Muscle Activation Pattern of Hip Arthroplasty Patients in Walking

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This study examined the hip abductor activation pattern of 14 hip replacement patients and 10 age-matched healthy controls by measuring surface electromyography (EMG) onset and cessation times. Stride characteristics, surface EMG from bilateral gluteus medius, and 3D pelvis kinematics were evaluated during treadmill ambulation. EMG onset times were normalized with regard to the individual stride time for each gait cycle. An ANOVA revealed significantly delayed EMG onset times (p < .001) in comparing hip abductors of the operated side with the unimpaired side and the healthy controls. Between subject effects also demonstrated significant differences (p < .01) for stance duration and sagittal pelvis range of motion. No significant differences were found for EMG cessation times and angular pelvis peak-to-peak ranges in the frontal and transverse planes. The results indicated deficiencies in the hip abductor recruitment pattern of hip arthroplasty patients. Further analysis should explore whether specific exercises, or rehabilitation programs can facilitate adequate muscle activation.

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Introduction

Following total hip replacement, the emphasis in rehabilitation lies on the optimization of independence in activities of daily living. Therefore hip abductor strength training is a standard recommendation after total hip arthroplasty (Horstmann, Martini, Mayer, et al. 1995; Vaz, Kramer, Rorabeck, et al. 1993). However, studies have demonstrated continued weakness on the side of the operated hip up to several months after surgery (Shih, Du, and Lin 1994). Despite concern about the importance of hip abductor strength training to improve patients’ gait performance, ambulatory independence and pelvis control only few studies have analyzed the neuromuscular activation of hip surrounding muscles (Long, Dorr, Healy, et al. 1993; Perron, Malouin, Moffet, et al. 2000). No study has clearly concentrated on the contractile pattern of the hip abductor muscles in walking and their control function for pelvis balance in the frontal plane.

For this reason the present study intends to provide a more detailed look at the hip abductor recruitment pattern of patients with a single hip arthroplasty by measuring surface EMG onset and cessation times.

Methods

Fourteen total hip replacement (THR) patients (9 m., 5 f.) with a mean age of 63 (56–72) years and 10 age-matched healthy volunteers (Ctrl; 7 m., 3 f.; average age 61 [47–71] years) participated in the investigation after the study was approved by the university’s ethics committee. Each subject of the control group was asymptomatic and denied any previous neurological, muscular, or skeletal disability. Hip arthroplasty subjects were 31 to 46 days postsurgery (average 41 days) and had completed their prescribed 3 week inpatient rehabilitation regimen before testing. The rehabilitation program included active stretching and strengthening exercises for the involved muscles, functional activities, ambulation, and stair climbing. The therapeutic exercises were initiated at the first postoperative day and carried out 5 days per week until rehabilitation discharge. Patients with bilateral hip arthroplasty, vascular insufficiency, or systemic problems (e.g. cancerous, cardiovascular, or endocrinologic diseases) as well as patients with concomitant ipsilateral knee, ankle, or foot problems were excluded from the study. Left and right leg length—measured as the distance between the superior anterior spine of the iliac bone and the medial malleolus—was not allowed to show more than 1cm inequality. All patients were rigorously screened and inducted into the study by one clinician skilled in the evaluation of hip diseases. The indication for surgery was degenerative arthritis of the hip. The hip arthroplasty surgeries were performed at three different hospitals. All hips were
Muscle Activation Pattern of Hip Arthroplasty Patients in Walking

