Osteoarthritis and Cartilage 22 (2014) 457–463

Osteoarthritis and Cartilage

Novel classification of knee osteoarthritis severity based on spatiotemporal gait analysis

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ARTICLE INFO

Article history:
Received 24 July 2013
Accepted 21 December 2013

Keywords:
Knee osteoarthritis
Gait
Disease severity classification

SUMMARY

Objective: To describe a novel classification method for knee osteoarthritis (OA) based on spatiotemporal gait analysis.
Methods: Gait analysis was initially performed on 2911 knee OA patients. Females and males were analyzed separately because of the influence of body height on spatiotemporal parameters. The analysis included the three stages of clustering, classification and clinical validation. Clustering of gait analysis to four groups was applied using the kmeans method. Two-thirds of the patients were used to create a simplified classification tree algorithm, and the model's accuracy was validated by the remaining one-third. Clinical validation of the classification method was done by the short form 36 Health Survey (SF-36) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaires.
Results: The clustering algorithm divided the data into four groups according to severity of gait difficulties. The classification tree algorithm used stride length and cadence as predicting variables for classification. The correct classification accuracy was 89.5%, and 90.8% for females and males, respectively. Clinical data and number of total joint replacements correlated well with severity group assignment. For example, the percentages of total knee replacement (TKR) within 1 year after gait analysis for females were 1.4%, 2.8%, 4.1% and 8.2% for knee OA gait grades 1–4, respectively. Radiographic grading by Kellgren and Lawrence was found to be associated with the gait analysis grading system.
Conclusions: Spatiotemporal gait analysis objectively classifies patients with knee OA according to disease severity. That method correlates with radiographic evaluation, the level of pain, function, number of TKR.
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Introduction

Knee osteoarthritis (OA) is the most common joint disease, with an estimated prevalence of 30% in individuals over 60 years of age[1]. Due to the effect of a continually graying population, it is expected that nearly one-half of the US adult population will develop symptomatic knee OA by the age of 85 years[2]. Populations in both developed and undeveloped countries share the effects of aging, making the problem a global one.

The diagnosis of knee OA and subsequent treatment decision-making are currently based on the clinical presentation together with the findings on standard knee radiography[3–6]. The American Society of Rheumatology has established diagnostic criteria based on those findings[7]. They report that the sum of the sensitivity (91%) and specificity (86%) is highest when using combined clinical and radiological criteria. The classification criteria and arthroscopically defined cartilage damage were also found to be correlated[8]. A grading system for knee OA based solely on radiography has also been suggested in order to determine the relative severity of the condition[6].

Gait analysis has become an important methodology in the study of knee OA[9–16]. Several studies have characterized the differences in gait patterns between patients with knee OA compared to healthy subjects, including differences in spatiotemporal parameters (specifically, slower walking velocity, shortened step length and lower cadence) and in kinetics and kinematics

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http://dx.doi.org/10.1016/j.joca.2013.12.015

variables[9,11,17]. The use of gait analysis for characterizing disease severity has recently evolved. Gait parameters enable an objective measure that reflects the functional capabilities of the patient regardless of physical/imaging findings, unlike static evaluations of the knee joint. In 2006 Thorp *et al.* concluded that the differences between mild and moderate symptomatic radiographic knee OA are not only structural but also functional, based on the magnitude of load in the medial knee joint expressed as knee adduction moment[18]. Other studies report different gait parameters that correlate with OA severity including knee kinetics and kinematics[19–22]. A recent review and meta-analysis by Mills *et al.*, found that spatiotemporal parameters are good indicators for knee OA severity[23]. Debi *et al.*[24] and Elbaz *et al.*[25] attempted to classify knee OA functional severity according to a simple spatiotemporal gait evaluation. More specifically, they evaluated the percentage of single limb support (SLS) from the gait cycle (GC). Their studies were the first to classify the functional severity of knee OA according to spatiotemporal gait parameters. However, those studies were carried out on a relatively small sample size (about 120 each), they focused on a single spatiotemporal gait measurement and classification was arbitrarily based on quintiles[25].

