Clinical Biomechanics 35 (2016) 1–6

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Postural control in degenerative diseases of the hip joint

Edit Sziver [a], Edit Nagy [a], Andrea Preszner-Domján [a], Gabriella Pósa [a], Gyöngyi Horvath [b,*], Attila Balog [c], Kálmán Tóth [d]

[a] Department of Physiotherapy, Faculty of Health Sciences and Social Studies, University of Szeged, Temesvári krt. 31, Szeged 6726, Hungary
[b] Department of Physiology, Faculty of Medicine, University of Szeged, Dóm ter 10, Szeged 2720, Hungary
[c] Department of Rheumatology, Faculty of Medicine, University of Szeged, Kalvaria sgt. 57, Szeged 6725, Hungary
[d] Department of Orthopaedics, Faculty of Medicine, University of Szeged, Semmelweis u. 6, Szeged 6725, Hungary

ARTICLE INFO

Article history:
Received 26 November 2015
Accepted 1 April 2016

Keywords:
Osteoarthritis
Rheumatoid arthritis
Postural sway
Compliant surface

ABSTRACT

Background: Few studies investigated the postural control in patients with hip joint impairments; in some cases, balance impairments have been found, while other researchers have seen no significant changes. The goal of this study was to characterize postural stability in patients suffering from unilateral osteoarthritis or rheumatoid arthritis in different balance tasks and to reveal potential differences between the two diseases in this respect.
Methods: Ten patients with hip osteoarthritis (mean age: 62.3 years), 10 patients with rheumatoid arthritis (mean age: 55.4 years) and 10 healthy control subjects (mean age: 54.3 years) took part in the study. Displacement of centre of pressure was measured with a force plate in mediolateral and anteroposterior directions during two-leg standing on firm and compliant surfaces with eyes opened and closed.
Findings: Standing on a firm surface sway path increased significantly in the anteroposterior direction in both patient groups and in the mediolateral direction in all groups with eyes closed as compared to eyes opened condition. Standing on a compliant surface, sway paths increased significantly in both directions in all groups with eyes closed as compared to eyes opened condition; furthermore, sway paths were significantly longer with eyes closed in patients with rheumatoid arthritis in comparison with control and osteoarthritis groups.
Interpretation: Our data revealed that the manipulation of both visual and somatosensory information can reveal subtle impairments in balance control. Thus, this paradigm can unmask the effects of decreased proprioception due to joint capsule lesion in patients with rheumatoid arthritis.

1. Introduction

Arthritic joint conditions are very prevalent, and they are a major cause of long-term pain and disability, and considerable health care resources are expended on their rehabilitation. Two of the most common forms of arthritic joint disorders are osteoarthritis (OA) and rheumatoid arthritis (RA) (Badley and Ibañez, 1994; Williams et al., 2010; Woolf and Pfleger, 2003). The burden of these diseases is substantial with one in four people developing OA by age 85, and the healthcare of RA costs of more than €4,000 per patient per year (Boonen and Severens, 2011; Murphy et al., 2010).

RA is characterized by the localization of inflammatory flares primarily to the synovial membrane of the joints (Mengshoel et al., 2000), while the involvement of the cartilage in osteoarthritis results in a secondary effect on the joint capsule and synovium (Heinegård and Saxne, 2011). A number of studies have reported balance disorders in patients with OA or RA localized to the knee or ankle joints (Barrett et al., 1991; Fridén et al., 1990; Hassan et al., 2001; Hinman et al., 2002; Marks et al., 1993; Renström and Konradsen, 1997; Tropp and Odenrick, 1988). However, only a few studies, with controversing results, are available on the changes in postural control when the hip joint is affected (Arokoski et al., 2006; Sturnieks et al., 2004; Williams et al., 2010). Arokoski et al. (2006) investigated patients with both unilateral or bilateral hip OA, while Sturnieks et al. (2004) and Williams et al. (2010) pooled patients with lower limb arthritis (hip, knee or foot joints were affected); thus, no results are available on the effects of single hip joint arthritis on postural control. Few studies have revealed that patients after total hip replacement (without exact diagnosis, i.e., the diseases led to the requirement of surgery) had balance impairments compared to surface replacement arthroplasty or to a healthy group, suggesting that they needed more sensory input from vision and vestibular sense, despite normal proprioceptive sense (Nallegowda et al., 2003; Nantel et al., 2008). On the contrary, Lugade et al. (2008) have observed deficits in balance during walking in patients before total hip arthroplasty (without exact diagnosis) compared to healthy subjects, but the results improved postoperatively.

* Corresponding author.
E-mail addresses: sziver@etszk.u-szeged.hu (E. Sziver), nedit@etszk.u-szeged.hu (E. Nagy), andrea@etszk.u-szeged.hu (A. Preszner-Domján), posa@etszk.u-szeged.hu (G. Pósa), horvath.gyongyi@med.u-szeged.hu (G. Horvath), balog.attila@med.u-szeged.hu (A. Balog), toth.kalman@med.u-szeged.hu (K. Tóth).

