The effect of knee arthroplasty on balancing ability in response to sudden unidirectional perturbation in the early postoperative period

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Article history:
Received 26 August 2014
Received in revised form 12 February 2015
Accepted 18 February 2015

Keywords:
Total knee replacement
Ultrasound-based measurement system
Sudden perturbation
Balancing ability
Lehr's damping ratio

Introduction and objective: Total knee arthroplasty (TKA) affects 1–3% of the entire population. The effectiveness of surgery and rehabilitation are of great significance. The goal of this study was to determine how different surgical methods (i.e., conventional and minimally invasive) influence balancing ability in response to sudden unidirectional perturbation during the first 12 weeks of the postoperative period.

Materials and methods: The balancing capacity after sudden unidirectional (horizontal) perturbation of 10 patients who had undergone TKA operations via the conventional method and 10 patients who had undergone TKA operations via the minimally invasive method were examined before and six and 12 weeks after TKA. Forty-five health age-matched participants composed the control group. The balancing capacities following unidirectional perturbation were characterised by the Lehr's damping ratio, which was calculated based on the results of the provocation tests that were performed with the patients standing on both the affected and non-affected limbs.

Results: In both patient groups, the Lehr's damping ratios increased during the postoperative period. However, in both patient groups, the Lehr's damping ratios calculated from the results of all three of the testing methods decreased compared to values obtained from the controls even at 12 weeks postoperatively. Six and 12 weeks after TKA, the Lehr's damping ratios of the patients who underwent operations utilising the minimally invasive exposure method were significantly higher than the values obtained from the patients who underwent operations by conventional exposure.

Discussion and conclusions: In both patient groups, the balancing capacities continuously improved over the first 12 weeks of the postoperative period, but the dynamic balancing capacities while standing on both limbs, on the affected limb and on the non-affected limb significantly differed from those of the controls. The balancing capacities of the patients who underwent the minimally invasive exposure procedures improved more rapidly than did the capacities of the patients who underwent operations utilising the conventional exposure method. This reduced balancing capacity should be considered when developing dynamic balancing abilities and abandoning therapeutic aids, and the difference in dynamic balancing abilities between the two patient groups should also be considered.

1. Introduction

Due to the ageing of the population, the frequency of knee osteoarthritis is increasing in a manner similar to that observed for hip osteoarthritis in recent decades. Knee osteoarthritis affects nearly 3% of the entire population. In greater than 5% of the elderly population, knee osteoarthritis is sufficiently serious that total knee arthroplasty is a reasonable option (Dillon et al., 2006; Felson and Zhang, 1998). Total knee arthroplasty (TKA) reduces pain and partially restores functional abilities; however, gait parameters (i.e., spatial, temporal and angular parameters; Bejek et al., 2011; Fuchs et al., 2002; Smith et al., 2006), including gait variability and stability (Kiss et al., 2012; McClelland et al., 2009; Yakhdani et al., 2010) do not return to normal values even over one-year long postoperative periods.

The effects of TKA on joint proprioception that have been reported in previous studies remain contradictory because some authors have reported decreases (Barrack et al., 1983; Simmons...
et al., 1996; Skinner et al., 1984), but other authors have reported positive changes (Atfield et al., 1996; Barrett et al., 1991; Ishii et al., 1997; Swanik et al., 2004; Warren et al., 1993) in joint proprioception after TKA.

Balance control is a complex sensorimotor function that involves components of movement detection and the control of coordinated voluntary and reflexive motor responses. Postural control is influenced not only by proprioceptive, visual and vestibular inputs and outputs but also by the conditions of the different joints (Fitzpatrick and McClosky, 1994). Seventeen days after TKA, the areas and paths of centre of pressure (COP) sway are much larger amongst patients than amongst control groups (Gauchard et al., 2010). Although the postural parameters improve significantly 6 weeks after TKA relative to the preoperative measurements, these measurements do not reach the values of control groups (Gauchard et al., 2010). Six months after TKA, balancing capacities during bipedal stances on unstable plates (Swanik et al., 2004) and during bipedal and monopedal stances on stable plates (Isaac et al., 2007) significantly improve compared to the results obtained prior to TKA. The postural parameters measured during bipedal stances improve significantly during later postoperative periods (i.e., after 6 months), but these values do not reach those of control groups even one year after TKA (Quagliarella et al., 2011).