One aim of this paper is to present a novel classification system for knee OA based on spatiotemporal gait analysis parameters that is more objective and more accurate than previous classifications (questionnaire or radiographic based) in order to better serve as a standard for OA classification and clinical decision-making. Another aim is to compare the new classification to (1) the information derived from two standardized clinical questionnaires (2) the number of total knee replacements (TKRs) and (3) radiologic knee OA classification by Kellgren and Lawrence.

Materials and methods

The protocol was approved by the Institutional Helsinki Committee Registry (Helsinki registration number 141/08, NIH protocol no. NCT00767780). A retrospective analysis of AposTherapy (blinded) dataset was performed. The initial study population included 3136 patients who were diagnosed with knee OA according to the American College of Rheumatology (ACR) criteria[7] by their treating physician and were referred to a single therapy center due to knee OA: 2433 (77.5%) had bilateral OA, 299 (9.5%) had left knee OA and 404 (13.0%) had right knee OA. Two-hundred and twenty-five patients (7.1%) were excluded due to previous knee replacement, meniscectomy or some other diagnosis (e.g., fibromyalgia, lupus, etc.), leaving an overall total of 2911 patients in this analysis. Data were retrieved on their general characteristics, such as gender, body mass index (BMI) and age. Patients' radiographic imaging was scored based on the Kellgren and Lawrence grading classification[6]. In addition, each patient had undergone a computerized gait analysis to evaluate spatiotemporal parameters and completed two clinical questionnaires to evaluate their quality of life and subjective levels of pain, stiffness and function.

Gait analysis

Measurements of spatiotemporal gait parameters were performed by a computerized walking mat (GaitMatTMII system, E.Q., Inc. Chalfont, PA, USA)[26]. Patients were asked to walk four times on the mat from one end to the other at a self-selected speed. The mean value of the four walks was calculated for each of the following parameters: velocity (cm/s), cadence (steps/min), step and stride lengths (cm), base of support (BOS) (cm) and step time (s). In addition, all GC phases were measured as absolute values and as % GC: swing time, stance time, SLS time, and double limb support (DLS) time. All parameters were measured separately for each leg. In the parameters for which both legs were measured separately, the measurements that reflected lower performances were chosen. For example, the minimum value of SLS of either the right or left leg was selected for analysis.

Self-assessment questionnaires

We used two questionnaires that are commonly used in the assessment of pain, function (Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)) and quality of life (short form 36 Health Survey (SF-36)) of patients with knee OA[27–30]. Responses to the WOMAC questionnaire are by a visual analogue scale (VAS) ranging from 0 to 100 mm, with 0 mm indicating no pain or no limitation in function and 100 mm indicating the most severe pain or the greatest limitation in function. The SF-36 is scored between 0 and 100, with 0 indicating the worst quality of life and 100 indicating the best quality of life.

Statistical methods

Data analysis was performed by an experienced Biostatistician (AH) using the software R© 2.11.1 (Vienna, Austria). Categorical variables are presented as count (percent). Continuous variables are presented as mean (standard deviation (SD)). Data analysis was performed separately for males and females[10,31]. The data analysis included three steps: clustering, classification and clinical validation of the classification model.

Clustering was performed by the 'kmeans' method using the following gait measurements as the clustering parameters: stride length, cadence, BOS, stance (% GC), and SLS (% GC). Clustering to three, four and five groups were tried. In this method, random group centers are chosen and each data point is attributed to each group center according to its distance from each center. New group centers are calculated based on this attribution. These two steps are repeated several times until convergence is achieved. This procedure produces several groups based on the clustering of the data.

Classification was done by means of classification and regression tree (CART) model, using the Tree library in R. Each dataset according to gender was randomly divided to train-set and test-set with the ratio of 2:1. The train-set was used to construct a classification tree with all the aforementioned parameters contained in the clustering model. The tree model automatically chose the parameter and cutoff point which best divided the data and decreased classification errors. The test-set was then used to examine correct classification rates.

