Gait analysis as a quantifiable outcome measure in hip or knee osteoarthritis: A systematic review

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A systematic literature search was performed in PUBMED and the Cochrane database until January 2008 by selecting manuscripts assessing any psychometric property of gait analysis in knee or hip OA. Were assessed feasibility (cost, time and access); reliability; discriminant capacity by differences between OA and non-OA patients; construct validity by correlation between gait analysis and OA symptoms: pain or functional disability (Lequesne/WOMAC); and responsiveness of gait analysis after treatment of OA using effect size.

Results: Among the 252 articles identified, the final analysis included 30 reports (i.e., 781 knee OA patients and 343 hip OA patients). Gait analysis presents various feasibility issues and there was limited evidence regarding reliability (three studies, 67 patients). Discriminant capacity showed significant reduction of gait speed, stride length and knee flexion in OA patients compared to healthy subjects. Few data were available concerning construct validity (three studies, 79 patients). Responsiveness of gait speed was moderate to large with effect size ranging respectively from 0.33 to 0.89 for total knee replacement, and from 0.50 to 1.41 for total hip replacement.

Conclusion: Available data concerning validity and reliability of kinematic gait analysis are insufficient to date to consider kinematic parameters as valuable outcome measures in OA. Further studies evaluating a large number of patients are needed.

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ABSTRACT

Objectives: Kinematic gait analysis consisting of measuring gait parameters (stride length, gait speed, dynamic joint angles) is a potential outcome measure in osteoarthritis (OA). The aim of this study was to evaluate its psychometric properties.

Methods: A systematic literature search was performed in PUBMED and the Cochrane database until January 2008 by selecting manuscripts assessing any psychometric property of gait analysis in knee or hip OA. Were assessed feasibility (cost, time and access); reliability; discriminant capacity by differences between OA and non-OA patients; construct validity by correlation between gait analysis and OA symptoms: pain or functional disability (Lequesne/WOMAC); and responsiveness by improvement of gait analysis after treatment of OA using effect size.

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Osteoarthritis (OA) is a common, degenerative joint disease characterized by progressive destruction of cartilage that can affect several joints, especially weight-bearing joints such as the hip or the knee. The main clinical manifestations of hip or knee OA are pain and stiffness leading to reduced joint mobility and progressive gait dysfunction.

As the technology supporting the three dimensional (3D) analysis of human gait has advanced dramatically in the last decade, quantitative gait analysis by electromyographic, kinetic or kinematic data performed and properly interpreted by experienced searchers is now proposed as a clinically useful tool in musculoskeletal diseases [1,2]. Kinematic measurements such as gait speed, stride length or joint angles are obtained by sophisticated optoelectronic systems via infrared cameras linked to a computer, which define kinematic patterns during walking. These parameters appear interesting in OA to identify the mechanisms causing gait disturbance and to understand compensatory gait strategies. Moreover, assessment of the efficacy of OA treatments (e.g., analgesics, non steroidal anti-inflammatory drugs (NSAIDs), arthroplasty, hyaluronic acid injection) by kinematic parameters could be useful in clinical trials. At the individual level, clinical consequences could be that patients suffering from hip or knee OA could be referred to motion analysis laboratories to be appropriately evaluated. The majority of the validated instruments developed for patients with OA of the lower limbs are self-assessment questionnaires such as the Western Ontario and McMaster Universities Index (WOMAC) [3], or the Lequesne index [4] which evaluate functional impairment subjectively. The principal advantage of gait analysis is that...
this outcome measure is not dependent on patient report, contrary to the widely used questionnaires. Moreover, changes in gait variables may occur in many OA patients before the appearance of clinically functional disability [5]. Before proposing gait analysis as a potential quantifiable outcome measure in OA, it is necessary to validate its psychometric properties, as defined by the Outcome Measures in Rheumatology (OMERACT) filter [6]. Thus, this outcome measure must be (a) feasible, (b) truthful, i.e., reflect what it is supposed to reflect and (c) discriminant which includes reliability and sensitivity to change. Therefore, the aim of the present study was to evaluate the psychometric properties of kinematic gait analysis in knee and hip OA through a systematic literature search.