In everyday life, people often encounter balancing after being bumped into while walking or standing. Highly complex coordination is required to attempt to regain balance after a sudden impulse or change in direction during standing, sitting, walking and running (Winter, 1995). This means that the examination of balancing capacity following sudden perturbation is more sensitive than the examination of balance control during standing (Kiss, 2011). Decreases in equilibrium might also be associated with an increased risk of falling (Robbins et al., 1989). The results of previous research have established that balancing capacity following sudden perturbation amongst patients with knee osteoarthritis is reduced compared to control participants (Kiss, 2012).

To our knowledge, no study has examined the effects of the surgical technique of TKA on balancing abilities after sudden perturbations. The aim of this study was to specify the dynamic balancing ability in response to sudden unidirectional perturbation following different surgical techniques during TKA (conventional: total anterior exposure with medial parapatellar incision; minimal invasive technique: quadrupling or midvastus incision depending on the anatomical situation with computer-assisted navigation). The joint capsule and muscles around the joints are affected differently depending on the method of surgery; consequently, the method of surgery in the case of TKA has a considerable impact on gait parameters (Bejek et al., 2011) and gait variability (Kiss et al., 2012). Therefore, it can be presumed that postoperative changes in dynamic balancing ability will be different. If the method of surgery technique affects not only the gait parameters but the dynamic balancing ability as well, it could be an important issue for the consideration of different surgical methods and their post-operative treatments. For this purpose, balancing capacity tests after sudden perturbation were conducted prior to, as well as at 6 and 12 weeks and 6 months after TKA.

2. Materials and methods

2.1. Participants

Patients with severe knee osteoarthritis (OA) were selected randomly from amongst the patients of the Department of Orthopaedics of Semmelweis University (Budapest, Hungary), with the inclusion and exclusion criteria taken into account. The inclusion criteria were unilateral knee OA as evidenced by X-ray, patients who were ambulatory without the use of an assisting device, and patients with less than 15° varus and 10° valgus axis deviations and less than 15° flexion contracture. The exclusion criteria included any clinical history of lesion or surgery affecting a lower limb or the lumbar spine, OA affecting any other joint of a lower limb (i.e., the opposite knee joint or either hip joint), neuro- logical alterations (e.g., Parkinson’s, dementia, vertigo, or cerebral apoplexy), uncontrolled hypertonia, unstable angina, or vision correction greater than ±5 dioptres.

Twenty patients were randomly allocated into two groups of 10 patients each. All TKA patients were operated on at the Orthopaedics Clinic of Semmelweis University (Budapest, Hungary) by one experienced surgeon who was blinded to the procedure each patient was to receive until a few hours before surgery, when a sealed envelope revealed which technique was to be used. Four women (age 64.3 ± 5.1 years; body mass 77.5 ± 11.3 kg; body height 166.3 ± 5.2 cm) and 6 men (age 71.7 ± 4.2 years; body mass 89.4 ± 9.3 kg; body height 173.1 ± 9.4 cm) composed the first group and underwent operations involving conventional methods of exposure; 5 women (age 67.2 ± 3.4 years; body mass 75.9 ± 5.9 kg; body height 163.6 ± 7.1 cm) and 5 men (age: 68.3 ± 3.5 years; body mass 88.4 ± 14.3 kg; body height 168.2 ± 8.8 cm) composed the second group who underwent operation involving the minimally invasive method that utilises an imageless Stryker–Leibinger navigation system. The patients were provided with the same preoperative and postoperative treatments (e.g., anaesthesia and pain relief), and the rehabilitation of all the patients was supervised based on a previously arranged protocol by the same physiotherapist until the 12th postoperative week.

Twenty-two women (age 60.4 ± 4.1 years; body weight 69.7 ± 10.2 kg; body height 166.7 cm ± 3.8 cm) and 23 men (age 60.9 ± 3.2 years; body weight 70.4 ± 9.8 kg; body height 170.4 cm ± 5.8 cm) composed the control group that was involved in the study of the effects of knee osteoarthritis (Kiss, 2012). The healthy controls had no histories of osteoarthritis of the knee or hip joint, knee instability, or major lower extremity joint surgery. The controls also exhibited normal strength, full lower extremity ranges of motion, and no neurological or balance deficiencies. With the exception of the existence of knee osteoarthritis, the inclusion and exclusion criteria corresponded to the criteria for the patient group. The dominant sides (used for kicking a ball with maximum force) were the left in 4 females and 6 males and the right in 18 females and 17 males.

Each of the examined participant had no special sport, physical activity. Each of the examined participants provided written informed consent regarding the risks and benefits of the study and were given the opportunity to withdraw at any time. This study was authorised by the Science and Research Ethics Committee of Semmelweis University (111/2004).

