Journal of Orthopaedics, Trauma and Rehabilitation 25 (2018) 11–15

Contents lists available at ScienceDirect

Journal of Orthopaedics, Trauma and Rehabilitation

Journal homepages: www.e-jotr.com & www.ejotr.org

Original Article

Comparison of gait biomechanics in patients with and without knee osteoarthritis during different phases of gait
比較有和沒有膝關節骨性關節炎的受試者在不同步態階段的步行生物力學

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ARTICLE INFO

Article history:
Received 1 January 2017
Received in revised form
7 August 2017
Accepted 20 September 2017

Keywords:
gait
knee
osteoarthritis

ABSTRACT

Background: This study aimed to characterise knee adduction angles (KAA) and knee adduction moments (KAM) and compare this with foot centre of pressure (COP) in volunteers with and without knee osteoarthritis (OA).
Methods: A total of 108 participants were recruited; 84 had no known pathology, 18 had medial knee OA, and six had lateral knee OA. Linear regression was used to determine correlations between the normalised COP, KAM, and KAA during each phase of gait for all participants.
Results: The first phase of gait demonstrated significant differences between groups for all measures: KAA in all phases, COP in phases one and two, and KAM in phase one only.
Conclusion: The largest mechanical changes are seen in the first phase of gait in osteoarthritic patients. Although COP is an easy to measure tool, it is not as sensitive as KAA and did not demonstrate a significant difference between healthy and medial OA patients.

中文摘要

背景：本研究旨在表徵膝關節內收角（KAA）和膝關節內收力矩（KAM），並將其與有和沒有膝關節骨性關節炎 (OA) 的志願者的腳部壓力中心（COP）進行比較。
方法：招收108名受試者；84例未見病理、18例有內側膝關節骨性關節炎、6例有外側膝關節骨性關節炎。 使用線性回歸來確定所有受試者的每個步態階段標準化的COP、KAM和KAA之間的相關性。
結果：步態的第一階段顯示了不同組別之間在所有測量參數具有顯著差異：所有階段的KAA，第一階段和第二階段的COP和第一階段的KAM。
結論：膝關節骨性關節炎患者步態第一階段發生最大的機械變化。 雖然COP是一個易於測量的工具，但它並不像KAA那樣敏感，並沒有顯示健康和內側OA患者之間的顯著差異。

Introduction

It has previously been shown that overloading of the cartilage plays an important role in the development of osteoarthritis (OA).[1] The medial knee condyles carry most of the load applied at the knee joint,[2] which can increase further in patients with the medial OA.[3] As such, the medial compartment is more commonly affected compared with the lateral compartment.[4] The development and progression of OA can be attributed, at least in part, to various biomechanical factors leading to these kinematic adaptations during gait.[5] As a result, gait analysis has the potential for disease diagnosis and monitoring as well as treatment and planning of surgeries.[6]

Such biomechanical factors include the knee adduction angle (KAA), which is associated with both progression and development of knee OA,[7] where varus deformity can increase the forces acting on the medial side while valgus deformity can increase the forces on the lateral knee compartment.[7] The external knee adduction moment (KAM), a surrogate measure for the tibio-femoral contact

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https://doi.org/10.1016/j.jotr.2017.09.005

force reflecting the load on the knee condyles,[8] has been reported to be higher in patients with medial OA comparedwith controls[9,10] with a high KAM correlating with increased OA severity and OA progression.[11] Yet, to measure KAM, costly motion-capturing equipment is required, and the procedure is time consuming, requiring considerable expertise.

Centre of pressure (COP) can be defined as the centre of all the external forces acting on the plantar surface of the foot. Recent studies have demonstrated a relationship between KAM and COP in medial OA patients during gait. COP has been shown to be laterally shifted in patients with medial knee OA,[12] and by modifying the COP medially a decrease in peak KAM can be achieved by shortening the lever arm for adduction moment.[13,14] Another study found that interventions to adapt COP can lead to reduced pain and increased function at the knee joint.[15] The usefulness of COP in comparison with KAA and KAM in identifying OA patients from healthy patients has not been well defined nor has the relationship of these gait factors within the different phases of gait. By determining an association between COP position, KAM, and KAA during different phases of the gait cycle, it may be possible to determine if COP position can be used as an alternative or in conjunction with peak KAM and KAA, through instrumented footwear or treadmills. This information could be used as a clinical marker to evaluate the success of interventions, thereby avoiding the reliance on expensive and time-consuming motion capturing systems, and to design patient-specific foot orthoses to customise COP modifications to alter knee coronal kinetics during gait.