http://dx.doi.org/10.1016/j.clinbiomech.2016.04.001
0268-0033/

Postural control is a complex function controlled by sensory input, central processing and neuromuscular responses. Sensory components include the vestibular, visual and different somatosensory information, i.e., receptors in joint capsules, ligaments, surrounding muscles and in the skin (Cross and McCloskey, 1973; McChesney and Woollacott, 2000; Missaoui et al., 2008; Schmidt, 1975; Zimny, 1988). Pathologies in and around the joints may affect the quality of sensory information resulting in decreased proprioception and disrupting the automatic postural responses to sensory inputs (Hurley, 1997; Mengshoel et al., 2000; Missaoui et al., 2008; Sturnieks et al., 2004). Nevertheless, some authors suggested that the intracapsular components have little influence on standing balance in the hip, while the stretch receptors of the adjacent tendons and muscles might have a greater influence on proprioception than the joint capsule (Arokoski et al., 2006; Ischii et al., 1999). It is well known that patients with OA and RA frequently suffer from pain due to the inflammatory and/or degeneratory processes in the joint. Therefore, pain should also be considered as an important factor in functional impairments, which can contribute to the risk of falls (Hassan et al., 2001; Jamison et al., 2003; Sturnieks et al., 2004).

The effective motor response including sufficient muscle strength and intact neuromuscular system is also essential to maintain proper balance control, and their impairment is an important risk factor in causing falls, e.g., in old persons, especially if they suffer from joint diseases (Aydoğ et al., 2006; Hassan et al., 2001; Hurley et al., 1998; Maki and McIlroy, 1996, 1997; Mengshoel et al., 2000; Sturnieks et al., 2004). Inactivity and physical dysfunction frequently accompany these diseases, resulting in reduced muscle strength and muscle endurance (Mengshoel et al., 2000; Sturnieks et al., 2004). Ekdahl and Broman (1992) have found that a great number of patients with large joints of the lower extremities affected by RA had strength deficits of musculature. Decreased muscle strength, proprioception and pain can result in balance impairments and may lead to disability and falls (Aydoğ et al., 2006; Jamison et al., 2003; Rome et al., 2009; Sturnieks et al., 2004).

In spite of the fact that balance impairments/falls usually appear in unstable situations, few data are available about the differences in postural control and balance strategies between rheumatologic and orthopedic disorders, and about the effects of the manipulation of both visual and somatosensory information by the combination of eyes closed (EC) with standing on foam surface (Hinman et al., 2002; Preszner-Domjan et al., 2012; Sturnieks et al., 2004; Williams et al., 2010). Williams et al. (2010) found no significant differences between the effects of exercise on postural control standing on the foam surface with EC in OA and RA subjects. However, they have not compared the two groups before the exercise program; therefore, the impact of the different forms of joint disorders on balance has not been evaluated in this study, and they have not involved a healthy (control) group.

The aim of our study was to determine the postural control in patients suffering from unilateral OA and RA of the hip joint during different conditions, i.e., on both stable and compliant surfaces with eyes opened (EO) or closed to determine the possible differences between these two diseases in this respect. The presence of balance impairments may suggest that early, effective treatment of patients with higher degree of postural control impairments should be very important to prevent these abnormalities and to decrease the potential danger of postural control disturbance.

2. Methods

2.1. Subjects

Ten patients with unilateral primary hip osteoarthritis (OA group), ten patients with unilateral inflammatory hip disease (RA group) and ten healthy subjects (control group) were enrolled in the study. The groups' anthropometric characteristics are presented in Table 1.

Patients had unilateral hip pain on most days for several months. Subjects with OA were selected from those waiting for a total hip replacement in the Department of Orthopaedics, and RA patients were receiving treatment at the Department of Rheumatology, University of Szeged. All subjects were independent and capable of self-care and daily household tasks. Patients were expected to be able to walk without an aid or physical assistance. Exclusion criteria were all patients with primary OA, and OA due to RA. All the other secondary OA cases were excluded (e.g., based on a history of trauma to the hip joint or in the pelvic region, hip surgery, hip joint infection and congenital or developmental diseases). We also excluded patients who had bilateral hip RA or OA, any complaints in the other joints of the lower limbs or impairments in the lumbosacral area. Subjects were also excluded if they had visual or vestibular impairments or any disease that could worsen their physical or balance parameters, such as cancer, endocrine, cerebrovascular disease, Parkinson's syndrome, epilepsy, polyneuropathia, neuromuscular disorder, uncontrolled cardiovascular disease or atherosclerosis of the lower extremities (Arokoski et al., 2006). C-reactive protein and Westergreen values had to be under the upper level of the normal values.

Table 1
Anthropometric characteristics of control, OA and RA subjects.

	Control ($n = 10$)	OA ($n = 10$)	RA ($n = 10$)
Variable	Mean (SE)	Mean (SE)	Mean (SE)
Age (y)	54.3 (0.83)	62.3 (2.06)	55.4 (4.27)
Gender	6F/4M	6F/4M	5F/5M
Weight (kg)	79.62 (6.17)	76.1 (3.36)	77.03 (3.05)
Height (m)	1.71 (0.04)	1.68 (0.02)	1.66 (0.03)
BMI (kg/m^2)	26.82 (1.25)	26.85 (0.97)	28.02 (1.32)

SE, standard error; BMI, body mass index.

Control subjects were recruited to the study as volunteers. The healthy reference group was matched with the patient groups for age, gender and body mass index (BMI). None of the controls had any hip pain or functional impairment in the hip joint or any other joint of the lower extremities. Excluding criteria for the control subjects were the same as for those in the patient groups.

