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Determinants of co-contraction during walking before and after arthroplasty for knee osteoarthritis

Hamid R. Fallah-Yakhdani [a,b], Hamid Abbasi-Bafghi [a,b], Onno G. Meijer [a,c,d,*], Sjoerd M. Bruijn [a,e], Nicolette van den Dikkenberg [f], Maria-Grazia Benedetti [g], Jaap H. van Dieën [a]

[a] *Research Institute MOVE, Faculty of Human Movement Sciences, VU University, Amsterdam, The Netherlands*
[b] *Department of Physical Education and Sports Science, Yazd University, Yazd, Islamic Republic of Iran*
[c] *Second Affiliated Hospital of Fujian Medical University, Quanzhou, Fujian, PR China*
[d] *Department of Rehabilitation, Fujian Medical University, Fuzhou, Fujian, PR China*
[e] *Motor Control Laboratory, Research Centre for Movement Control and Neuroplasticity, Department of Biomedical Kinesiology, K.U. Leuven, Belgium*
[f] *Rehabilitation Centre Amsterdam, Amsterdam, The Netherlands*
[g] *Istituto Ortopedico Rizzoli, University of Bologna, Italy*

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ABSTRACT

Background: Knee osteoarthritis patients co-contract in knee-related muscle pairs during walking. The determinants of this co-contraction remain insufficiently clear.

Methods: A heterogeneous group of 14 patients was measured before and one year after knee arthroplasty, and compared to 12 healthy peers and 15 young subjects, measured once. Participants walked on a treadmill at several imposed speeds. Bilateral activity of six muscles was registered electromyographically, and co-contraction time was calculated as percentage of stride cycle time. Local dynamic stability and variability of sagittal plane knee movements were determined. The surgeon's assessment of alignment was used. Pre-operatively, multivariate regressions on co-contraction time were used to identify determinants of co-contraction. Post-operatively it was assessed if predictor variables had changed in the same direction as co-contraction time.

Findings: Patients co-contracted longer than controls, but post-operatively, differences with the healthy peers were no longer significant. Varus alignment predicted co-contraction time. No patient had post-operative varus alignment. The patients' unaffected legs were more unstable, and instability predicted co-contraction time in both legs. Post-operatively, stability normalised. Longer unaffected side co-contraction time was associated with reduced affected side kinematic variability. Post-operatively, kinematic variability had further decreased.

Interpretations: Varus alignment and instability are determinants of co-contraction. The benefits of co-contraction in varus alignment require further study. Co-contraction probably increases local dynamic stability, which does not necessarily decrease the risk of falling. Unaffected side co-contraction contributed to decreasing affected side variability, but other mechanisms than co-contraction may also have played a role in decreasing variability.

1. Introduction

Knee osteoarthritis is one of the most prevalent afflictions of the elderly, with patients reporting pain and functional limitations (Kauppila et al., 2009; Laxafoss et al., 2010). Objectively, there is a loss of articular cartilage, visible as a narrowing of the joint space, particularly at the medial side (Hunter et al., 2009), and often accompanied by varus alignment. Other structures are also involved, and clinical investigation often reveals laxity of the knee joint (Lewek et al., 2004) and/or quadriceps weakness (Hortobágyi et al., 2005). Patients with knee pain (Heiden et al., 2009), or effusion (Torry et al., 2000), may alter their muscle activity, as do patients who feel unstable during gait (Schmitt and Rudolph, 2008). Over the last decade, muscle activation patterns in gait have drawn considerable attention in the knee osteoarthritis literature. It was often reported that patients co-contract longer, co-contract more, or have higher muscle activity during walking than controls (e.g., Benedetti et al., 1999; Briem et al., 2007; Childs et al., 2004; Heiden et al., 2009; Hortobágyi et al., 2005; Hubley-Kozey et al., 2006; Lewek et al., 2003; Rudolph et al., 2001; Schmitt and Rudolph, 2007; Zeni et al., 2009).