2.2. Experimental procedure

The PosturoMed® device (Haider-Bioswing, Weiden, Germany) included a rigid platform (12 kg, 60 cm × 60 cm) connected to a rigid frame with eight 15-cm steel springs of identical strength; this allowed the platform to shift freely in two dimensions along the horizontal plane (Fig. 1). The four-spring condition was selected, which allows only unidirectional movement in the horizontal plane. A fastening unit (provocation unit) locked the platform into a fixed position (Fig. 1). The rigid plate was set into motion by releasing the unit out of a locked position, because the platform would swing back into the resting position, simulating a sudden unidirectional disturbance in the horizontal plane while standing. The participant had to counter this sudden disturbance to the
body's centre of balance with compensatory equilibrium reactions. The short name for this test was the provocation test (Müller et al., 2004; Boeer et al., 2010; Kiss, 2011), which models balancing capacity in response to sudden unidirectional perturbation.

The participants stood barefoot in a double-leg stance in the middle of the platform, the stance width of the feet was standardized by the width of each subject's shoulder. Each participant wore a safety harness, part of the PosturoMed device, which allowed natural arm motion. To reduce the effects of habituation, participants stood on the PosturoMed platform during the instruction to become accustomed to the unsteady platform. Participants were instructed to look straight ahead and to balance with arm motion, without holding onto anything. The platform was moved 20 mm in the medio-lateral direction towards the subject's dominant side during the double limb trials and towards the investigated limb during the single limb trials, and locked with the fastening unit. The participants assumed the standardized measuring position was taken as the damped oscillation (Fig. 2). The maximum difference in body mass (<15%) and body height (<7%) was small, so the influence of these physical factors on Lehr’s damping ratio (on the balancing capacity in response to a sudden unidirectional perturbation) is negligible. Previous research has shown that Lehr’s damping ratio is significantly affected by age and lateral dominance but not influenced by body mass, body mass index (BMI), and body height (Kiss, 2011). Kiss (2012) also established that Lehr’s damping ratio was influenced by the severity of osteoarthritis in the knee joints.

2.3. Statistical analysis

The Lehr’s damping ratio was expressed as the mean and SD. The normality of the data distribution was assessed by the Kolmogorov–Smirnov test, and an F-test was used to assess the
uniformity of standard deviations. The data received were analysed using a multi-variable ANOVA method, supplemented, if necessary, by a Tukey post-hoc test. For the healthy group, the variables included laterality (dominant and non-dominant) and subject gender (male or female). In the patient group, the variables included laterality (non-affected and affected), subject gender (male or female), testing time (preoperatively, 6 weeks, 12 weeks), and type of surgery (conventional and minimal invasive). Data were processed using an SPSS 14 software (SPSS, Chicago, IL, USA). Significance levels (p) were set at 0.05 in each case.

### 3. Results

The F-test results revealed the uniformity of the standard deviation, and the Kolmogorov–Smirnov test revealed a normal distribution. The result of the post hoc power analysis was 0.91. The Lehr’s damping ratio (D, %) was determined by the motion of the rigid plate during the provocation test; the figures are summarised in Table 1.

Amongst both patient groups, the Lehr’s damping ratio measurements were not affected by the participants’ gender (p > 0.09; Table 1).

Amongst the conventional exposure cases (Fig. 3) the Lehr’s damping ratios based on the values measured 6 weeks after TKA did not differ significantly compared to the Lehr’s damping ratios that were calculated from the preoperative values (p > 0.09). In the second part (i.e., from the 6th week until the 12th week) of the postoperative period, the Lehr’s damping ratios continuously increased; however, 12 weeks after TKA, these values were significantly lower (p < 0.008) than those of the controls.

In the cases of minimally invasive exposure (Fig. 4), the Lehr’s damping ratios based on the values measured at 6 and 12 weeks after TKA were significantly higher (p < 0.04) than those that were calculated from the preoperative values. However, even 12 weeks after TKA, the Lehr’s damping ratios were significantly smaller (p < 0.01) than those of the controls. In the postoperative period, the Lehr’s damping ratios of the patients who underwent operations that employed minimally invasive exposures were significantly higher than those of the patients who underwent operations that utilised conventional exposures (p < 0.03).