All of the subjects gave their informed consent prior to participation in the study, which was approved by the local Institutional Ethics Committee.

2.2. Determination of functional status

2.2.1. Visual analogue scale

Hip pain (average pain on movement over the previous 72 h) was assessed by using a visual analogue scale (VAS) (range, 0–100 mm; end-points, no pain–unbearable pain).

2.2.2. Harris hip score

Functional status of the hip joint was rated with the Harris hip score (HHS) (Harris, 1969). The score has a maximum at 100 points (best possible function), covering pain (part I, 1 item, 0–44 points), function and activities (part II, 7 items, 0–47 points) and range of motion and absence of deformity (part III, 3 items, 0–9 points). [Grading: <70 poor, 70–79 fair, 80–89 good, 90–100 excellent (Marchetti et al., 2005)]

2.2.3. Western Ontario and McMaster universities osteoarthritis index

The Western Ontario and McMaster universities osteoarthritis index (WOMAC) (Bellamy et al., 1988) was used to assess pain (WOMAC A, 5 items), joint stiffness (WOMAC B, 2 items) and disability (WOMAC C, 17 items) by using visual analogue scales. Lower scores indicated less pain, less stiffness or less disability.

2.2.4. Timed up & go test

To assess the functional mobility of the subjects, we applied the timed up & go (TUG) test (Shumway-Cook et al., 2000). During the testing procedure, subjects were timed (recorded in seconds) for standing up from a chair (45 cm), walking 3 m, passing around an object and then returning to a sitting position in the chair. Subjects were instructed to walk as quickly as possible but not to run. The subjects had three trials with 1 min pause between each trial; the trials were recorded in seconds. The best result of the three trials was included in data analysis.

The VAS, HHS and WOMAC tests were performed consecutively before the postural test, while the TUG test was determined in the end. An approximately 10 min interval was ensured between the different tests.

2.3. Postural control tests

The Clinical Test of Sensory Interaction on Balance (CTSIB) designed by Shumway-Cook and Horak (1986) uses different conditions to test how people adapt to changing sensory conditions during the maintenance of stance. We used the modified CTSIB by NeuroCom to perform the test on a computerized force plate to measure body sway. Static postural stability [displacement of Centre of Pressure (CoP)] was measured during standing on a single force platform (Stabilometer, ZWE-PII, Budapest, Hungary) for 20-s periods in a quiet room. Signals were amplified and sampled at 16 Hz via an analogue-to-digital converter. Subjects stood barefoot on the platform, with arms hanging freely at their side and the feet positioned side by side with closed heels, but a slight (max 15°) toe-out was allowed for subjects' comfort. The CoP excursions along the anteroposterior (AP) and mediolateral (ML) axes were performed both on firm (the stable surface of the platform) and foam surfaces [an Airex Balance Pad (dimensions: 50 cm length × 41 cm width × 6 cm height) placed on the platform], always starting with standing on the stable surface. In each condition, subjects had to stand first with their eyes opened (EO), when subjects had to look at a target fixed at eye level at a distance of approximately 1 m, and then measurements were also performed with eyes closed (EC). To decrease the effects of mental or physical fatigue on the balance control, a single measurement for each condition was performed. The same order of the investigation ensured that all of the patients could get customized to the task for the identical condition.

2.4. Data analysis

Means and standard errors are given as descriptive statistics.

Sway paths in both ML (x) and AP (y) directions were calculated—as applied earlier by Preszner-Domjan et al. (2012)—via the formulae:

$$s_x = \sum_{i=1}^{n-1} \sqrt{(x_{i+1} - x_i)^2}$$

$$s_y = \sum_{i=1}^{n-1} \sqrt{(y_{i+1} - y_i)^2}$$

where n is the total number of samples, i is the numbering, s_x is the lateral displacement of the CoP and s_y is the AP sway.

Data were subjected to analysis of factorial variance (ANOVA) in order to make comparisons between the groups and the different experimental conditions, which constituted the independent variables (four factors: groups, eyes condition, surface condition and axis). Newman–Keuls test was used for post hoc evaluation. Correlation analyses were performed in both patient groups to determine the relationships between the level of pain (measured on VAS) and daily activity (WOMAC C, measured on VAS), and between pain and the sway paths in each direction. The level of significance was determined at $p < 0.05$. Data analyses were carried out with Statistica 11 software.

3. Results

3.1. Functional status

The age, body weight, body height and BMI did not differ significantly between the groups (Table 1).

Both patient groups were categorized into "poor" functional status category (scores <70) according to HHS results with significantly lower scores compared to the control group (Table 2). Statistically, no significant difference was found between the two patient groups. Significantly higher scores were measured with the WOMAC Index in total scores and in the scores of all WOMAC subcategories in the OA and RA groups compared with the control group, but statistically no significant difference could be detected between the OA and RA patients (Table 2). Both patient groups needed significantly more time during testing TUG than the control group with no significant difference between the patient groups (Table 2).

Significant positive correlations were found between the hip joint pain (measured on VAS) and the disabilities during daily activities (measured as part "C" of WOMAC index) in both patient groups (OA: $r = 0.72$; RA: $r = 0.67$).

