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Correlations among measures of knee stiffness, gait performance and complaints in individuals with knee osteoarthritis

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ABSTRACT

Background: Stiffness is a common complaint in individuals with knee osteoarthritis and is a component of the osteoarthritis diagnosis. Yet the relationship between stiffness and function is poorly understood and methods to quantify stiffness are limited.
Methods: Using a cross-sectional observational design with 66 subjects with knee osteoarthritis, stiffness and damping coefficients were calculated from a relaxed knee oscillation procedure. Gait parameters were measured using an electronic walkway. Self-reported pain, stiffness, and function were measured with the Western Ontario and McMaster Osteoarthritis Index. Correlation and Alexander's normalized-t approximation analyses were used to assess associations among the variables. Subset analysis was performed on subjects with and without tibiofemoral joint crepitus.
Findings: Slight to moderate correlations existed between stiffness and damping coefficients and most gait parameters (($|r|=0.30$–0.56; $P<.05$) and between Western Ontario and McMaster Osteoarthritis Index scores and all gait parameters ($|r|=0.35$–0.62; $P<.05$). The damping coefficient was only slightly associated with patient-rated Western Ontario and McMaster Osteoarthritis Index stiffness subscale scores. Subset analysis revealed significant correlations that differed between those with and without crepitus.
Interpretation: These findings suggest that laboratory measured stiffness and damping coefficients, Western Ontario and McMaster Osteoarthritis Index scores and gait-related measurements assess different aspects related to movement in individuals with knee osteoarthritis. Stiffness and damping coefficients may offer the ability to explain gait changes in the knee that are independent of a person's perceptions particularly in the early stages of the disease.

1. Introduction

Osteoarthritis is the most common form of arthritis. The knee is the most commonly involved joint affecting almost 17% of the US population 45 years and older (Lawrence et al., 2008). Typical symptoms of knee osteoarthritis are knee pain and stiffness and decreased functional ability including difficulty walking and climbing stairs.

Stiffness is one of the six criteria used for clinical diagnosis of knee osteoarthritis (Altman, 1991) and may contribute to disability associated with knee osteoarthritis. Stiffness is typically assessed by a two-question subscale of the Western Ontario McMaster Osteoarthritis Index (WOMAC), a standardized self-report measure of pain, stiffness and functional disability, higher scores indicating greater problems. (Bellamy et al., 1988). Accurate methods to measure physical properties of joint stiffness are needed to develop effective treatments for joint stiffness that occurs in a variety of orthopaedic disorders (Hughes, 2011). Oatis described a method to quantify knee joint stiffness by calculating stiffness and damping coefficients measured when the knee swings in a relaxed pendular motion (Oatis, 1993). Quantitative knee joint stiffness is based on a model of the knee joint consisting of two segments joined by a viscously damped, torsional spring with linear stiffness (Oatis, 1993). One segment represents the thigh, which is immobile, and the other represents the lower leg and foot. The model is comparable to a compound pendulum. The premise of the model is that stiffness and damping coefficients can be determined by tracking displacement of the leg-foot segment during relaxed oscillations.

Anthropometric measurements of the lower leg and foot are used to derive inertial properties, and the displacement history of relaxed oscillations of the lower leg are recorded and analyzed to determine the decay in swing over time. These values determine stiffness and damping coefficients of the knee according to the methods described

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by Oatis (1993). A similar approach has been used to assess knee stiffness in individuals with rheumatoid arthritis (Valle et al., 2006). Others have used the test to compare knee stiffness in individuals with and without patellofemoral syndrome (Hamstra-Wright et al., 2005) and to examine elbow stiffness in healthy subjects (Lin et al., 2005).

The pendulum method yields stiffness and damping coefficients which are related to mechanical properties of the neuromusculoskeletal tissues of the joint. Stiffness is the force or moment needed to produce a given deformation (linear or torsional) expressed in Newton/meter or in Newton-meters/radian (Nm/rad). Larger stiffness coefficients indicate increased stiffness, meaning that, in a system such as the knee joint that undergoes rotational movement, larger moments are required to produce a movement. The damping coefficient reflects the time dependent nature of the deformation expressed in Newton-meter-second/radian (Nm s/rad). Larger damping coefficients indicate increased damping, or larger moments required to produce more rapid movements.

A pilot study reported a statistically significant increase in damping coefficients of subjects with knee osteoarthritis compared to age and gender matched subjects without knee osteoarthritis (Oatis et al., 2006). Additionally the damping coefficient correlated with the WOMAC stiffness subscale with no correlation between the stiffness coefficient and WOMAC stiffness. The authors noted that this finding suggests that complaints of stiffness are more accurately reflected by viscoelastic properties of the joint than by its elastic properties.