1. Methods

1.1. Literature search

1.1.1. Data selection process

A systematic literature search was performed using PUBMED (1966 through January 2008) and Cochrane (1988 through January 2008) electronic databases. Abstracts from the European League against Rheumatism & the American College of Rheumatology congresses (2004–2007) were also included in the analysis. Reference sections of the papers initially detected were further searched manually to identify additional relevant reports. Among the resulting abstracts, only articles dealing with primary hip or knee OA and reporting at least one of the OMERACT filter criteria for kinematic gait analysis were selected (feasibility, reliability, validity and responsiveness). The search was conducted using the following combination of keywords: (hip osteoarthritis [MeSH] OR knee osteoarthritis [MeSH]) AND (gait analysis OR motion gait OR kinem-a tic gait OR walking analysis). Keywords were determined with the help of an experienced librarian. Restrictions were languages (English and French) and human. Electromyographic or kinetic studies, reports of ambulatory or non optoelectronic gait systems, review articles and editorials were excluded.

1.1.2. Data extraction

A predetermined grid was used to collect data for each selected article based on reviewing the full text. One reviewer (PO) systematically extracted the following information from the included studies: localization (hip/knee), study design, baseline characteristics of patients (age, sex, body mass index [BMI]), X-ray grades by Kellgren and Lawrence grading scale. Because of the large number of available kinematic parameters, only the following descriptors of gait (stride length, gait speed, joint flexion and extension) were analysed.

1.2. Assessment of psychometric properties

1.2.1. Feasibility

It was anticipated that no statistics would be available in the selected reports to evaluate feasibility. Data about equipment cost, procedure duration, apparatus availability and safety were collected.

1.2.2. Reliability

Evaluation of the test-retest reliability of quantitative kinematic parameters using the intraclass correlation coefficient (ICC) was collected. An ICC of more than 0.80 is usually considered to be indicative of excellent reliability [7].

1.2.3. Validity

1.2.3.1. Construct validity. Construct validity was assessed by correlations between kinematic parameters and validated OA outcome measures (pain by Visual Analogue Scale [VAS], functional impairment by Lequesne index or WOMAC).

1.2.3.2. Discriminant capacity. Discriminant capacity was assessed by comparing the kinematic parameters of OA and comparators (healthy subjects) in cross-sectional studies using Wilcoxon’s test.

1.2.4. Responsiveness

In longitudinal trials (controlled or not) evaluating OA treatments (total joint replacement, intra articular steroid injection, NSAIDs), responsiveness was assessed as change in kinematic parameters after treatment at different time points (< 3 months, 3–6 months, > 6 months). To allow calculation of effect size, only studies reporting baseline standard deviation were included.

1.2.5. Statistical analysis

Baseline characteristics of OA population were calculated using weighted mean and range. For feasibility and reliability no pooling of data was attempted. For sample size > 30, if mean values were not available, the median was analysed as mean. For discriminant capacity, weighted mean values in each group were calculated by naive pooling, then the mean difference between the weighted means was calculated with confidence interval (www.cemcenter.org). For responsiveness, effect size [8] was calculated, i.e., the mean score change between baseline and follow up values divided by the standard deviation of the baseline value. An effect size > 0.8 is considered large [8]. Due to the small number of studies and heterogeneity of assessed populations, effect sizes were not pooled. The Statistical Package for the Social Sciences (SPSS) version 14.0 was used for data management and statistical analyses.

2. Results

2.1. Data selection process (Fig. 1)

Among the 252 articles identified by the literature search, 57 articles reporting one of the OMERACT filter criteria were selected. Two additional articles were found by manual search. After reviewing the full-texts, another 29 reports were excluded because preselected 3D kinematic data were not available. Thus, the final analysis included 30 full-length reports (19 knee OA studies, 11 hip OA studies) studying 781 knee OA patients (weighted mean age = 64.4 years, 59% females, weighted mean BMI = 29.0 kg/m2) and 343 hip OA patients (weighted mean age = 59.1 years, 68% females, weighted mean BMI = 27.3 kg/m2) (Table 1).