3.2. Postural control

Factorial ANOVA revealed the significant effect of surface ($p < 0.001$) and eye ($p < 0.001$) conditions and groups ($p < 0.001$) as well as the interactions of axis and surface condition ($p < 0.05$), the surface and eye conditions ($p < 0.001$), the group and surface condition ($p < 0.005$), group and eye condition ($p < 0.005$) and the interaction of group, surface and eye conditions ($p < 0.005$). The post hoc analysis showed that standing on the firm surface with EO or EC, no significant differences were found in the sway paths between the three groups either in AP or in ML direction (Figs. 1 and 2). The AP sway path increased significantly in both patient groups when the eyes were closed as compared to the open eye condition, and the changes were also close to significant in the control group (Control, $p = 0.055$; OA, $p < 0.001$; RA, $p < 0.05$) (Fig. 1). In ML direction, significant differences were found in all groups in the EC condition compared with the EO condition (Control, $p < 0.05$; OA, $p < 0.001$; RA, $p < 0.001$) (Fig. 2).

Standing on a foam surface with EO, the post hoc comparison did not show significant enhancements in AP or ML sway paths in all groups compared to a firm surface, and no significant difference was observed between the three groups in this condition (Figs. 1 and 2).

Manipulation of both the availability of visual information (by closing the eyes) and the surface condition (standing on foam) simultaneously, led to significant increases in the sway paths in both AP and ML directions in all groups compared to any other conditions ($p < 0.001$). Furthermore, the sway paths were significantly longer in the RA group in both directions compared with the control (AP: $p < 0.001$; ML: $p < 0.05$) and OA groups (AP: $p < 0.001$; ML: $p < 0.05$), but no significant difference was found between the OA and control groups (Figs. 1 and 2).

The correlation analysis of the sway paths during this condition with the VAS data did not reveal significant correlations between the two parameters in the patients groups (data are not shown).

4. Discussion

In the present study, our aim was to determine disease-specific changes in postural stability and functional capacity at unilateral osteoarthritis and rheumatoid arthritis of the hip joint. Our aim was also to find similarities and differences between these two common joint disorders, especially focusing on the inflammatory joint process in the pathomechanism of rheumatoid arthritis. The main findings of this study are the significant changes observed in the sway paths in the RA group in both directions on a compliant surface with the eyes closed condition in comparison with the control group and OA patients.

Table 2
HHS, VAS, WOMAC indices and TUG data of control, OA and RA subjects.

	Control ($n = 10$)	OA ($n = 10$)	RA ($n = 10$)	p value	p value	p value
Variable	Mean (SE)	Mean (SE)	Mean (SE)	Control—OA	Control—RA	OA—RA
HHS	100	50.40 (5.15)	55.50 (5.11)	<0.001	<0.001	0.40
VAS	0.00	55.90 (6.63)	49.70 (4.15)	<0.001	<0.001	0.34
WOMAC total	0.20 (0.20)	42.17 (7.80)	45.68 (4.41)	<0.001	<0.001	0.64
WOMAC A	0.00	40.94 (8.16)	44.26 (4.90)	<0.001	<0.001	0.67
WOMAC B	0.60 (0.60)	45.90 (9.05)	45.60 (6.84)	<0.001	<0.001	0.97
WOMAC C	0.00	39.69 (6.90)	47.19 (4.20)	<0.001	<0.001	0.27
TUG (s)	6.05 (0.28)	8.38 (0.67)	8.49 (0.59)	<0.05	<0.05	0.88

SE, standard error; HHS, Harris hip score; VAS, visual analogue scale; WOMAC, Western Ontario and McMaster universities osteoarthritis index; TUG, timed up & go test.

The lower degree of balance in this patient group may suggest that early, effective treatment of patients should be crucial to prevent these abnormalities and to decrease the potential danger of postural control disturbance.

Postural control is a complex function to maintain the centre of mass of the body over the base of support during standing still or movement. It is a perceptual–motor process involving the central nervous system for command, peripheral afferents for regulation and the musculoskeletal system as the effector. Sensory components include the visual, vestibular and proprioceptive systems. Visual input plays a significant role in balance control; therefore, the lack of visual information leads to increased postural sway (Brandt et al., 1986; Brooke-Wavell et al., 2002; Lee and Lishman, 1977; Nagy et al., 2007; Schmidt, 1975; Sheldon, 1963). In our results, the significant increase in sway paths in the RA group as compared to the OA and control persons might suggest a greater degree of visual dependence of the RA patients while standing on a compliant surface.

Rome et al. (2009) have evaluated postural control in patients with RA. Poorer dynamic and static postural stability have been observed in the RA group in comparison with the non-RA group. In contrast with our results, their patients have shown significantly greater postural sway in AP direction both in EO and EC conditions (about 140% increase) during standing on the force plate compared to the control group. Their results demonstrate a greater degree of visual dependence of RA patients to maintain AP stability standing on a stable surface, but the effect of compliant surface on postural stability has not been assessed. Although the study has involved RA patients, no comparisons have been made with another patient group. Unfortunately, no data are presented about the localization of joint abnormalities; thus, other and more joints could have been involved in RA, which might explain the differences from our study.

In the assessment of Williams et al. (2010), patients with lower limb OA or RA (affecting the hip/knee/feet joints) participating in a 4-month exercise program, showed improvement in several WOMAC subcategories. They also measured CTSIB in 4 conditions, on stable and foam surfaces with EO and EC situations. In the outcome measurements, no significant differences were found in the changes of the scores between OA and RA subjects, but the authors did not compare the baseline data between the OA and RA groups.

