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A classification study of kinematic gait trajectories in hip osteoarthritis

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ABSTRACT

The clinical evaluation of patients in hip osteoarthritis is often done using patient questionnaires. While this provides important information it is also necessary to continue developing objective measures. In this work we further investigate the studies concerning the use of 3D gait analysis to attain this goal. The gait analysis was associated with machine learning methods in order to provide a direct measure of patient control gait discrimination. The applied machine learning method was the support vector machine (SVM). Applying the SVM on all the measured kinematic trajectories, we were able to classify individual patient and control *gait cycles* with a mean success rate of 88%. With the use of an ROC curve to establish the threshold number of cycles necessary for a subject to be identified as a patient, this allowed for an accuracy of higher than 90% for discriminating patient and control *subjects*.

We then went on to determine the importance of each trajectory. By ranking the capacity of each trajectory for this discrimination, we provided a guide on their order of importance in evaluating patient severity. In order to be clinically relevant, any measure of patient deficit must be compared with clinically validated scores of functional disability. In the case of hip osteoarthritis (OA), the WOMAC scores are currently one of the most widely accepted clinical scores for quantifying OA severity. The kinematic trajectories that provided the best patient–control discrimination with the SVM were found to correlate well but imperfectly with the WOMAC scores, hence indicating the presence of complementary information in the two.

1. Introduction

Hip osteoarthritis is a chronic degenerative joint disease leading to the progressive destruction of the cartilage at the hip joint. Pain and stiffness are the key symptoms which lead to reduced joint mobility and gait dysfunction [1]. Among the several disease-specific questionnaires used to assess functional impairment in OA, the Western Ontario and McMaster Universities (WOMAC) index [2,3] is currently considered the gold standard for hip OA patient questionnaires [1,4]. While these patient-reported scores provide important information concerning the capacity for daily functioning, they can be criticized for not being objective and sufficiently sensitive to change [1,5].

One possible objective measure could come from radiographic analyses. Numerous studies however have reported that radiographic measures which are the recommended validated technique to assess OA structural anomalies, correlate poorly at the individual level with patient symptoms [6–8]. Such measures are also made in static conditions during which the principle deficits related to movement may not appear. A better measure of functional capacities may come from a tool that directly measures an important daily activity e.g. gait. Functional mobility is one of the important categories in the activities of daily living [9,10]. When compared to control subjects, 3D gait analysis has revealed differences in the gait of hip OA patients [1,11–13]. It therefore has the potential to be used as an objective functional measure of patient condition. A detailed gait analysis might also address the criticism of not being sufficiently sensitive. Alterations in gait may already be present in the patient before the appearance of clear functional disability [14]. 3DGA can also be useful for distinguishing fine grained differences that may exist between different types of treatment such as different prostheses. Hip replacement surgeries are among the most successful procedures performed once other therapies such as physical therapy and pain medication have failed [15–17]. Only a detailed gait analysis would be able to evaluate and compare

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different prostheses. The purpose of this project is to contribute to the objective characterization and evaluation of hip OA and its treatment.

Several questions however must be answered before the usefulness of 3DGA becomes more convincing for hip OA. After an extensive meta-analysis of hip and knee osteoarthritis 3DGA studies, Ornetti et al. [1] concluded that it was necessary to demonstrate the discriminant capacities of 3DGA before it becomes an established tool in the clinical setting. The first step taken in the study therefore was to demonstrate that sufficient information exists in the data gathered from 3DGA to discriminate hip OA patients and controls. Twelve kinematic trajectories were computed for each subject walking in a straight line at normal speed. We applied a classification paradigm in order to address the issues raised above i.e. We used a machine learning algorithm to identify from the kinematic trajectories whether a gait cycle belonged to a hip OA patient or to a control subject. Such algorithms use part of the data to find the hyperplane that best separates two data groups. The remaining data is then used for testing if the computed surface is able to separate previously unused examples. The machine learning technique applied was the support vector machine (SVM). The capacity of the SVM to classify gait cycles or subjects would demonstrate the presence of clinically relevant information in the gait data. Previous studies have shown that statistically significant differences are present between the gait variables of hip OA patients and controls [11–13]. None of these studies however have taken the step of then quantifying the discriminatory capacity that comes from the differences.