### 4. Discussion

The goal of this study was to determine the effects of total knee arthroplasties utilising various exposures (i.e., conventional and minimally invasive) on dynamic balancing capacity. Dynamic balancing capacity was represented by the Lehr’s damping ratio, which was calculated from the measurements of provocation tests (i.e., measurements during unidirectional perturbation). Earlier studies have established that postural balance improves during the postoperative period (Gauchard et al., 2010; Isaac et al., 2007; Swanik et al., 2004), but does not reach normal values even one year after TKA (Quagliarella et al., 2011).

The data from the control group corresponded to the results from earlier research (Kiss, 2011, 2012): lateral dominance and gender significantly affected dynamic balancing capacities as indicated by the Lehr’s damping ratio (Table 1). Differences in the anatomy and the different degrees of deterioration of vestibular and somatosensory function between males and females (Masui et al., 2005) might account for this gender difference.

The results of both patient groups prior to TKA corresponded to those from earlier research (Kiss, 2012). The Lehr’s damping ratios as calculated using each of the three testing methods (i.e., standing on both limbs, on the affected limb and on the non-affected limb) were significantly smaller than those of the controls. The results of the present study also revealed that gender did not influence the dynamic balancing abilities of cases of severe knee osteoarthritis, as no significant difference in the Lehr’s damping ratios was found between males and females (Table 1).

At 6 weeks after TKA with conventional exposure, the significantly decreased Lehr’s damping ratios compared to controls (Fig. 3) confirmed the results of earlier findings based on stabilometry testing because the postural balances measured during bipedal stances were significantly decreased in the early postoperative period compared to those of the healthy participants (Gauchard et al., 2010). Our research also proved that dynamic balancing ability did not improve when standing on both limbs, on the affected limb or on the non-affected limb.

At 12 weeks after TKA, the Lehr’s damping ratio significantly increased as measured by all three testing methods (Fig. 3) compared to the results at 6 weeks after TKA; however, they failed

### Table 1

Lehr’s damping ratios (D, %) for the control group and the patients who were operated on with the different methods of exposure, calculated on the basis of measurement data from the provocation tests within the first 3 months of the postoperative period.

<table>
<thead>
<tr>
<th>Type of test</th>
<th>Male</th>
<th>Female</th>
<th>Male</th>
<th>Female</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preop</td>
<td>4.65 ± 0.33</td>
<td>4.99 ± 0.29</td>
<td>4.67 ± 0.30</td>
<td>4.83 ± 0.28</td>
<td>2.90 ± 0.39</td>
<td>3.41 ± 0.31</td>
</tr>
<tr>
<td>6 weeks postop</td>
<td>3.75 ± 0.31</td>
<td>3.62 ± 0.37</td>
<td>3.11 ± 0.39</td>
<td>3.57 ± 0.35</td>
<td>1.05 ± 0.39</td>
<td>1.87 ± 0.35</td>
</tr>
<tr>
<td>12 weeks postop</td>
<td>3.08 ± 0.37</td>
<td>3.21 ± 0.34</td>
<td>1.59 ± 0.38</td>
<td>3.04 ± 0.37</td>
<td>1.08 ± 0.33</td>
<td>2.17 ± 0.34</td>
</tr>
<tr>
<td>Conventional exposure</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Preop</td>
<td>3.25 ± 0.49</td>
<td>3.20 ± 0.41</td>
<td>3.05 ± 0.42</td>
<td>3.12 ± 0.49</td>
<td>0.84 ± 0.49</td>
<td>0.88 ± 0.47</td>
</tr>
<tr>
<td>6 weeks postop</td>
<td>3.21 ± 0.34</td>
<td>3.62 ± 0.37</td>
<td>3.17 ± 0.39</td>
<td>3.57 ± 0.35</td>
<td>1.05 ± 0.39</td>
<td>1.87 ± 0.35</td>
</tr>
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<td>12 weeks postop</td>
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<td>3.04 ± 0.37</td>
<td>1.08 ± 0.33</td>
<td>2.17 ± 0.34</td>
</tr>
<tr>
<td>Minimal invasive exposure</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preop</td>
<td>3.28 ± 0.49</td>
<td>3.20 ± 0.41</td>
<td>3.11 ± 0.42</td>
<td>3.12 ± 0.49</td>
<td>0.85 ± 0.41</td>
<td>0.88 ± 0.47</td>
</tr>
<tr>
<td>6 weeks postop</td>
<td>3.75 ± 0.31</td>
<td>4.14 ± 0.37</td>
<td>3.58 ± 0.35</td>
<td>4.02 ± 0.31</td>
<td>1.57 ± 0.37</td>
<td>2.09 ± 0.35</td>
</tr>
<tr>
<td>12 weeks postop</td>
<td>3.41 ± 0.35</td>
<td>3.38 ± 0.40</td>
<td>3.79 ± 0.32</td>
<td>3.24 ± 0.49</td>
<td>1.59 ± 0.38</td>
<td>0.99 ± 0.47</td>
</tr>
</tbody>
</table>