Postoperative pain, stiffness, and function during routine activities were assessed by the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Reliability and validity of this condition-specific instrument, in which lower scores are better, has been extensively described (Bellamy, Buchanan, Goldsmith, et al. 1988; Stucki, Meier, Stucki, et al. 1996). Postoperative gait analysis evaluated stride characteristics, surface EMG from bilateral gluteus medius, and 3D pelvis kinematics. Bipolar (Ag/AgCl) surface electrodes (BlueSensor®) with an interelectrode distance of 20mm were used to sample EMG activity during treadmill ambulation (Woodway® Reha ES2, Germany) at self-selected walking speeds (2.4–4.5 km/h). The reference electrode was attached to the subjects’ posterior superior iliac spine. The skin of the recording site was prepared by shaving, sanding, and rubbing with gauze saturated with alcohol. All electrode cables were secured with tape to reduce any possibility of artifact produced by cable movement. Prior to testing the subjects had time to practice treadmill walking until they reported they had gotten used to the walking conditions. The treadmill habituation time ranged from 4 to 10 min. The EMG activity was recorded by a multichannel EMG datalogger system (BIOVISION®, Germany) operating at 1000 Hz. A minimum of 20 successful walking cycles formed the basis for all subsequent analysis. Muscle onset/cessation was considered to have occurred when 25 consecutive data points of a sliding window exceeded the current mean baseline by three-standard deviations. EMG onset and cessation times were normalized with regard to the individual stride time (% stride) for each gait cycle (Vogt, Pfeifer, and Banzer 2003) and ensembled averaged. The different phases of the gait cycle were registered by four pressure-sensitive footswitches. The ZEBRIS CMS70® ultrasound movement analysis system, with an absolute accuracy better than 0.6 mm (Himmelreich, Stefanicki, and Bunzer 1998), was used for movement data acquisition. Sufficient test–retest reliability of the measurement system has been demonstrated for gait analysis and gross motions of the trunk (Vogt and Banzer 1997; Portscher, Vogt, Pheifer, et al. 2000). Three ultrasound microphones, determining a local cartesian coordinate system, were used to track (50Hz) a small lightweight T-plate with three ultrasonic markers attached to the posterior midline of the sacrum (S1). Angles were defined as cardanic angles of a single body segment. The three coordinate axes were defined using the three markers on the rigid T-plate. The medial–lateral axis was orientated as a line passing through the two markers on the lateral ends of the T-plates’ horizontal bar with its positive direction to the left. The vertical axis was constructed to lie in the plane formed by all three markers of the rigid T-plate, orthogonal to the medial-lateral axis with its positive direction upward. The body embedded anterior–posterior axis was perpendicular to both the medial–lateral and the vertical axes with its positive direction forward. Prior to testing, subjects were asked to maintain a relaxed upright posture with surface markers visible to the ultrasound...
The anatomical orientation of the pelvis was defined as zero for computing relative angular displacement during the movement. The obtained net angular displacements were low-pass filtered (2nd order, critical damped, double pass) using a cutoff frequency of 6 Hz, normalized with regard to the stride time (one stride corresponds to 100%) and ensembed averaged at intervals of 1% of the gait cycle, to give the mean and standard deviation for that subject. Data were processed using LabView (National Instruments®) and ALEA® Solution software (Switzerland). Levene’s test for homogenity of variance and univariate two-factor (group × body side) ANOVA for repeated measures were selected to determine significant differences in stance durations and EMG measurements. Scheffé test was used for post-hoc analysis of significant findings. Mean rotation amplitudes of the pelvis were compared using Student t-tests. \(P<0.05\) was regarded as significant.

**Results**

All patients walked without walking aids and were able to ambulate on the treadmill while not holding onto the handrail for support. The average WOMAC Osteoarthritis Index was 8.52 (range: 0–17.25) for the operated side and 0.73 (range: 0–7.35) for the nonoperated limb on the day of investigation.

In comparing the hip abductors of the operated side with the nonoperative side and the healthy controls repeated measures ANOVA revealed a significantly (\(P<.001\)) delayed EMG onset on the operative side (Table 1). Thus, due to the extremely shortened preactivation phase of the gluteus medius muscle of the replaced hip, the electrical onset occurred almost simultaneously with the ipsilateral heel contact (Figure 1). Additionally the analysis indicated significant differences (\(P<.01\)) for stance duration (THR: operated 58.1 \(\pm\) 6.8%; nonoperated 65.2 \(\pm\) 3.9% vs. Ctrl: right 64.8 \(\pm\) 2.7%; left 64.6 \(\pm\) 2.8%) and a increased pelvis range of motion in the sagittal plane (\(P<.01\)) after hip arthroplasty. There were no significant differences found for EMG cessation times and angular pelvis peak-to-peak ranges in the frontal and transverse planes (Table 1). No significant side differences in gait cycle durations were detected. Bivariate correlation analysis revealed a negative linear association (\(r = –.761; P<.05\)) between the delayed onset in hip abductor activity and the reduced stance time duration.

**Discussion**

The present findings, obtained at rehabilitation discharge, indicated that patients who had undergone a total hip replacement operation, following hip osteoarthritis, continue to walk with particular disorders even though they received a guided 3-week inpatient exercise program. The determined changes in stride characteristics are consistent with those of other authors (James, Nicol, and Hamblen 1994; McCrory, White, and Lifeso 2001), who also found that hip arthroplasty...
Table 1
Average Range of Motion of Angular Sacrum Movements and EMG Onset and Cessation Times for THR and Control Subjects

<table>
<thead>
<tr>
<th>Sacrum, range of motion [degree]</th>
<th>EMG, onset/cessation [% gait cycle]</th>
</tr>
</thead>
<tbody>
<tr>
<td>frontal</td>
<td>operated/left</td>
</tr>
<tr>
<td>sagittal</td>
<td>operated/left</td>
</tr>
<tr>
<td>transverse</td>
<td>operated/left</td>
</tr>
<tr>
<td>THR</td>
<td>3.3 +/- 1.7</td>
</tr>
<tr>
<td>Ctrl</td>
<td>4.5 +/- 1.3</td>
</tr>
</tbody>
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Note: (Mean, 1SD) (**p < .01; *p < .001).
patients walk with a considerable asymmetry of stance times. At this early postoperative stages the majority of patients had shorter stance periods on the operated limb. However, studies (Murray, Brewer, and Zuege, 1972) revealed continued postoperative improvement where the stance times for the two limbs become more equal after the third and sixth postoperative months (Murray, Gore, Brewer, et al., 1979).