Arthritic joint damages lead to the lesion of the capsule and other joint structures causing decrease in proprioception (Hurley, 1997; Mengshoel et al., 2000; Missaoui et al., 2008; Sturnieks et al., 2004). In RA, the synovial membrane secretes a large amount of fluid, which stretches the capsule of the joint leading to widespread lesions of the structures situated in and around the joints (particularly ligaments and adjacent tendons). These signs, however, are very rarely observed in patients with OA. We suppose that these differences between the two diseases may explain the higher degree of increase in the sway paths on foam surface in patients with RA.

One of our aims was to determine the changes in balance control on a compliant surface as it is well known that in the case of joint damage, balance impairment usually occurs during walking, stair climbing or standing on an unstable supporting surface, and less frequently during static activities (Aydoğ et al., 2006; Missaoui et al., 2008). Our findings

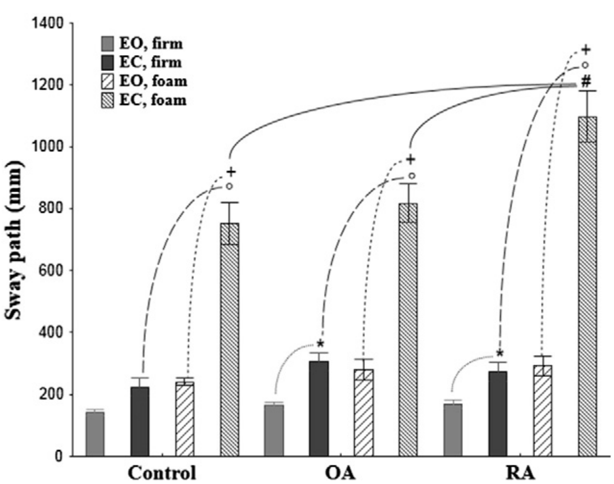

Fig. 1. Sway path (mean and SE) in AP direction in the control, OA and RA groups, standing on firm or foam surface with open or closed eyes (EO, eyes open; EC, eyes closed). Firm surface: Statistically significant differences ($p < 0.05$) in OA and RA groups in EC condition in comparison with the EO condition (*). Foam surface: Statistically significant differences ($p < 0.05$) in all groups in EC condition in comparison with the EO condition (+), and as compared with standing on firm surface with closed eyes (○). Statistically significant differences ($p < 0.05$) in RA group with eyes closed in comparison with the OA and control groups (#).

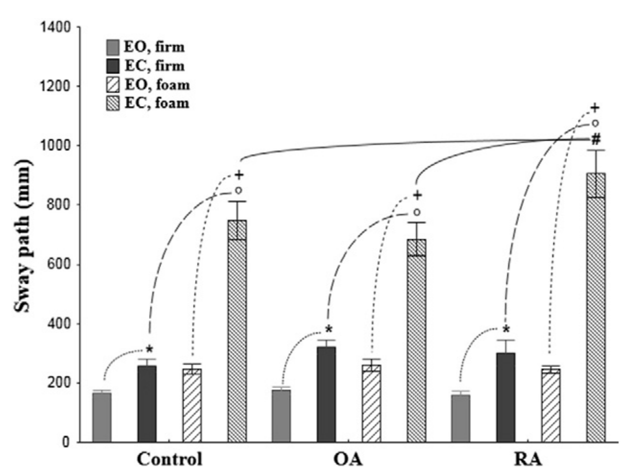

Fig. 2. Sway path (mean and SE) in ML direction in the control, OA and RA groups, standing on firm or foam surface with open or closed eyes (EO, eyes open; EC, eyes closed). Firm surface: Statistically significant differences ($p < 0.05$) in all groups in EC condition in comparison with the EO condition (*). Foam surface: Statistically significant differences ($p < 0.05$) in all groups in EC condition in comparison with the EO condition (+) and as compared with standing on firm surface EC condition (○). Statistically significant differences ($p < 0.05$) in RA group with eyes closed in comparison with the OA and control groups (#).

support these results, as the sway paths in RA increased significantly on a foam surface in EC condition compared to the OA and control groups.

Although in our findings sway path increased in both directions in the RA group standing on a foam surface when the eyes were closed, we should emphasize the importance of the ML axis, as several studies have reported lateral instability to be a marker of impaired balance control in older persons, and the increased ML sway to be an indicator of the risk of falling (Maki and McIlroy, 1996, 1997; Maki et al., 1994; Mitchell et al., 1995). Hip joint strategies and hip ab/adductor muscle function play essential roles in balance control, especially on a compliant surface. Nashner and McCollum (1985) have suggested that hip strategy could be observed in situations when the effectiveness of the ankle torque is limited during whole-body motion (e.g., compliant or shortened support surfaces). During standing still in a side-by-side stance position, the frontal plane (ML) balance is supported by hip (ab/adductor) control (Williams et al., 1997; Winter et al., 1996). As we found disturbed postural control in RA patients standing on a compliant surface, this could predict the higher risk of falling in this patient group.