Co-contraction may be beneficial, but can also increase joint loading (e.g., Lewek et al., 2004), possibly leading to further loss of cartilage

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[*] Corresponding author at: Research Institute MOVE, Faculty of Human Movement Sciences, VU University, Amsterdam, The Netherlands.
E-mail address: o_g_meijer@fbw.vu.nl (O.G. Meijer).

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(Childs et al. 2004). Hence, to optimise treatment, we need to know why patients co-contract, that is: What is the effective stimulus for, and what are the possible advantages of, co-contraction? The literature suggests that co-contraction may be related to mechanical factors, such as alignment, stability, and/or variability. Unfortunately, the literature is largely observational, with cross-sectional comparisons of patients and healthy peers. Still, three studies assessed patients after knee arthroplasty (Benedetti et al., 2003; Hubley-Kozey et al., 2010; Wilson et al., 1996), some studies followed patients before and after high tibial osteotomy (Briem et al., 2007; Kean et al., 2009; Ramsey et al., 2007a, 2007b), and a few studies used reversible experimental manipulations (Ramsey et al., 2007a; Schmitt and Rudolph, 2008).

In a study of alignment, valgus perturbations in healthy subjects were found to increase muscle activity on the medial side of the joint (Buchanan et al., 1996). In another experimental study (Ramsey et al., 2007a), patients with varus alignment had more co-contraction on the lateral side of the joint, which decreased when a neutral-position brace was applied, but when the brace was removed, co-contraction increased again. Varus alignment was also suggested to induce co-contraction in studies of high tibial osteotomy. Successful realignment decreased co-contraction of VM (vastus medialis) and GM (gastrocnemius medialis; Ramsey et al., 2007b), but unsuccessful realignment led to more post-operative co-contraction of VM and MH (medial hamstrings), and of VL (vastus lateralis) and GL (gastrocnemius lateralis; Briem et al., 2007). This literature suggests that varus alignment induces co-contraction in knee osteoarthritis. Still a relationship between varus alignment and co-contraction was not always found (e.g., Schmitt and Rudolph, 2008).

In the lumbar spine literature, co-contraction could be “explained entirely on the basis of the need for the neuromuscular system to provide […] mechanical stability […]” (Cholewicki et al., 1997, p.2207). Co-contraction can be an effective strategy to provide stability (Gardner-Morse and Stokes, 2001), but in knee pathology, this was not always found. In anterior cruciate ligament rupture, sagittal plane stability during gait may be recovered by an unusual contraction of a hamstring (Boerboom et al., 2001), but in subjects who remained unstable, more general co-contraction was found (Lewek et al., 2003; Rudolph et al., 2001). In knee osteoarthritis, subjects with serious self-reported instability had more VM–MH co-contraction before, during, and after a frontal plane perturbation of gait (Schmitt and Rudolph, 2008), which suggests that self-reported instability is a determinant of co-contraction. Still, subjective instability (Fitzgerald et al., 2004) may be confounded by fear (Van Galen and Van Huygevoort, 2000; Vlaeyen et al., 1995), and to the best of our knowledge, the relationship between objective stability (Bruijn et al., 2009a) and co-contraction during walking with knee osteoarthritis remains to be established.

In a study on manual tracking (Selen et al., 2006), increased precision demands were found to induce co-contraction, which decreases kinematic variability. In knee osteoarthritis, reduced variability of knee movements has been reported (Fallah-Yakhdani et al., 2010; Lewek et al., 2006). Reduced variability may be harmful to the joint (Lewek et al., 2006), but increased variability suggests a lack of control, and coincides with a higher risk of falling (e.g., Hausdorff, 2007; Leitner et al., 2007; Maki, 1997). Earlier, we hypothesised that subjects with knee osteoarthritis co-contract in order to reduce variability (Fallah-Yakhdani et al., 2010), which may enhance the control over knee motion (e.g., Benedetti et al., 2003; Kean et al., 2009; Schmitt and Rudolph, 2008; Van Dieën et al., 2003). Some authors see co-contraction as a strategy to compensate for quadriceps weakness (e.g., Hortobágyi et al., 2005). When taken literally, this is a paradox, but maybe the argument is that a weaker quadriceps muscle often coincides with problems of control (Rudolph et al., 2007), which would be visible as increased variability.