Although stiffness is a common complaint in osteoarthritis, it is unclear if patient-reported complaints relate to the integrity of the joint. Similarly it is unknown whether patients' perceptions of knee joint stiffness change during the course of their disease. Knee osteoarthritis can be diagnosed by radiographs showing articular damage or without radiographs by the presence of pain and at least three out of six of the clinical criteria identified by Altman (1991), one of which is crepitus. Crepitus is the grating sound or sensation generated in a joint during movement and reflects significant cartilage damage. Individuals with clinically diagnosed osteoarthritis may or may not have radiographic changes. Presence of tibiofemoral crepitus helps to distinguish individuals with radiographic knee osteoarthritis from those with clinically diagnosed knee osteoarthritis who have cartilage defects without frank radiographic changes. These individuals are diagnosed with “pre-radiographic” knee osteoarthritis (Cibere et al., 2010). Thus crepitus can distinguish individuals with greater joint destruction from those with less.

Functional performance is diminished in individuals with knee osteoarthritis. Decreased walking velocity, shortened stride lengths, increased time in stance and decreased knee joint motion are commonly reported gait changes in these patients (Hubley-Kozey et al., 2008; Zeni and Higginson, 2009). Relationships between functional performance and patient-reported function appear complex. There is a lack of agreement regarding relationships between the WOMAC self-report measure and subjects' locomotor performance (Debi et al., 2009; Nebel et al., 2009; Pua et al., 2009).

The pendulum test offers a new way to quantify joint stiffness in people with arthritis. Before the test's clinical utility can be determined, we need to understand its properties and its relationship to other widely used measures of stiffness and functional performance. The primary purpose of this study was to examine relationships between the stiffness and damping coefficients as measured during the pendulum test and reports of WOMAC pain, stiffness and disability in individuals with knee osteoarthritis. Additionally we sought to identify relationships between the stiffness and damping coefficients and subjects' walking speed and stride characteristics and to reexamine relationships between WOMAC scores and these gait variables. We hypothesized that there would be positive correlations between the stiffness and damping coefficients and WOMAC scores, negative correlations between the coefficients and walking speed and step and stride lengths and positive correlations with double support time. Another purpose was to examine if the presence of knee joint crepitus altered relationships among the coefficients, WOMAC scores and gait variables. Finally, we explored the predictive ability of age, gender, BMI and crepitus on stiffness and damping coefficients and the relative contributions of these characteristics and coefficients in predicting gait variables.

2. Methods

2.1. Subjects

Subjects with knee osteoarthritis ($n=66$) who completed a randomized clinical trial of a non-invasive intervention for knee osteoarthritis were entered into this study. All data reported in this study were collected at baseline prior to any intervention. Subjects were recruited from local hospitals and physician offices, and from advertisements in local newspapers.

Subjects were eligible for inclusion if they reported a doctor's diagnosis of knee arthritis, had moderate to severe knee pain and were able to walk without assistance (assistive devices were allowed). Subjects were excluded if they reported uncontrolled cardiovascular disease, knee joint arthroplasty, or unresolved injuries to any joints of the lower extremities.

2.2. Procedure

The study was approved by the Arcadia University Committee for the Protection of Research Subjects. All testing was performed in the research laboratories of the Department of Physical Therapy at Arcadia University. Upon entering the study, subjects read and signed an informed-consent document. Participants completed a brief medical history questionnaire and underwent a physical examination of both knee joints. One of three investigators (LAM, CAO, MAL) performed the clinical examination. The examination included the following: height in cm, weight in kg, presence of varus/valgus malalignment (Y/N), presence of flexion contracture (Y/N), presence of knee joint swelling (Y/N), presence of knee joint laxity (Y/N), and presence of tibiofemoral crepitus, (Y/N).

Examination procedures were reviewed and standardized prior to the initiation of the study. Tibiofemoral joint crepitus was identified by palpation along the tibiofemoral joint line on the medial and lateral aspects of the knee during active knee flexion and extension. Data from the clinical examination were used to identify the more symptomatic knee which became the test knee. If both knees were equally symptomatic, one knee was chosen randomly by flipping a coin.

The WOMAC questionnaire (visual analog scale format, v 3.1) was administered according to published procedures (Bellamy, 1995). The WOMAC consists of twenty-four questions, five addressing pain, seventeen addressing function and two addressing stiffness. Its validity and reliability in patients with knee osteoarthritis are well established (Bellamy et al., 1988). Participants were instructed to answer each question based on the preceding 48 h.

The Motion Analysis Corporation™ computer-assisted video motion analysis system recorded motion of the leg during relaxed oscillations. The camera arrangement was calibrated at the beginning and end of every recording session using a 0.4 m^3 volume according to the manufacturer's recommended procedures. Motion was recorded from three cameras and data were collected at 60 Hz. Motion data were filtered using a low-pass 4 Hz Butterworth filter. Data collected were analyzed with the software packages from Motion Analysis Corporation (ExpertVision and Kintrak)™.

Each subject was seated on a table with the leg not being tested supported by a stool. Retroreflective markers were placed on the following bony prominences: acromion process, greater trochanter, lateral femoral epicondyle, and lateral malleolus. The line between the