Therefore, the major aim of this preliminary research was to:

(1). characterise and compare the COP positions, KAA, and peak KAM during barefoot gait between OA patients and healthy patients
(2). determine in which phases of gait osteoarthritic patients show the most measurable mechanical adaptations
(3). determine the usefulness of COP positions in differentiating healthy and OA patients compared with KAA and KAM.

Materials and methods

This study had ethical approval from the South West London Research Ethics Committee with all patients providing written informed consent. A total of 108 participants were recruited and analysed, of which 84 had no known pathology, 18 had medial OA, and six had lateral OA (Table 1). Participants were volunteers who agreed to take part in the advertised study. For healthy patients, results from both left and right legs are included in the data set and for OA patients only the affected legs are included. OA diagnosis was based on clinical and radiographic evidence from the individuals' medical records. Exclusion criteria were predefined as follows: neurological or musculoskeletal conditions other than knee OA, rheumatoid or other systemic inflammatory arthritis, morbid obesity [body mass index (BMI) >35 kg/m^2], or previous surgical treatment for knee OA. All participants completed the Knee Osteoarthritis Outcome Scores (KOOSs) questionnaire.[16] Participant's height, weight, foot length, and foot width were measured. Because of the small numbers, severity of disease was not considered.

Motion Capture Protocol

Twenty reflective markers were positioned on the patient's pelvis and lower limbs and four marker clusters were positioned on the patient's left and right thigh and calf segments.[17] A static trial was initially captured. Two Kistler portable force plates (Kistler Type 9286B, Kistler Instrumente AG, Winterthur, Switzerland) were embedded into a 6-m walkway, and a 10-camera Vicon motion capture system was used (Vicon Motion Systems Ltd, Oxford, UK). Patients were asked to walk at a comfortable speed along the 6-m walkway five times, or until three clean foot strikes had been recorded from each force plate. The results were averaged across three trials for each patient.

Data analysis

The gait cycle was normalised to 100% with respect to time. The stance phase was divided into the following three phases using force plate data: (1) early-stance [initial contact (ground reaction force {GRF} $\geq$ 40N) until the first peak GRF], (2) mid-stance (first peak GRF to second peak GRF), and (3) late-stance [second peak GRF until toe off (GRF $\leq$ 40N)].

Kinematic and kinetic parameters at the ankle, knee, and hip were determined using a custom-made cluster model (ClussBB), as described previously by Duffell et al in 2014.[17] This model uses the Horsman method to define hip joint centres.[18] and knee and ankle joint centres were defined as the central points between medial and lateral femoral epicondyles and malleoli, respectively. Local reference frames were constructed from the bilateral thigh and shank clusters. Transformation between the cluster frames and the anatomical frames for each segment was obtained from the static trial. The clusters were tracked during dynamic trials and the transformations obtained were used to derive the anatomical frames at each instant. Using Euler angles, kinematics were calculated for each joint (in the sequence X–Y–Z). Moments were calculated using dynamics and anthropometric properties.

KAA and KAM were averaged for each phase, KAM was normalised to the patient's bodyweight $\times$ height. COP trajectory in the global frame was transformed to the local frame at the foot (where X and Y axes represented medio-lateral and antero-posterior directions, respectively). The COP trace in X and Y directions was then normalised with respect to the known width and length of each patient's foot, respectively. This was plotted on the footprint and comparisons were made between healthy and OA patients. Linear regression was used to determine correlations between COP and KAM and KAM and KAA for all patients.

Significant differences between group's height, weight, and BMI and significant differences of KAM, KAA, and COP between groups at each stance phase of gait were determined using a one-way analysis of variance. Significant results were analysed with a

Table 1
Demographics of patients analysed in this study.

Number of knees	KOOS pain score	Height (cm)	Weight (kg)	BMI (kg/m^2)	Age (yr)	Male/Female
A—Healthy ($n = 168$)	95 (8)	170 (10)	68 (12)	23.4 (3)	45 (17)	36/48
B—Medial OA ($n = 18$)	59 (12)	173 (12)	82 (20)	26.9 (3.8)	57 (12)	11/7
C—Lateral OA ($n = 6$)	57 (22)	169 (11)	71 (10)	24.8 (2.8)	46 (15)	2/4

Standard deviations are shown in brackets.
BMI = body mass index; KOOS = Knee Osteoarthritis Outcome Score; OA = osteoarthritis.