Clinical validation was done by analyzing the clinical questionnaires according to classification group. Lower functional levels and higher pain and TKR rates were expected for higher knee OA functional severity grades. Comparisons of categorical variables between groups were done by the chi-square test. Comparisons of continuous variables were done by the Kruskal–Wallis rank test for several groups.

Kellgren and Lawrence classification of radiographs was used to evaluate the patients' radiographic characteristics of the knee OA[6]. Whenever classification was available for both knees the severe score was used. The distribution of radiographic grading was compared between gait analysis grading groups. The cumulative probability functions were compared between groups to establish stochastic orders between gait analysis grading groups. The chi-bar test for stochastic order was used to test for stochastic orders. Stochastic orders mean that a patient with a poorer gait pattern has a higher probability to have a worse radiographic grade than a patient with better gait pattern.

A P value <0.05 was considered to be statistically significant. All reported P values are two-sided.

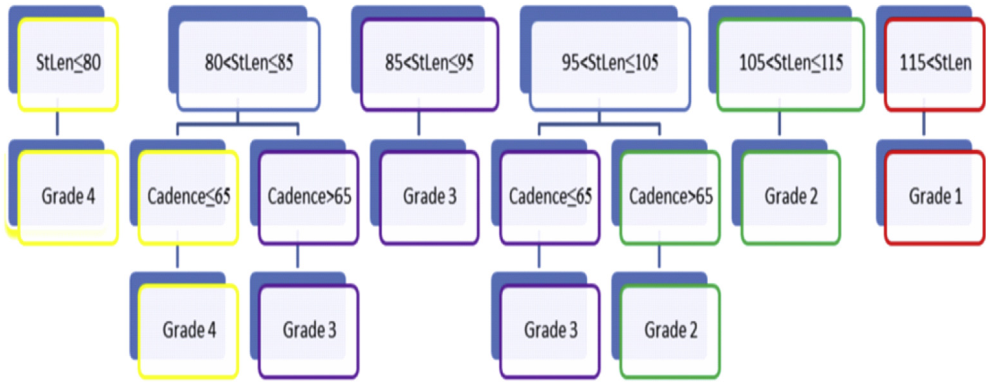

Fig. 1. Classification tree for knee OA functional severity grade by spatiotemporal gait parameters – females. The level of accuracy in model classification is 89.5%. Cadence is measured in steps/min. StLen = minimum (left or right) stride length (cm).

Results

A cohort of 2911 patients with knee OA were analyzed, including 1210 males (41.5%) and 1701 females (58.5%) whose mean age was 70.0 (SD 21.8) and 60.5 (SD 16.5) years, respectively. The classification trees according to gender (Figs. 1 and 2) demonstrated that stride length was the primary parameter separating knee OA groups and that cadence represented a secondary parameter for fine tuning between grades. Importantly, the classification trees of males and females were highly similar. The accuracy of the classification rates was 90.8% (95% CI 87.5–94.1%) for males and 89.5% (95% CI 86.8–92.1%) for females. All misclassifications were off by a margin of error of 1, e.g., grade1 might have been classified as grade 2, but never as grade 3 or 4.

Clinical and gait parameters according to knee OA functional severity grades are presented for males in Table I and for females in Table II. The WOMAC score for the combined genders was higher as the knee OA functional severity grade increased ($P = 0.0001$). Analysis of the SF-36 questionnaire by its eight domains is presented for males and females in Figs. 3 and 4, respectively. Similar to the WOMAC score, the overall SF-36 score decreased as the knee OA functional grade increased ($P = 0.0001$).

We also analyzed the rates of TKRs among the four functional severity grades spanning a period of 30 months from baseline assessment with the purpose of examining whether there was any correlation between them. It emerged that higher functional grades of knee OA were associated with higher rates of TKR ($P = 0.0095$). The specific rates of TKR were 1.4% (95% CI = 0–2.9%), 2.8% (1.4–4.1%), 4.1% (1.8–6.3%) and 8.2% (3.5–12.8%) for knee OA functional severity grades 1–4, respectively, among the females, while they were 1.1% (95% CI = 0–2.3%), 2.2% (0.8–3.5%), 2.8% (0.9–4.6%) and 4.9% (1.7–8.0%) for knee OA functional severity grades 1–4, respectively, among the males.