The results showed that the calculated reference means and standard deviations of pelvis movement amplitudes meet normal reference limits, reported in other studies (Vachalathiti, and Smith Thurston 1982; Crosbie, 1997). The patients’ increased anterior–posterior pelvic tilting, seen in the current investigation, might compensate for movement reductions in the hip joint because of postoperative hip flexion contractures, or due to the failure to correct the antalgic preoperative gait pattern. These speculations are supported by Jacobs, Shorecki, and Charnley (1972), who also noted that patients produced larger movements of the pelvis helping to minimize movement of the hip joint.

The postoperative analysis of EMG peak characteristics and the linear relationship between stance time and EMG onset provided preliminary evidence that hip arthroplasty patient’s gait patterns are characterized by some deficiencies in the hip abductor recruitment. These findings are in agreement with data of Franz and coworkers (2002), who described later preactivation of the gluteal muscles during walkway ambulation. Even though the patients in the present research

Figure 1. Characteristic raw EMG’s (operated and unoperated side) of one hip arthroplasty patient during iterated walking trials.
Muscle Activation Pattern of Hip Arthroplasty Patients in Walking

experienced only moderate pain intensities at the time of testing, their hip abductor activation pattern was marked by a significant delay probably adopted when these subjects had intense and usually constant pain in the hip joint before surgery. Because it is assumed that muscular dysfunction around the hip joint is secondary to pathologic hip pain (Andersson, Kammerere, and Greer 1979; Shih, Du, and Lin 1994), the delayed recruitment strategy of the hip abductors could be interpreted as a preoperative functional adaptation of the neuromuscular system to decrease joint pressure and to prevent additional pain.

Although it is likely that a preoperative gait habit is carried on after joint arthroplasty, there are other possible interrelated causes for the subnormal abductor function. Among these are surgical trauma because of stretching and retraction force inherent in the surgical approach; injury to its innervation (Baker and Bitounis 1989); and decreased mechanical and physiological advantage of the hip muscles, which may result from bony leverage changes or from shortened distances between the origin and insertion of the hip muscles.

Another possible explanation for the altered muscle function may be that patients’ proprioception in the hip joint was affected (Grigg, Finerman, and Riley 1973; Skinner 1993). This complex process of peripheral feedback and afferent information is likely to play an important role in the control of locomotion. Following suggestions from previous investigations (Skinner 1993), receiving less or possibly inappropriate spatial, temporal, or kinetic information might impair the precise control of the timing of events in the gait cycle.

On the other hand, it is worth noting that hip abductor dysfunction might be more of a problem in the anterolateral or Hardinge approach (Fagerson 1998), which can involve more disruption to gluteus medius.

Regardless of whether the mentioned changes could be attributed to preoperative adaptations, surgical trauma, neural impairment, inadequate or diminished joint proprioception, altered muscle activity could change the hip joint forces and lead to joint instability or a loss of balance (MacKinnon and Winter 1993), probably increasing the risk of injury and falls. Moreover atypical gait patterns could have an impact on the physiological loading of adjacent structures and may contribute to arthritic changes at the contralateral hip level.

Long-term investigations should evaluate if the EMG onset differences between limbs will diminish with increasing stance time symmetry (Murray et al. 1979). Studies also should overcome one limitation of the present research by additionally measuring muscle strength.

Conclusions

Although patients with THR can make significant improvements in hip abductor strength following surgery (Kilgus, Amstutz, and Wolgin 1990; Sicard-Rosenbaum, Light, and Behrman 2002), additional rehabilitative emphasis should be placed on the optimization of muscle activation patterns. It could be speculated that hip
arthroplasty patients may profit from specific exercises or rehabilitation programs to facilitate adequate muscle activation in different types of motor activities. Therefore, strengthening exercises for the hip abductors could be combined with specific therapeutic interventions, as they have been shown by Bullock-Saxton, Janda, and Bullock (1993), to influence the intensity and timing of muscle activation.

Further analysis should focus on possible ways of therapeutic interventions and explore whether specific exercises or rehabilitation programs can facilitate adequate muscle activation.

References


Muscle Activation Pattern of Hip Arthroplasty Patients in Walking