2.2. Assessment of psychometric properties

2.2.1. Feasibility

On the basis of the literature search, 3D gait analysis procedure seemed to be easy to perform, safe, non-threatening, even to persons with severe gait dysfunction due to OA. No data were found about the cost of the equipment or the time needed for the examination. A great variety of gait analysis systems was noted: six different types of optoelectronic system were used in hip OA studies (11 studies) and 12 in knee OA studies (19 studies).

2.2.2. Reliability

Only three studies (67 patients) reported reliability data. Test-retest reliability of the gait analysis system was assessed in a first study of 41 knee OA patients [9]. In this study, intrasession reliability (five gait trials recordings) and intersession reliability (one-week interval) was excellent with ICCs > 0.85 for gait speed and stride length. In another study of 15 knee OA patients [10].
the ICCs of dynamic knee angles (including knee flexion) during walking ranged from 0.97 to 0.99. In a study of 11 hip OA patients assessing reliability over time (one-month interval), ICCs of kinematic parameters were not reported but the amplitude of the variation observed was about 10% for gait speed, stride length and about 20% for hip angles in the sagittal plane, which cannot be considered satisfactory.

### 2.2.3. Validity

#### 2.2.3.1. Construct validity

Only three studies (79 patients) reported data for construct validity. The first one, evaluating correlations between kinematic parameters and Lequesne index in 51 hip OA patients [11] reported good correlations for gait speed ($r = 0.62$) and hip flexion ($r = 0.60$). In contrast, the second study evaluating 17 hip OA patients [12] showed weak correlations between WOMAC subscores (pain, function and stiffness) and gait speed ($r = -0.21$ or less) or stride length ($r = -0.11$ or less). However, correlations were good between changes in these gait parameters and changes in WOMAC subscores three months after total hip replacement ($r = -0.5$ or more). In a study of 11 knee OA patients [13], no significant correlation was found after NSAIDs treatment between the decrease in the VAS pain score and the increase in stride length ($r = 0.14$) or gait speed ($r = 0.17$).

#### 2.2.3.2. Discriminant capacity (Table 2)

Eighteen studies reported data for discriminant capacity, with very similar results in hip (126 patients) and knee OA (598 patients). Results from 16 studies comparing gait speed and stride length in knee [14–24] and hip [25–31] OA patients with those in healthy subjects indicated a good discriminant capacity, with significantly reduced gait speed (mean relative reduction 13 to 14%) and reduced stride length (mean relative reduction 8%). In knee OA patients (six studies), knee flexion during walking was decreased in patients compared to healthy subjects (mean relative reduction 18%) [14–16,20,32,33]. In hip OA patients (three studies), conflicting results were found for hip flexion but hip extension was also significantly reduced [25,27,28].

#### 2.2.4. Responsiveness (Table 3)

Six studies [13,19,20,34–36] evaluating knee OA patients reported results concerning responsiveness. Conflicting data were found for responsiveness in terms of gait speed, with effect size ranging from 0.33 to 0.89 for total knee replacement, from 0.12 to 0.69 for NSAIDs and of 0.47 after intra-articular corticosteroids injection. The effect size of stride length ranged from 0.57 to 1.25 for total knee replacement and from 0.10 to 0.50 for NSAIDs. The effect size on knee flexion was not significant (0.17) after total knee replacement in one study [20]. Two studies (42 patients) [12,29] reported responsiveness data for total hip arthroplasty with effect size ranging from 0.5 to 1.41 for gait speed and equal to 0.40 for stride length. No data were found for hip angles in the sagittal plane after total hip replacement.