Radiographic classification by Kellgren and Lawrence was available for 733 (25.18%) patients, of which 488 (61.11%) were females and 285 (38.89%) were males. Kellgren and Lawrence classification distribution was 120 (16.4%), 224 (30.6%), 234 (31.9%) and 155 (21.1%) for OA functional severity grades 1–4, respectively. The distribution of radiographic grades by OA functional severity grades is presented in Table III. Stochastic orders were found in the distribution of radiographic grades between OA functional severity grading groups (chi-bar square test, P-value < 0.0001, Fig. 5). This means that higher functional severity OA grade is associated in probability with higher OA radiographic grade.

Discussion

We describe a novel classification and grading system for knee OA based on a functional computerized gait test evaluation of spatiotemporal parameters. We describe the connection between

Fig. 2. Classification tree for knee OA functional severity grade by spatiotemporal gait parameters – males. The level of accuracy in model classification is 90.8%. Cadence is measured in steps/min. StLen = minimum (left or right) stride length (cm).

Table I
Demographic, WOMAC, SF-36 and gait parameter distribution by knee OA functional severity grade – females*

	Grade 1 No. = 287 (16.8%)	Grade 2 No. = 727 (42.7%)	Grade 3 No. = 451 (26.5%)	Grade 4 No. = 236 (13.8%)	*P* value
Age (*yr*)	55.6 ± 14.5	58.5 ± 16.8	62.7 ± 16.1	68.0 ± 15.1	0.0001
BMI	27.6 ± 4.7	30.1 ± 5.6	32.6 ± 6.4	32.9 ± 6.2	0.0001
Height (cm)	164.4 ± 5.7	160.1 ± 6.2	158.4 ± 6.6	155.4 ± 6.2	0.0001
TKR/available data (%)	3/208 (1.4)	15/535 (2.8)	13/312 (4.1)	11/133 (8.2)	0.0095
Time to TKR (months)	11.7 ± 0.3	13.6 ± 6.5	13.9 ± 7.0	9.1 ± 5.4	0.2404
WOMAC-pain	36.9 ± 22.2	45.2 ± 22.6	55.8 ± 22.4	59.2 ± 19.1	0.0001
WOMAC-function	29.9 ± 21.5	42.1 ± 22.9	55.3 ± 22.4	62.0 ± 18.8	0.0001
WOMAC-stiffness	36.6 ± 27.9	47.6 ± 28.6	56.9 ± 29.0	61.8 ± 26.7	0.0001
WOMAC-overall	31.9 ± 20.6	43.2 ± 21.9	55.5 ± 21.5	61.3 ± 18.1	0.0001
SF-36 physical score	52.2 ± 16.4	46.5 ± 16.7	38.7 ± 16.3	32.3 ± 14.9	0.0001
SF-36 mental score	65.5 ± 17.9	59.9 ± 18.4	51.8 ± 18.7	45.4 ± 19.4	0.0001
Velocity (*cm/s*)	112.6 ± 12.3	93.7 ± 8.6	74.8 ± 7.4	54.8 ± 10.7	0.0001
Step length (*cm*)	60.7 ± 3.2	52.0 ± 2.8	45.3 ± 3.0	35.6 ± 5.2	0.0001
Cadence (*step/min*)	73.2 ± 6.1	70.8 ± 5.2	64.7 ± 6.3	59.0 ± 7.5	0.0001
Stride length (*cm*)	122.6 ± 6.2	105.7 ± 5.4	92.5 ± 5.7	73.6 ± 9.1	0.0001
BOS (*cm*)	5.1 ± 2.6	6.3 ± 2.8	7.5 ± 3.0	9.4 ± 3.2	0.0001
Step time (*s*)	0.54 ± 0.04	0.56 ± 0.04	0.61 ± 0.06	0.66 ± 0.09	0.0001
Swing time (*% GC*)	39.7 ± 1.5	38.4 ± 1.7	36.8 ± 1.9	35.4 ± 3.7	0.0001
Stance time (*% GC*)	61.4 ± 1.7	62.8 ± 1.7	65.1 ± 2.2	68.4 ± 4.1	0.0001
SLS (*% GC*)	38.7 ± 1.7	37.2 ± 1.7	35.0 ± 2.1	31.8 ± 3.7	0.0001
DLS (*% GC*)	21.6 ± 3.12	24.4 ± 3.1	28.2 ± 3.6	33.1 ± 6.5	0.0001

