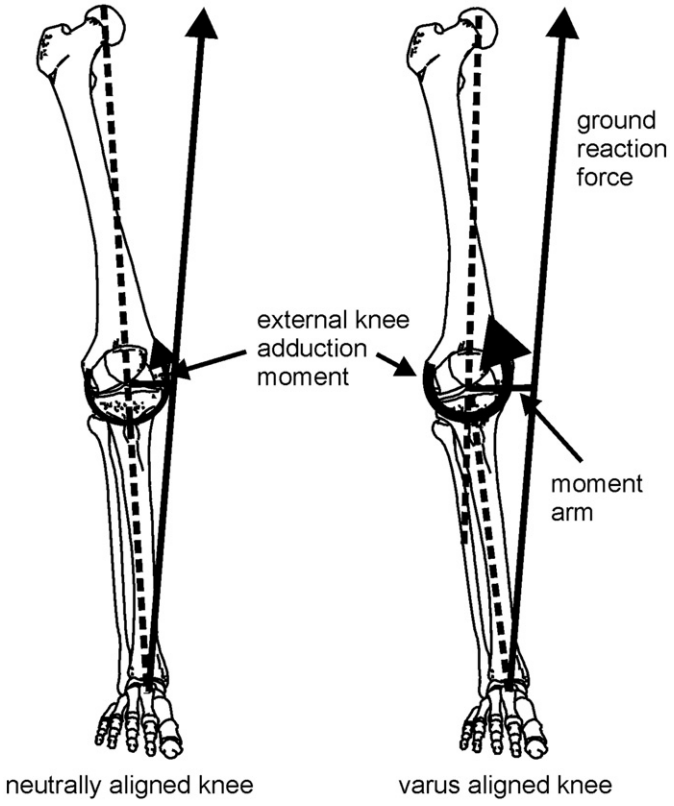

Fig. 2. The external knee adduction moment tends to be greater in varus aligned knees (right) compared to neutrally aligned knees (left) due to a greater moment arm of the ground reaction force about the knee joint center.

and anthropometric measurements could allow for a time efficient and radiation-free estimation of the mechanical axis alignment during gait assessments of knee OA populations or of populations that are at higher risk of developing knee OA such as older adults, female persons and obese persons who undergo gait analysis [20].

The purpose of this study was to investigate if the mechanical axis alignment can be estimated using anatomical landmarks and anthropometric measurements during stance and a stereophotogrammetric system and whether the association with OA severity is similar for both measurements. We hypothesized that the mechanical axis alignment measured from standing radiographs can be predicted from the mechanical axis alignment measured using anatomical landmarks and anthropometric measurements, and that mechanical axis alignment predicted from anatomical landmarks is associated with OA severity.

2. Methods

2.1. Patients

Sixty-two patients with bilateral OA in the medial compartment of the knee participated in this study (Table 1) after giving written consent in accordance with the Institutional Review Board. All subjects fulfilled all inclusion criteria for at least one knee for participation in this study: definite osteophyte presence