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# Detecting knee osteoarthritis and its discriminating parameters using random forests

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ABSTRACT

This paper tackles the problem of automatic detection of knee osteoarthritis. A computer system is built that takes as input the body kinetics and produces as output not only an estimation of presence of the knee osteoarthritis, as previously done in the literature, but also the most discriminating parameters along with a set of rules on how this decision was reached. This fills the gap of interpretability between the medical and the engineering approaches. We collected locomotion data from 47 subjects with knee osteoarthritis and 47 healthy subjects. Osteoarthritis subjects were recruited from hospital clinics and GP surgeries, and age and sex matched healthy subjects from the local community. Subjects walked on a walkway equipped with two force plates with piezoelectric 3-component force sensors. Parameters of the vertical, anterior–posterior, and medio-lateral ground reaction forces, such as mean value, push-off time, and slope, were extracted. Then random forest regressors map those parameters via rule induction to the degree of knee osteoarthritis. To boost generalisation ability, a subject-independent protocol is employed. The 5-fold cross-validated accuracy is 72.61% ± 4.24%. We show that with 3 steps or less a reliable clinical measure can be extracted in a rule-based approach when the dataset is analysed appropriately.



## 1. Introduction

Osteoarthritis (OA) rates are rising, in part a reflection of our growing ageing population. Currently OA is the second leading cause of disability [1], and one of the most common forms of arthritis worldwide, accounting for 83% of the total OA burden [2]. The global prevalence of knee OA is over 250 million people [2], according to Vos et al. Currently diagnosis of OA is based upon patient-reported symptoms and X-rays. The alternative is MRI but this is associated with high cost and is rarely used until symptoms progress and patients are referred for specialist surgical opinion. Thus effective management and early identification of knee OA is a key health issue and is of interest to the population at large as well as a range of clinicians and health service managers. The method presented here represents an effective solution with significantly lower costs compared to MRIs and ultimately aims to be used as a part of standard clinical assessment for the general population, in contrary to imaging that requires severe symptoms to be present. For all the aforementioned reasons, our vision and our long-term motivation is to develop a diagnostic tool for automatic detection of early markers of knee OA that does not act as a black box for the clinical personnel, as is the common case today.

In this paper, we propose a computer system that uses computational methods from the area of machine learning to estimate the degree of knee OA. This approach overcomes limitations of previous methods, such as Astephen et al. [4], Federolf et al. [6], Beynon et al. [8], Deluzio and Astephen [9], and Mezghani et al. [11], in the sense that it (i) automatically estimates the degree of knee OA by recognising patterns that are more discriminating of knee OA; (ii) discriminates the most important parameters for reaching its decision; and (iii) produces a set of rules that have a clear clinical rationale. Machine learning concerns the construction of computer systems that are able to learn from data. Such approaches have recently been adopted by the biomechanical field

*Abbreviations:* Osteoarthritis, OA; Ground reaction forces, GRFs.

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**Table 1**
Mean value and standard deviation about the age, height, weight, and sex of the control and the knee OA subjects.

| | Controls (47 subjects) | Knee OA (47 subjects) |
|---|---|---|
| Age (years) | 54.4 (13.3) | 58.1 (12.7) |
| Height (mm) | 1705.7 (88.9) | 1695.8 (113.2) |
| Weight (kg) | 69.4 (10.6) | 76.2 (14.4) |
| Male/Female | 22/25 | 22/25 |

with great effect. The common trend in biomechanics research is to consider individual parameters such as flexion moment peak value, or rotation moment, as done by Kaufman et al. [3] and then statistically test if there are significant differences in each parameter between the patients and normal subjects. However, machine learning looks at the complexity of the data as a whole [4], overcoming limitations that arise from hypothesis testing using individual parameters, thereby losing the richness and complexity of the data. For example, machine learning can be used to interpret electromyographic, kinematic and kinetic data from the knee, hip and ankle joints during gait and has been shown to be able to separate healthy patients, mild, and severe knee OA according to Haber et al. [5]. Federolf et al. [6] identified systematic differences between healthy and medial knee-osteoarthritic gait using principal component analysis. In this study we analyse parameters of ground reaction forces (GRFs) to estimate using an objective scale the degree of knee OA and to extract parameters that differentiate more effectively between normal and knee OA subjects. To the best of the authors' knowledge, this is the first study on detecting knee OA via analysing the GRFs using random forests. We believe that a purely data-driven approach yields objective measures and patterns useful for both biological and clinical advancement as suggested by Faisal et al. [7]. Emphasis is given on detecting parameters with physical meaning and in inducting rules that remain fully interpretable even to non-data analysis experts. The guidance rules may be adopted in a routine clinical visit to provide support to healthcare professionals during decision-making. Our final aim is to derive a software tool that can be used either to assist the physician when diagnosing new patients or to train students to diagnose patients.