The values are given as mean and the standard deviation. *P* values represent comparisons between the four OA gait grades.
* BMI = body mass index; TKR = total knee replacement; SF-36 = short form 36 Health Survey; BOS = base of support; SLS = single limb support; DLS = double limb support; GC = gait cycle.

Table II
Demographic, WOMAC, SF-36 and gait parameters distribution by knee OA functional severity grade – males*

	Grade 1 No. = 286 (23.6%)	Grade 2 No. = 431 (35.6%)	Grade 3 No. = 307 (25.3%)	Grade 4 No. = 186 (15.3%)	*P* value
Age (*yr*)	52.8 ± 18.6	56.9 ± 20.2	58.8 ± 23.4	60.2 ± 26.3	0.0001
BMI	30.9 ± 24.2	31.6 ± 19.6	30.6 ± 5.3	32.3 ± 7.2	0.0001
Height (cm)	176.1 ± 7.1	172.5 ± 7.8	170.0 ± 6.8	166.2 ± 9.3	0.0001
TKR/available data (*%*)	2/179 (1.1)	6/276 (2.2)	6/215 (2.8)	6/122 (4.9)	0.0402
Time to TKR (*mo*)	12.4 ± 11.8	14.8 ± 7.8	9.7 ± 6.18	11.0 ± 6.6	0.762
WOMAC-pain	29.4 ± 20.8	35.1 ± 20.3	44.8 ± 22.9	51.0 ± 24.7	0.0001
WOMAC-function	24.6 ± 20.9	32.2 ± 21.3	41.1 ± 24.3	52.2 ± 24.8	0.0001
WOMAC-stiffness	29.2 ± 26.0	34.1 ± 26.9	45.7 ± 29.4	29.6 ± 31.0	0.0001
WOMAC-overall	25.9 ± 20.3	32.9 ± 20.3	42.2 ± 23.2	51.7 ± 23.8	0.0001
SF-36 physical health	57.9 ± 16.6	53.8 ± 17.0	48.3 ± 17.7	41.2 ± 16.6	0.0001
SF-36 mental health	69.2 ± 16.3	65.5 ± 17.2	60.5 ± 19.1	54.3 ± 19.7	0.0001
Velocity (*cm/s*)	120.7 ± 12.7	101.7 ± 8.6	84.6 ± 7.4	64.9 ± 11.1	0.0001
Cadence (*step/min*)	71.7 ± 5.5	69.9 ± 5.4	66.5 ± 5.9	61.7 ± 7.2	0.0001
Step length (*cm*)	66.2 ± 3.9	57.0 ± 2.7	49.5 ± 2.6	40.4 ± 5.1	0.0001
Stride length (*cm*)	134.2 ± 7.9	116.1 ± 5.0	101.6 ± 4.5	83.7 ± 9.7	0.0001
BOS (*cm*)	6.3 ± 2.7	6.9 ± 2.7	7.6 ± 2.6	8.6 ± 3.4	0.0001
Step time (*s*)	0.55 ± 0.04	0.56 ± 0.04	0.59 ± 0.05	0.64 ± 0.08	0.0001
Swing (*% GC*)	39.6 ± 1.4	38.9 ± 1.6	38.2 ± 1.8	36.8 ± 2.6	0.0001
Stance (*% GC*)	61.6 ± 2.3	62.4 ± 1.6	63.6 ± 1.7	66.2 ± 2.9	0.0001
SLS (*% GC*)	38.4 ± 2.3	37.5 ± 2.4	36.4 ± 1.7	33.9 ± 2.7	0.0001
DLS (*% GC*)	22.0 ± 3.2	23.6 ± 3.6	25.4 ± 3.1	29.4 ± 4.7	0.0001