The second step in the study dealt with the important question of identifying the most pertinent gait variables for the discrimination. The vast quantity of data generated in 3DGA remains an obstacle to its use in the clinical as well as research setting. What measures could be used to select the most pertinent variables? One way to do this would be to rank the individual kinematic angles in the order of their capacities to discriminate patients and controls. The previously cited gait studies did not take this step. By using the SVM to do this, we provide two important points of departure from previous methods of analyzing data from 3DGA. 1) Rather than hand picking a few variables that we consider to be important, we analyze the entire dataset to objectively uncover the important discriminatory variables. This takes into account the fact that even disorders at isolated points in the lower limbs are likely to have ramifications for all the interconnected body segments involved in gait. It cannot at all be ruled out that greater discriminatory differences may in fact lie at points distal to the original dysfunctional joint. 2) Since the SVM is able to carry out a trial by trial analysis of the data, we are able to take into account the high variability of patient gait rather than compute averages that may not convey accurate information.

The final step taken was to ask how the parameters from gait analysis compared with the WOMAC index. Since this is the gold standard for hip OA patient questionnaires [1,4], it is necessary when proposing any new tool, to relate it to the WOMAC index. It should be noted that the study does not seek to replace the WOMAC scores with the results from 3DGA but rather to probe the relationship between the variables from the two studies. Would 3DGA provide answers that just reflect what is already available from the patient questionnaires? Or would the 3DGA provide information that is supplementary to what is available in the WOMAC index and hence correlate imperfectly with the patient questionnaires?

2. Methods

The study was carried out by placing markers on the joints of subjects who walked in a straight line at normal speed. Twelve kinematic trajectories were computed for each subject. An SVM classification paradigm was then applied to the kinematic trajectories in order to 1) find out if sufficient information was available in the kinematic data to discriminate patients and subjects 2) rank the discriminatory capacities of the individual kinematic angles to carry out the discrimination.

Table 1
Characteristics of subjects included in the study.

	Patients	Controls
N	20	20
Age	63.82 ± 6.55	62.23 ± 6.24
BMI	26.02 ± 4.35	24.07 ± 4.03
WOMAC pain	60.81 ± 21.04	NA
WOMAC stiffness	53.75 ± 25.03	NA
WOMAC function	55.05 ± 21.59	NA

2.1. Subjects

Patient and control characteristics are displayed in Table 1. Patients with hip OA were diagnosed by an experienced rheumatologist (PO). Patients aged 40–80, with unilateral symptomatic hip OA, defined using the American College of Rheumatology criteria [18] were included. Other inclusion criteria were Kellgren and Lawrence stages II, III, or IV on the X-ray and no indications of surgical procedure as defined by an experienced rheumatologist. All patients were in the mild to moderate stage of hip OA: 70% of the subjects were at stage 2 of the Kellgren and Lawrence scores while 30% were in stage 3. Control participants were subjects aged 40–80 without symptomatic joint rheumatism. Exclusion criteria for all participants were secondary hip OA, inflammatory hip OA, significant painful ankle, knee or foot disorders, chronic back pain, Alzheimer's disease, Parkinson's disease, motoneuronal disorders, non-stabilized diabetes mellitus, cardiac or respiratory insufficiency and inability to understand the procedure. The rheumatologist also evaluated the WOMAC scores for each patient. Each subsection of the WOMAC scores had a range from 0 to 100.

The study protocol was approved by the local ethics committee (CPP Est I, Dijon, France). It was conducted in compliance with the principles of Good Clinical Practise and the Declaration of Helsinki. All patients signed an informed consent form.

2.1.1. Procedure

Gait analyses were carried out by a single experienced investigator (DL), blinded to previous measurements. Body kinematics were recorded during barefoot walking along a 4-m-long straight pathway indicated by a path drawn on the floor. The participants were given the instruction (given orally by the examiner at the beginning of each session) to walk at the most comfortable speed ("as if you were in the street"). They performed 10 trials, and were then asked if they had experienced any difficulties during the test.

2.2. Three dimensional gait analysis

For the gait analysis, the body was represented as an interconnected chain of rigid segments, and kinematics were recorded at a rate of 120 Hz using a 3-dimensional computerized movement analysis device (Smart, e-Motion, Italy). The device was made up of eight video-based cameras with infrared strobes. Retro-reflective markers were always attached to the skin over the following body landmarks (Fig. 1): acromion, anterior superior iliac spines, posterior superior iliac spines, femur, lateral epicondyles, tibia, lateral malleoli, distal head of the second metatarsals, heels. In order to minimize the risk of cross-talk, each participant performed an initial trial to check the position of the thigh markers. Blankevoort et al. [19] and Lafortune et al. [20] have shown that the ab/adductor motion of