### 3. Discussion

The major increase in the use of 3D gait analysis during the past decade has followed the technological advances in collecting gait parameters. Kinematic data will allow physicians to obtain and process accurate objective measurements of sophisticated movement such as human walking. Henceforth, one of the main challenges today is no longer how to measure data that quantifies human walking but how to use this information so that it can be of clinical benefit. There is still considerable controversy concerning the use of motion analysis as a tool for clinical decision-making in OA, including the difficulty of interpreting large amounts of information [24] and the limited of validation to date. Indeed, in this systematic literature search, few data were available concerning validity of the psychometrics properties in particular reliability and construct validity. On the other hand, discriminant capacity (difference between OA patients and healthy subjects) is demonstrated and responsiveness seems to be satisfactory. In the present study, similar results have been found between hip and knee patients for all psychometric properties of kinematic parameters. Therefore, this technique could be applied in both diseases.

3D gait analysis presents feasibility issues, with long procedure and expensive systems. Kinematic analysis takes around 30 minutes per patient in our experience, and a vast room dedicated to the collection of data is required.
to gait examination is needed. This could be major drawbacks for its use in clinical practice in OA patients. Whereas the reliability of measurement parameters using 3D motion analysis systems has been well evaluated in normal adult gait, it has not yet been sufficiently evaluated for quantitative kinematic gait variables in OA patients. It is therefore necessary to improve the intersession and intrasession reliability of gait parameters to minimize the numbers of trials and to limit the number of patients to be included in each study. Concerning construct validity, unexpected weak correlations were found in one study [12] between WOMAC function subscores and selected gait parameters in hip OA patients. This might suggest that the self-perceived physical status did not reflect objective physical performance such as gait speed. However, good correlations between changes of both tools after total hip replacement were reported. This provides evidence of complementarity to evaluate global locomotor performance. The present results show that 3D gait analysis is capable of discriminating between healthy subjects and OA patients. In a future study, it would be interesting to evaluate the capacity of these parameters to discriminate between OA of varying severity. Moreover, the results suggest that kinematic parameters are probably responsive outcome measures in OA. A trend towards an increase in effect size was observed with the time interval after total joint replacement but without reaching the effect size level of other validated outcome measures such as WOMAC after arthroplasty [39]. However, the sensitivity to change remains to be confirmed in additional studies because of conflicting results observed for total joint replacement and because of the lack of sufficient data. In contrast with the large number of studies conducted in the literature on sophisticated gait analysis parameters after knee or hip arthroplasty, there are few studies that have evaluated the responsiveness of simple classically-used descriptors of gait. Moreover, the responsiveness of gait analysis for less effective OA treatments than arthroplasty such as knee braces, rehabilitation programs or hyaluronic acid injection needs to be evaluated in hip or knee OA patients.

The findings from this study must be considered in the light of its limitations, which reflect limits in the field of motion analysis. Firstly, heterogeneity in gait analysis systems and in experimental walking protocols was noticed. Secondly, the low number of patients included does not provide sufficient statistical power to detect small differences. Thirdly, the heterogeneity of the hip or knee OA populations and of study designs made meta-analysis inappropriate. Data must therefore be interpreted with caution. Moreover, only the psychometric properties of kinematic parameters were assessed in the present study and a specific systematic literature search on kinetic and electromyographic parameters in OA of the lowers limbs is now warranted.

In conclusion, in the future, gait analysis as a noninvasive aid to clinical assessment could become an important clinical method of functional assessment in knee and hip OA. However, on the basis of the present systematic literature search, the available data concerning validity and reliability are clearly insufficient to consider kinematic parameters as quantifiable outcome measures in OA. Further, gait analysis studies evaluating a large number of patients and using OMERACT filter criteria are needed.

**Conflict of interest**

None of the authors has any conflicts of interest to declare.

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**Table 2**

Discriminant capacity of kinematic parameters: differences between healthy subjects and osteoarthritis (OA) patients.