The values are given as mean and the standard deviation. *P* values represent comparisons between the four OA gait grades.
* BMI = body mass index; TKR = total knee replacement; SF-36 = short form 36 Health Survey; BOS = base of support; SLS = single limb support; DLS = double limb support; GC = gait cycle.

the proposed functional classification, clinical subjective questionnaires and radiographic grading of knee OA. We find that the three are directly related, i.e., higher OA functional severity grade is associated with higher radiographic grade and higher reported disability. Currently, knee OA severity is evaluated via radiographic grading and self-assessment questionnaire. These methods are limited as radiographic grading has poor inter and intra reliability and also poor correlation with the patients symptoms, whereas the questionnaires lack objectivity. This work however uses objective, computerized measures to evaluate functional severity. We believe that the simplicity of the classification enables the adoption of spatiotemporal gait analysis as a part of the in-office clinical examination of patients with knee OA to evaluate their functional severity status.

Knee OA severity is currently classified according to radiographic imaging assessment of the knee joint together with clinical assessment of the patient's complaints of knee joint pain[7]. To date, there is no assessment of functional status to complete the medical assessment of a patient with knee OA. Patient testimony is subjective and may be held up to suspicion, but, at the same time, what may appear radiologically and clinically as an OA knee grade 1 may actually cause considerable pain and greater than predicted functional restriction. It had been recently suggested that applying easy to measure objective spatiotemporal gait parameters may help to determine the functional condition of the patient[24,25]. Interestingly, a recent review and meta-analysis by Mills *et al.* concluded that spatiotemporal parameters, specifically stride duration and cadence, better reflect knee OA severity than kinematic and kinetic measures[23]. However, to the best of our knowledge, there is only one publication in which the researchers suggested the need for a functional classification of knee OA severity, which is based on spatiotemporal measures[25]. A previous report measured one gait

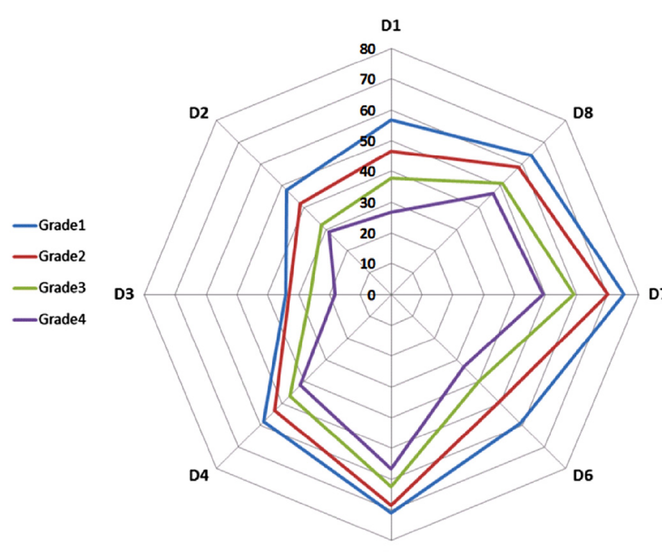

Fig. 3. Domains of the short form short form 36 Health Survey (SF-36) according to knee OA functional severity grade – females. The *P* value for all domains is <0.0001. Domains: D1 = physical function; D2 = pain; D3 = role limitation due to physical health; D4 = energy; D5 = emotional well-being; D6 = role limitation due to mental health; D7 = social function; D8 = general health.