- Significant difference compared to the Lehr’s damping ratio calculated from testing during the double leg stance.
- Significant difference compared to the Lehr’s damping ratios calculated during testing for stance on the dominant/affected limb.
- Significant difference compared to control group values.
- Significant difference compared to preoperative values.
- Significant difference compared to values measured at 6 weeks after TKA.
- Significant difference compared to conventional exposure.
- Significant difference between male and female values.
to reach those of the controls, which correspond to earlier results of stabilometry testing (Gauchard et al., 2010; Isaac et al., 2007; Swanik et al., 2004). Our results suggested that the non-affected side was unable to compensate for the decrease in the balancing ability of the affected side during bipedal stance. The decreased dynamic balancing abilities compared to controls might be explained by the fact that the muscles were unable to assume the role of the affected joint capsule and eradicated ligaments (Freeman, 1965). The reason for the decreased dynamic balancing ability during standing on both limbs might be related to the pain in the affected joint experienced following the operation (Smith et al., 2004).

During the postoperative period, the patients who underwent operations involving the minimally invasive technique exhibited improvements in the Lehr’s damping ratios that represent significant improvements compared to those calculated on the basis of preoperative measurement data (Fig. 4). However, these measurements failed to reach the level of those taken from the controls even 12 weeks after TKA (Fig. 4). Similar to the patients operated on using the conventional technique, the reason for the decreased dynamic balancing ability during standing on both limbs (Fig. 4) might be related to the pain in the affected joint experienced following the operation or the sustained improper regeneration of the joint capsule or the muscles of the affected side (Smith et al., 2004). It means that the non-affected side was unable to compensate for the decreased balancing capacity of the affected side.

A comparison of the Lehr’s damping ratios between the patient groups revealed that, amongst the patients who underwent the operation involving the minimally invasive technique, the Lehr’s damping ratio, as calculated with all three testing methods, was significantly higher during the postoperative period compared to the values obtained for the patients who underwent operations by the conventional technique (Table 1). The cause of this difference between the results for the patients who underwent operations involving the different surgical methods might be due to the damage of patella ligaments. The patella and the patella ligaments, which play an important role in balancing capacity (Freeman, 1965) are much less affected by the minimally invasive method than by the conventional method. An earlier study on the effect of surgical techniques of total hip arthroplasty has shown
that the balancing capacity after sudden perturbation of patients operated on by the minimal invasive technique, which effects less the joint capsule and ligaments, increased more rapidly compared to patients operated on by the conventional method (Holnapy and Kiss, 2013).

The limitations of the present study are that the kinematics of the joint motions and muscle activities were not measured during the provocation test. Furthermore, dynamic balancing ability was analysed only during the first 3 months of the postoperative period. Future investigations should address these issues.

Additionally, 12 weeks after the TKAs in both patient groups, the balancing abilities decreased compared to controls; these findings indicate that adaptations to changes in external circumstances decreased (Robbins et al., 1989) and that the risk of falling increased (Nevitt et al., 1989) relative to controls. In other words, during the early postoperative period, it is more difficult for patients to adjust to unexpected situations (e.g., walking on uneven or slippery surfaces); therefore, the use of therapeutic walking aids should be recommended for longer periods to prevent trauma. Differences related to the methods of exposure should be considered when compiling rehabilitation protocols and abandoning therapeutic aids.

The provocation test that characterised dynamic balancing capacities after a sudden perturbation modelled balance after a sudden impulse, which requires highly complex coordination (Winter, 1995). The dynamic balancing abilities of both patient groups progressively improved over the first 12 weeks of the postoperative period; however, the balancing abilities as calculated with all three testing methods (i.e., standing on both limbs, on the affected limb and on the non-affected limb) deteriorated compared to the controls. The dynamic balancing abilities of the patients who were exposed to minimally invasive techniques improved more quickly than did those of the patients who underwent the conventional exposure. The provocation test might be applicable for monitoring of stages and effects of rehabilitation.

Acknowledgments

This project was supported by the Hungarian Science Fund OTKA K83650. The authors wish to express their thanks to Katalin Kolló for her assistance in the evaluation of the X-ray images and to Prof. Miklós Szendrői for his assistance with the surgeries and measurements.

References


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