Previous biomedical studies by Beynon et al. [8], Deluzio and Astephen [9], Moustakidis et al. [10], and Mezghani et al. [11] have discriminated between subjects with knee OA versus normal subjects, as detailed below. For example Beynon et al. [8] explored the use of sagittal/frontal/transverse plane range of motion and the peak vertical ground reaction force during the stance phase of gait and cadence. They were able to discriminate knee OA subjects (total 30 subjects, 15 with knee OA, 6 gait cycles per subject) using the Dempster-Shafer theory of evidence. Depending on whether the proposed method's heuristic values are computed by descriptive statistics or provided by an expert, the system had a performance of 90% or 96.7% respectively. In another study by Deluzio and Astephen [9] 50 patients with end-state knee OA and 63 control subjects performed five walking trials. Knee flexion angle, flexion moment, and adduction moment were classified using linear discriminant analysis after principal component analysis, achieving a 93% correct classification. More recently, GRFs have been studied. Wavelet analysis by Moustakidis et al. [10] has shown that a reduction in peak anterior–posterior ground reaction forces during the stance phase occurs in knee OA subjects (12 healthy, 24 with knee OA). They were grouped in no, moderate, and severe OA categories with a 93.4% performance. A second study by Mezghani et al. [11] calculated the coefficients of a polynomial expansion and the coefficients of wavelet decomposition for 16 healthy and 26 tibiofemoral knee OA subjects. A nearest neighbour classifier achieved accuracies ranging from 67% to 91%, depending on the set of parameters.

The main objective of this work is to give emphasis to clinicians' rationale. That is the reason why we refrain from abstract mathematical approaches such as wavelet packet decomposition as done by Moustakidis et al. [10], as they lack a direct physical interpretation. Moreover, we consider all the trials provided by each subject, rather than averaging across trials in order to calculate the mean GRFs, as is the case of Mezghani et al. [11]. Averaging disregards the intra-subject variability. While previous work focussed on predicting discrete outcomes, our approach provides a continuous number between 0 and 2, since we felt that clinicians would value a continuous output, rather than a yes/no answer, whilst at the same time reflecting the progressive degenerative nature of osteoarthritis. Very few previous studies provide an alternative to discrete predictions. Beynon et al. [8] provided a level of belief that a subject has knee OA or is normal and the associated level of uncertainty. Finally, our approach does not adopt any ad hoc heuristics, like the one proposed by Beynon et al. [8].

It is worth mentioning that the focus of machine learning does not have to be knee OA prediction. For example, the authors Favre et al. [12] applied neural networks to predict knee adduction moment during walking based on ground reaction force and anthropometric measurements, whereas Begg and Kamruzzaman [13] applied support vector machines to discriminate young from elderly subjects exploiting kinetic and kinematic parameters, and Muniz et al. [14] evaluated Parkinson disease exploiting GRFs. Accordingly, the proposed system here is tackling the problem of estimating the presence of knee OA via a rule based approach that concurrently estimates the most discriminating features of the pathology. However, it could also be utilised to analyse additional musculoskeletal diseases, like back pain, given the respective kinetic parameters for its re-training.

## 2. Materials and methods

In this study, subjects diagnosed with OA were recruited, along with gender and age matched control subjects. We collected locomotion data from 47 subjects with knee osteoarthritis and 47 healthy subjects. The mean value and the standard deviation between normal and knee OA subjects of the age, height, weight, and sex for the 47 controls and the 47 knee OA subjects are depicted in Table 1. Ethical approval for this study was obtained from the South West London Research Ethics Committee and written in-

**Table 2**
Basic statistics and signal processing features that are computed for all three axes. Additionally, axis-specific parameters are computed.

| GRZ-Z GRF-X GRF-Y |
|---|
| Maximum, mean, median, and standard deviation and the differences between the aforementioned values for the both legs. |
| Skewness, kurtosis, interquartile range, 75th percentile, and 90th percentile. |
| Energy and the power spectral density of each leg. |
| The length of the stance phase, along with the Spearman correlation between the two legs. |