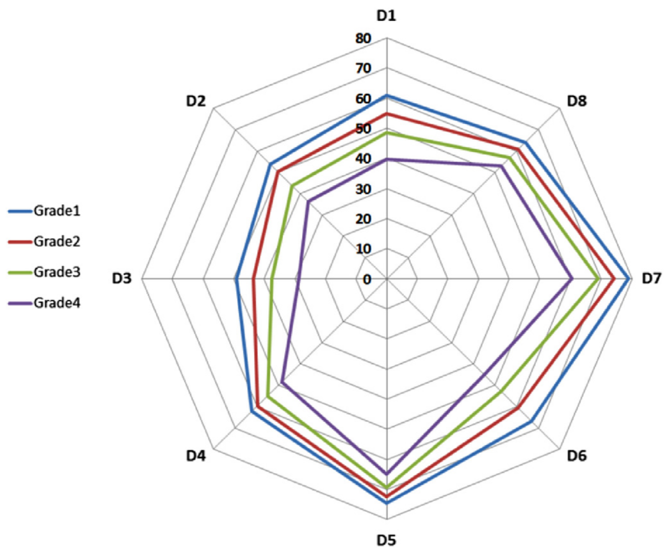

Fig. 4. Domains of the short form 36 Health Survey (SF-36) according to knee OA functional severity grade – males. The *P* value for all domains is <0.0001. Domains: D1 = physical function; D2 = pain; D3 = role limitation due to physical health; D4 = energy; D5 = emotional well-being; D6 = role limitation due to mental health; D7 = social function; D8 = general health.

Table III
Knee OA functional severity grade by Kellgren & Lawrence radiographic grade

	Gait grade 1	Gait grade 2	Gait grade 3	Gait grade 4	Total
X-ray grade 1	26 (3.5%)	54 (7.4%)	31 (4.2%)	9 (1.2%)	120 (16.4%)
X-ray grade 2	35 (4.8%)	101 (13.8%)	58 (7.9%)	30 (4.1%)	224 (30.6%)
X-ray grade 3	31 (4.2%)	96 (13.1%)	73 (10.0%)	34 (4.6%)	234 (31.9%)
X-ray grade 4	13 (1.8%)	44 (6.0%)	58 (7.9%)	40 (5.5%)	155 (21.1%)
Total	105 (14.3%)	295 (40.2%)	220 (30.0%)	113 (15.4%)	733 (100.0%)

parameter (SLS) to classify knee OA functional severity while using arbitrary divisions according to quintiles[25]. According to that classification, a low value of SLS would be associated with poorer function and increased pain, and, as the value of SLS increases, the level of pain and extent of functional limitation will decrease. The current work differs from previous works as it has better statistical methodology and a larger sample size, making it more sound and valid. The classification model proposed in the current study uses two additional spatiotemporal parameters, i.e., stride length and cadence, to classify knee OA functional severity, as well as a different statistical methodology. According to our model, a shorter stride length with lower cadence is indicative of a higher functional severity grade disease (more severe knee OA), while a longer stride length with higher cadence is indicative of a lower functional severity grade of disease (less severe knee OA). The results of our current study showed that clinical parameters of pain, function and quality of life as well as the rates of TKR were all correlated with the functional severity grade of knee OA. Specifically, a more severe grade correlated with more deteriorated parameters and a higher rate of TKR surgery. This model had a high rate of accuracy, i.e., 90.8% for males and 89.5% for females, and misclassifications were off by a margin of error of only 1.

An interesting finding is the symmetry between the classification trees. The cadence cutoff point value used is the same throughout each grade. Furthermore, there is a similarity between the male and female representations: differences in stride length values range between 5 and 10 cm and cadence increases by 5 steps/min, probably due to height differences.

Another important finding is the relations between the Kellgren and Lawrence radiographic classification and the proposed gait analysis classification. The radiographic grade is associated (in probability) to the gait analysis grading system. This means that higher radiographic grades have a higher probability for higher functional severity grade. The *vice versa* statement also holds – lower radiographic grade has higher probability for lower functional severity grade. This finding cannot be overemphasized, it offers a holistic view of the clinical presentation of knee OA including gait features, clinical subjective questionnaires and radiographic evaluation.