Wu and Chiang (1996) have reported that pressure inputs from the foot decreased during standing on a compliant surface, as tactile and pressure information from the plantar mechanoreceptors are inaccurate during this situation; thus, mainly the visual and vestibular inputs would assist orientation during standing on foam. In our results, the significant increase in sway paths in the RA group as compared to OA and control persons might suggest a greater degree of visual dependence of RA patients while standing on a compliant surface, which might be due to the damaged hip joint's proprioception and the disturbed neuromuscular control. The question arises of whether increased sway paths of our RA patients standing on foam in EC condition could be at least partially due to the impaired vestibular function. We would suggest, even if a vestibular problem has not been diagnosed yet, CTSIB (Shumway-Cook and Horak, 1986) or modified CTSIB could be the proper assessment to detect such problems at an early stage. Preszner-Domjan et al. (2012) have used a modified CTSIB method to investigate the effect of plantar sole stimulation on balance parameters in healthy adults. Standing on a foam surface, the main effect of vision was observed, as closed eyes caused significant increase in the sway paths in AP and ML directions in the baseline measurements and also after applying stimulations. We suppose that the combined application of foam surface and EC condition can reveal fine differences in balance disorders caused by OA or RA. Similar to their results, the manipulation of both visual and somatosensory information by EC and foam surface caused about 400% increase in the sway paths in all groups in both directions.

The functional status of patients with degenerative or inflammatory hip diseases was significantly impaired as compared to healthy subjects. RA is a chronic disease characterized by inflammatory flares primarily localized to the synovia of the joints and tendon sheaths. Inflammation may cause pain and episodic or permanent changes in muscles and joints. These temporary or permanent factors may result in physical inactivity and dysfunction. Pain, stiffness and fatigue are reported as common symptoms by RA patients. With these symptoms, RA patients often have problems in physical activity and in several activities of daily living (Guccione, 1994; Mengshoel et al., 2000; Pincus et al., 1983). Inactivity and physical dysfunction can lead to reduced muscle strength and muscle endurance, and vice versa; deficits in muscle function are also likely to affect proprioception and balance strategies (Aydoğ et al., 2006; Ekdahl and Broman, 1992; Hassan et al., 2001; Mengshoel et al., 2000; Sturnieks et al., 2004). Appropriate physical therapy, by increasing muscle strength and proprioception, can improve balance and prevent falls in people with deficits in the joints of the lower extremities (Aydoğ et al., 2006; Sturnieks et al., 2004; Williams et al., 2010). An important way of improving the control of ML stability and preventing falls could be enabling patients to control a greater degree of freedom of their hip joints, as it has been highlighted earlier (Nagy et al., 2007); thus, further research is planned to extend the study and investigate the effects of exercise training on balance disorders caused by degenerative or inflammatory joint diseases.

Pain is an important sign of both of these diseases. Poorer functional status and balance is often associated with pain, and pain is determined as an important factor in functional and balance impairments, which can contribute to fall risk (Hassan et al., 2001; Jamison et al., 2003; Sturnieks et al., 2004). In our findings, pain appeared to be an affecting factor in the level of the daily activities, as positive correlations were found between pain and WOMAC C (disability) scores. However, pain does not seem to be the cause of the differences between the two groups, since the pain score did not differ between the two groups, the pain score and sway paths did not correlate, which suggests that balance disturbances in this condition may result from factors other than pain (intracapsular components, adjacent tendons or muscles). Similarly to our results, Ekdahl and Broman (1992) have found that postural sway does not correlate to the pain scale in RA patients, while Arokoski et al. (2006) have shown that unilateral osteoarthritis does not modify postural balance, and they suggest that unstability is more proportionate to the pain caused by disease. As we did not find correlation between pain and balance parameters, we suggest that the widespread sensorimotor deficit, the lack of proprioceptive information and disturbed neuromuscular control caused by the inflammatory process affecting the hip could result in disturbed balance in RA patients tested on compliant surface in EC condition. However, our recent study has shown that the level of β-endorphin is significantly higher in RA patients compared to OA ones (Toth et al., 2011), and this enhanced endogenous opioid level in RA patients can decrease the pain sensation, but it seems that it will not influence postural control.

5. Limitations

It was supposed that the same order of investigation ensured that all the patients could be customized to the task for identical conditions; however, it cannot be excluded that habituation to the experimental conditions did not influence the results. An important limitation of our study was the small number of subjects in the different groups. The exclusion criteria were very strict for the selection of patients, and only few patients could be involved in the study, and especially few patients were available with unilateral hip impairments in the RA group. Even with these strict criteria, we could not totally exclude the possibility of the involvement of other lower limb joints beside the hip, as RA is an inflammatory polyarthritis which can affect any of the small and large joints. However, based on the above-mentioned results, we suppose that primarily the chronic inflammatory processes in the synovia of the joints and tendon sheaths might have led to the differences. However, further studies are required in this respect.

6. Conclusions

Our data supported earlier studies showing slight disturbances in postural control in patients with hip joint impairments. However, manipulation of both visual and somatosensory information by EC and standing on foam surface can unmask the effects of joint impairments on postural control in RA patients, which might be significant in patients during daily routine conditions. Therefore, patients with RA might require special physiotherapeutic intervention with attention to the improvement of the postural control. The sensorimotor deficit caused by the inflammatory process affecting the hip joint could result in disturbed postural control in RA patients. We suppose that the combination of compliant surface and EC conditions can reveal subtle disturbances and differences between OA and RA patients in balance control. Furthermore, it is suggested that early, effective treatment of these patients, including both pharmacological and physiotherapeutic approaches, might be crucial to prevent the impairment of postural control leading to accidents.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors are grateful to Cs. Keresztes for linguistic correction of the manuscript. The authors would like to thank all participants. We declare that the experiments reported in this paper fully comply with all current Hungarian laws and regulations.