<table>
<thead>
<tr>
<th>Localization</th>
<th>Number of studies</th>
<th>Number patients (OA/healthy)</th>
<th>Mean difference between OA and healthy subjects (95% IC)</th>
<th>% relative difference between OA and healthy</th>
<th>p value</th>
<th>Effect Size*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait speed (m/s)</td>
<td>Hip</td>
<td>6</td>
<td>126/141</td>
<td>−0.16 (-0.20 -0.12)</td>
<td>−13.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Knee</td>
<td>10</td>
<td>523/295</td>
<td>−0.16 (-0.18 -0.14)</td>
<td>−14.0</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>Hip</td>
<td>4</td>
<td>89/72</td>
<td>−0.08 (-0.11 -0.04)</td>
<td>−8.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Knee</td>
<td>6</td>
<td>237/172</td>
<td>−0.15 (-0.21 -0.09)</td>
<td>−8.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Flexion (degree)</td>
<td>Knee</td>
<td>6</td>
<td>320/100</td>
<td>−14.4 (-19.5 -9.3)</td>
<td>−17.6</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

95% CI: confidence interval.

The difference is presented as (OA-healthy) data therefore a negative result indicates greater gait speed, stride length or flexion in healthy subjects.

* p-value was obtained by Wilcoxon’s non parametric comparison of means, between the weighted means of the 2 groups.

**Table 3**

Responsiveness of selected kinematic parameters in knee osteoarthritis (OA) patients.

<table>
<thead>
<tr>
<th>Ref</th>
<th>Number of patients</th>
<th>Treatments</th>
<th>Follow up (months)</th>
<th>Mean T0 (SD)</th>
<th>Mean T1 (SD)</th>
<th>p value</th>
<th>Effect Size*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (m/s)</td>
<td>[34]</td>
<td>65</td>
<td>A</td>
<td>&lt;3</td>
<td>0.8 (0.3)</td>
<td>0.7 (0.2)</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>65</td>
<td>A</td>
<td>3-6</td>
<td>0.8 (0.3)</td>
<td>0.9 (0.3)</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>[36]</td>
<td>22</td>
<td>A</td>
<td>3-6</td>
<td>1.07 (0.19)</td>
<td>1.16 (0.16)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22</td>
<td>A</td>
<td>&gt;6</td>
<td>1.07 (0.19)</td>
<td>1.24 (0.21)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>[13]</td>
<td>11</td>
<td>B</td>
<td>&lt;3</td>
<td>0.73 (0.21)</td>
<td>0.86 (0.21)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[35]</td>
<td>8</td>
<td>B</td>
<td>&lt;3</td>
<td>0.72 (0.26)</td>
<td>0.75 (0.21)</td>
</tr>
<tr>
<td></td>
<td>[19]</td>
<td>20</td>
<td>C</td>
<td>&lt;3</td>
<td>0.86 (0.13)</td>
<td>0.91 (0.11)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stride length (m)</td>
<td>[36]</td>
<td>22</td>
<td>A</td>
<td>3-6</td>
<td>0.62 (0.07)</td>
<td>0.66 (0.07)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22</td>
<td>A</td>
<td>&gt;6</td>
<td>0.62 (0.07)</td>
<td>0.68 (0.08)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td></td>
<td>[20]</td>
<td>11</td>
<td>B</td>
<td>&gt;6</td>
<td>0.89 (0.08)</td>
<td>0.99 (0.04)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[13]</td>
<td>11</td>
<td>B</td>
<td>&lt;3</td>
<td>0.89 (0.18)</td>
<td>0.98 (0.17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[35]</td>
<td>8</td>
<td>B</td>
<td>&lt;3</td>
<td>0.96 (0.2)</td>
<td>0.98 (0.18)</td>
</tr>
<tr>
<td>Knee (degree)</td>
<td>[20]</td>
<td>24</td>
<td>A</td>
<td>3-6</td>
<td>47 (6)</td>
<td>46 (5)</td>
<td>NS</td>
</tr>
</tbody>
</table>

In bold: significant effect sizes. NS: no statistical difference; Ref: manuscript reference; TKR: Total Knee Replacement; IA: intra articular; NSAIDs: Non-Steroidal Anti-Inflammatory Drugs; A: TKR; B: NSAIDs; C: IA steroid injection.
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References