We are aware of several limitations to this study. First, all the patients were examined at a single referral therapy center, a feature that might have skewed the classification and clinical outcome towards worse results. Second, this work is based solely on spatiotemporal gait analysis. Although incorporating a three-

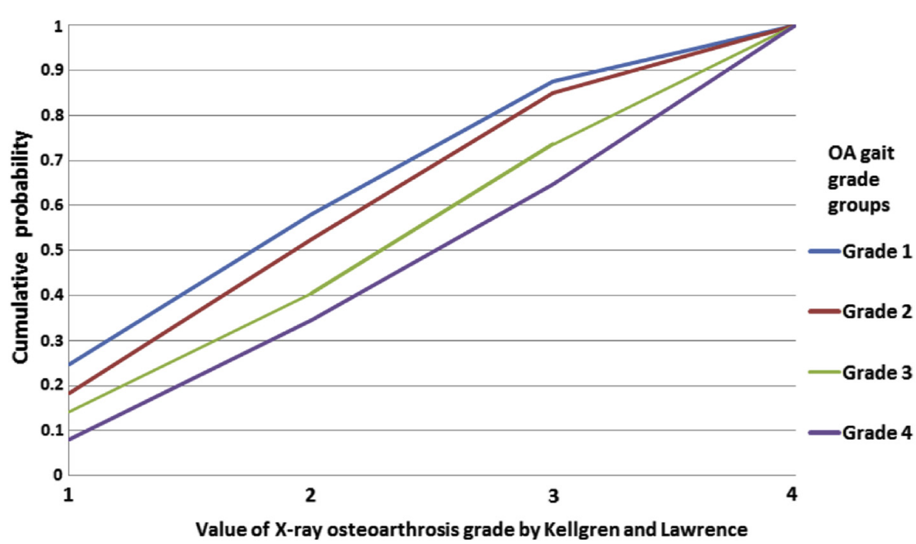

Fig. 5. Association between radiographic grade and knee OA functional severity grade. Fig. 5 shows that the OA functional severity grades have ordered cumulative probability functions. More specifically, this figure shows show that functional grade 1 has higher cumulative probability function (CPF) than grade 2 which have higher CPF than grade 3 which has higher CPF than grade 4. This means that they are ordered in probability which implies that higher (worse) OA functional grades have higher probability of having high (worse) radiographic grades and *vice versa*.

dimensional analysis might find stronger indicators for disease severity, the use of spatiotemporal parameter enables a low-cost, rapid and easy way to evaluate gait. Third, stride length was found to be an indicator of disease severity but it correlates with a patient's height. However, the classification used in the current study separates males and females (a primary cause for height difference) to eliminate height differences between genders.

Another limitation is the fact that other confounders, such as BMI and age were excluded from the classification. It can be seen that there were differences in the above mentioned parameters between the classification groups. The correlation between BMI, age and knee OA incidence and progression is well documented[32,33] and characterizes knee OA patients. It may be argued that the difference between groups in BMI reflects the fact that higher BMI led to a more severe knee OA functional severity grading. However, we did not consider these parameters as cofounders as we believe that they are part of the patient's profile, are reflected in his gait pattern and should not be disregarded.

Height was included as the denominator for using the variable normalized stride length in one of the models tried. However the classification algorithm preferred stride length as a differentiating variable over normalized stride length.

Conclusion

The simplicity of the classification described in the current study enables the adoption of spatiotemporal gait analysis as a part of the in-office clinical examination of patients with knee OA. It offers a user-friendly and completely objective way to evaluate and grade knee OA patients. Further studies are warranted to evaluate the clinical implications of this novel classification so that it will have future use for reporting results in knee OA treatment and clinical decision-making.

Author contributions

Avi Elbaz – Conception and design of the study, revising it critically for important intellectual content, final approval of the version to be submitted.

Amit Mor – Conception and design of the study, revising it critically for important intellectual content, final approval of the version to be submitted.

Ganit Sega – Conception and design of the study, analysis and interpretation of data, drafting the article, final approval of the version to be submitted.

Ronen Debi – Revising it critically for important intellectual content, final approval of the version to be submitted.

Nachshon Shazar – Revising it critically for important intellectual content, final approval of the version to be submitted.

Amir Herman – Conception and design of the study, analysis and interpretation of data, drafting the article, final approval of the version to be submitted.

Role of the funding source

This study was not funded.

Conflict of interest

None to declare.

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