References

Arokoski, J.P.A., Leinonen, V., Arokoski, M.H., Aalto, H., Valtonen, H., 2006. Postural control in male patients with hip osteoarthritis. Gait Posture 23, 45–50.
Aydoğ, E., Bal, A., Aydoğ, S.T., Çakci, A., 2006. Evaluation of dynamic postural balance using the Biodex Stability System in rheumatoid arthritis patients. Clin. Rheumatol. 25, 462–467.
Badley, E.M., Ibañez, D., 1994. Socioeconomic risk factors and musculoskeletal disability. J. Rheumatol. 21, 515–522.
Barrett, D.S., Cobb, A.G., Bentley, G., 1991. Joint proprioception in normal, osteoarthritic and replaced knees. J. Bone Joint Surg. (Br.) 73, 53–56.
Bellamy, N., Buchanan, W.W., Goldsmith, C.H., Campbell, J., Stitt, L.W., 1988. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J. Rheumatol. 15, 1833–1840.
Boonen, A., Severens, J.L., 2011. The burden of illness of rheumatoid arthritis. Clin. Rheumatol. 30 (S1), S3–S8.
Brandt, T., Paulus, W., Straube, A., 1986. Vision and posture. In: Bles, W., Brandt, T. (Eds.), Disorders of Posture and Gait. Elsevier, Amsterdam, pp. 157–175.
Brooke-Wavell, K., Perret, L.K., Howarth, P.A., Haslam, R.A., 2002. Influence of the visual environment on the postural stability in healthy older women. Gerontology 48, 293–297.
Cross, M.J., McCloskey, D.I., 1973. Position sense following surgical removal of joints in man. Brain Res. 55, 443–445.
Ekdahl, C., Broman, G., 1992. Muscle strength, endurance, and aerobic capacity in rheumatoid arthritis: a comparative study with healthy subjects. Ann. Rheum. Dis. 51, 35–40.
Fridén, T., Zätterström, R., Lindstrand, A., Moritz, U., 1990. Disability in anterior cruciate ligament insufficiency. An analysis of 19 untreated patients. Acta Orthop. Scand. 61, 131–135.
Guccione, A.A., 1994. Arthritis and the process of disablement. Phys. Ther. 74, 408–414.
Harris, W.H., 1969. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J. Bone Joint Surg. Am. 51, 737–755.
Hassan, B.S., Mockett, S., Doherty, M., 2001. Static postural sway, proprioception, and maximal voluntary quadriceps contraction in patients with knee osteoarthritis and normal control subjects. Ann. Rheum. Dis. 60, 612–618.
Heinegård, D., Saxne, T., 2011. The role of the cartilage matrix in osteoarthritis. Nat. Rev. Rheumatol. 7, 50–56.
Hinman, R.S., Bennell, K.L., Metcalf, B.R., Crossley, K.M., 2002. Balance impairments in individuals with symptomatic knee osteoarthritis: a comparison with matched controls using clinical tests. Rheumatology (Oxford) 41, 1388–1394.
Hurley, M.V., 1997. The effects of joint damage on muscle function, proprioception and rehabilitation. Man. Ther. 2, 11–17.
Hurley, M.V., Rees, J., Newham, D.J., 1998. Quadriceps function, proprioceptive acuity and functional performance in healthy young, middle-aged and elderly subjects. Age Ageing 27, 55–62.
Ischii, Y., Tojo, T., Terajima, K., Terashima, S., Bechtold, J.E., 1999. Intracapsular components do not change hip proprioception. J. Bone Joint Surg. (Br.) 81, 345–348.
Jamison, M., Neuberger, G.B., Miller, P.A., 2003. Correlates of falls and fear of falling among adults with rheumatoid arthritis. Arthritis Rheum. 49, 673–680.
Lee, D.L., Lishman, J.R., 1977. Vision, the most efficient source of proprioceptive information for balance control. Agressologie 18, 83–94.
Lugade, V., Klausmeier, V., Jewett, B., Collis, D., Chou, L.S., 2008. Short-term recovery of balance control after total hip arthroplasty. Clin. Orthop. Relat. Res. 466, 3051–3058.
Maki, B.E., McIlroy, W.E., 1996. Postural control in the older adult. Clin. Geriatr. Med. 12, 635–658.
Maki, B.E., McIlroy, W.E., 1997. The role of limb movements in maintaining upright stance: the "change-in-support" strategy. Phys. Ther. 77, 488–507.
Maki, B.E., Holliday, P.J., Topper, A.K., 1994. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J. Gerontol. 49, M72–M84.
Marchetti, P., Binazzi, R., Vaccari, V., Girolami, M., Morici, F., Impallomeni, C., Commessatti, M., Silvello, L., 2005. Long-term results with cementless Fitek (or Fitmore) cups. J. Arthroplast. 20, 730–737.
Marks, R., Quinney, H.A., Wessel, J., 1993. Proprioceptive sensibility in women with normal and osteoarthritic knee joints. Clin. Rheumatol. 12, 170–175.
McChesney, J.W., Woollacott, M.H., 2000. The effect of age-related declines in proprioception and total knee replacement on postural control. J. Gerontol. A Biol. Sci. Med. Sci. 55, 658–666.