The present study focused on determinants of co-contraction during gait in knee osteoarthritis patients, waitlisted for arthroplasty. Alignment, local dynamic stability, and kinematic variability were the variables of interest. The surgeon's assessment of alignment was registered, and self-reported fear of movement/reinjury was included. Objective local dynamic stability and variability of sagittal knee movements were determined. We hypothesised that pre-operative patients would co-contract longer than controls, that co-contraction time would decrease after surgery, and that determinants of co-contraction would change post-operatively in the same direction as co-contraction time. More specifically, we hypothesised that varus alignment and instability would lead to co-contraction, and that co-contraction would reduce variability.

2. Methods

2.1. Participants

We were interested in relationships with major impact, and opted for an intensive study with a small number of subjects, different surgeons, and different techniques of arthroplasty. Pre-operatively, 16 knee osteoarthritis patients enrolled, one of whom was never operated, whereas another found the measurements too demanding, resulting in 14 patients who were also measured 1 year after arthroplasty. Exclusion criteria were: replacement of the other knee, revision, other conditions interfering with gait, or inability to adhere to the protocol. Patients were compared with 12 self-reportedly healthy peers, with similar age, gender, and BMI, and with 15 young subjects. Orthopaedic surgeons used the Knee Society (KS) rating scale (Insall et al., 1989), including alignment, which was registered as varus, valgus, or normal. All participants signed an informed consent, after the local Medical Ethical Committee had accepted the project.

2.2. Data acquisition

To assess fear of movement/reinjury, the TAMPA scale for kinesiophobia was used (Dutch version; Vlaeyen et al., 1995). For expected pain during the experiment, VAS forms (Visual Analogue Scales) were used, from 0 mm (“no pain at all”) to 100 mm (“maximal pain”).

Bilateral muscle activity of RF (rectus femoris), BF, VL, VM, GM, and TA (tibialis anterior) was recorded with surface electromyography (EMG), in accordance with SENIAM recommendations (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles; Hermens et al., 1999). Pairs of electrodes (H93SG, MedCat supplies, Erica, The Netherlands) were placed with 2-cm centre-to-centre distance, and a reference electrode over the tibia. Data were recorded at 1000 samples/s with a Porti EMG recorder (TMS-international, Enschede, The Netherlands; input impedance $>10^{12}$ Ω, CMRR $>$ 90 dB, 22 bits AD conversion after 20× amplification).

For movement registration, clusters of 3 markers (Infrared Light Emitting Diodes), fixed on light metal plates, were attached with neoprene bands to the thighs, shanks, and heels of each subject. An optoelectric system, OptoTrak™ (Northern Digital, Waterloo, Ontario, Canada), with two 3-camera arrays, was used to record movements at 50 samples/s. When the OptoTrak recording started, a trigger pulse was sent to the Porti for synchronisation.

Participants were invited to walk on a treadmill. Gait parameters are dependent on speed, and seven speeds were used, 0.6–5.4 km/h (increments 0.8 km/h), in increasing order. Initially, some practice time was offered to the subjects. Each speed was maintained during 4 min, with EMG and kinematics recorded in the last 2. Subjects were encouraged to take a break whenever they wanted, and were instructed to indicate if the speed was too high. If so, the belt was stopped, and the preceding speed was designated as “maximum”.

2.3. Calculations

All calculations were performed with MATLAB 7.0.4 (The MathWorks, Natick, MA, USA). Heel strike was inferred from the minimum