Mengshoel, A.M., Clarke-Jenssen, A.C., Fredriksen, B., Paulsen, T., 2000. Clinical examination of balance and stability in rheumatoid arthritis patients. Physiotherapy 86, 342–347.
Missaoui, B., Portero, P., Bendaya, S., Hanktie, O., Thoumie, P., 2008. Posture and equilibrium in orthopaedic and rheumatologic diseases. Neurophysiol. Clin. 38, 447–457.
Mitchell, S.L., Collins, J.J., De Luca, C.J., Burrows, A., Lipsitz, L.A., 1995. Open-loop and closed-loop postural control mechanisms in Parkinson's disease: increased mediolateral activity during quiet standing. Neurosci. Lett. 197, 133–136.
Murphy, L.B., Helmick, C.G., Schwartz, T.A., Renner, J.B., Tudor, G., Koch, G.G., Dragomir, A.D., Kalsbeek, W.D., Luta, G., Jordan, J.M., 2010. One in four people may develop symptomatic hip osteoarthritis in his or her lifetime. Osteoarthr. Cartil. 18, 1372–1379.
Nagy, E., Feher-Kiss, A., Barnai, M., Domján-Preszner, A., Angyan, L., Horvath, G., 2007. Postural control in elderly subjects participating in balance training. Eur. J. Appl. Physiol. 100, 97–104.
Nallegowda, M., Singh, U., Bhan, S., Wadhwa, S., Handa, G., Dwivedi, S.N., 2003. Balance and gait in total hip replacement: a pilot study. Am. J. Phys. Med. Rehabil. 82, 669–677.
Nantel, J., Termoz, N., Centomo, H., Lavigne, M., Vendittoli, P.A., Prince, F., 2008. Postural balance during quiet standing in patients with total hip arthroplasty and surface replacement arthroplasty. Clin. Biomech. 23, 402–407.
Nashner, L., McCollum, G., 1985. The organisation of human postural movements: a formal basis and experimental synthesis. Behav. Brain Sci. 8, 135–172.
Pincus, T., Summey, J.A., Soraci, C., Wallston, K.A., Hummon, N.P., 1983. Assessment of patient satisfaction in activities of daily living using a modified Stanford Health Assessment Questionnaire. Arthritis Rheum. 26, 1346–1353.
Preszner-Domjan, A., Nagy, E., Szíver, E., Feher-Kiss, A., Horvath, G., Kranicz, J., 2012. When does mechanical plantar stimulation promote sensory re-weighing: standing on a firm or compliant surface? Eur. J. Appl. Physiol. 112, 2979–2987.
Renström, P.A., Konradsen, L., 1997. Ankle ligament injuries. Br. J. Sports Med. 31, 11–20.
Rome, K., Dixon, J., Gray, M., Woodley, R., 2009. Evaluation of static and dynamic postural stability in established rheumatoid arthritis: exploratory study. Clin. Biomech. 24, 524–526.
Schmidt, R.A., 1975. A schema theory of discrete motor skill learning. Psychol. Rev. 82, 225–260.
Sheldon, J.H., 1963. The effect of age on the control of sway. Gerontol. Clin. (Basel) 5, 129–138.
Shumway-Cook, A., Horak, F.B., 1986. Assessing the influence of sensory interaction on balance: suggestion from the field. Phys. Ther. 66, 1548–1550.
Shumway-Cook, A., Brauer, S., Woollacott, M., 2000. Predicting the probability for falls in community-dwelling older adults using the timed up & go test. Phys. Ther. 80, 896–903.
Sturnieks, D.L., Tiedemann, A., Chapman, K., Munro, B., Murray, S.M., Lord, S.R., 2004. Physiological risk factors for falls in older people with lower limb arthritis. J. Rheumatol. 31, 2272–2279.
Toth, K., Barna, I., Nagy, G., Wellinger, K., Horvath, G., Bender, T., 2011. Synovial fluid β-endorphin level in avascular necrosis, rheumatoid arthritis, and osteoarthritis of the femoral head and knee. A controlled pilot study. Clin. Rheumatol. 30, 537–540.
Tropp, H., Odenrick, P., 1988. Postural control in single-limb stance. J. Orthop. Res. 6, 833–839.
Williams, S.B., Brand, C.A., Hill, K.D., Hunt, S.B., Moran, H., 2010. Feasibility and outcomes of a home-based exercise program on improving balance and gait stability in women with lower-limb osteoarthritis or rheumatoid arthritis: a pilot study. Arch. Phys. Med. Rehabil. 91, 106–114.
Williams, H.G., McCleanaghan, B.A., Dickerson, J., 1997. Spectral characteristic of postural control in elderly individuals. Arch. Phys. Med. Rehabil. 78, 737–744.
Winter, D.A., Prince, F., Frank, J.S., Powell, C., Zabjik, K.F., 1996. A unified theory regarding A/P and M/L balance in quiet stance. J. Neurophysiol. 75, 2334–2343.
Woolf, A.D., Pfleger, B., 2003. Burden of major musculoskeletal conditions. Bull. World Health Organ. 81, 646–656.
Wu, G., Chiang, J.H., 1996. The effects of surface compliance on foot pressure in stance. Gait Posture 4, 122–129.
Zimny, M.L., 1988. Mechanoreceptors in articular tissues. Am. J. Anat. 182, 16–32.