TOTAL KNEE ARTHROPLASTY AFFECTING BALANCING ABILITY AFTER SUDDEN UNIDIRECTIONAL PERTURBATION

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ABSTRACT
Total knee arthroplasty significantly influenced gait parameters and the variability of gait. The aim of this research was to analyze the effect of total knee arthroplasty (TKA) on balancing ability after sudden perturbation in the early postoperative period. Balancing ability after sudden perturbation was modeled by a provocation test and characterized by the Lehr’s damping ratio during double leg and single leg stance. 10 patients operated on by conventional total knee arthroplasty were investigated by the provocation test before TKA and 6 and 12 weeks after TKA and their results were compared with the results of 20 healthy elderly subjects. The results of testing during stance on the affected limb in patients differed significantly from the results of standing on both limbs and on the unaffected limb in the early postoperative period. These results indicated that TKA significantly decreased balancing ability on the affected side after sudden perturbation. Our results showed that 12 weeks after TKA, balancing ability after sudden perturbation improved compared to the results prior to surgery, although it did not return to normal. Deterioration in balancing ability after sudden perturbation can increase the risk of falling.

KEY WORDS
medical measurement, biomechanics, balancing capacity, total knee arthroplasty, sudden perturbation

1. Introduction
Knee osteoarthritis influenced gait parameters and balancing capacity significantly [1,2]. Our previous research established that the total knee arthroplasty (TKA) influenced the variability of gait one year after the surgery [3].
Balance control is a complex sensorimotor function that includes components of movement detection and control of coordinated voluntary and reflexive motor response. Postural control influenced not only proprioceptive, visual and vestibular inputs and outputs, but the condition of different joints as well [4]. Results of joint proprioception after TKA are controversial because some authors have established increases [5-11], while other authors have established decreases [12-14] in joint proprioception after TKA. Balancing ability during standing, represented by the antero-lateral motion of Centre of Pressure (CoP) and path length of COP, is deteriorated in the early postoperative period [11]. Balancing capacity improved compared to the results prior to surgery, although it did not return to normal [11, 15].
The goal of this study is to analyze balancing ability after sudden perturbation in the early postoperative period after TKA. Balancing ability after sudden perturbation was modeled by a provocation test and characterized by the Lehr’s damping ratio during double leg and single leg stance. In this study the Lehr’s damping ratio was determined 6 weeks and 12 weeks after total knee arthroplasty at patients and compared to the values determined preoperatively and to the values of the healthy group. Our hypothesis was that balancing capacity after TKA improved during the early postoperative period; however, it would not reach normal level.

2. Subjects and Methods

2.1 Subjects
The patient group consisted of 6 men and 4 women (age 68.4± 7.2 years, body weight 87.7 ± 8.2 kg, body height 169.8± 8.6 cm). The severity of osteoarthritis of the knee joint was determined by the Kellgren and Lawrence radiographic index [16], which was grade 4 in 7 patients and grade 3 in 3 patients.
Inclusion criteria were the following: unilateral knee arthritis evidenced by X-ray, walking without aid, and age
between 65-80 years. Exclusion criteria were the following: any lesion and/or surgery affecting a lower limb or the lumbar spine, osteoarthritis affecting opposite hip or bilateral knee joints, neurological alterations, uncontrolled hypertonia, and unstable angina. The population of the healthy control group consisted of 5 women and 5 men (age 70.4± 6.22 years, body weight 71.5 ± 15.6 kg, body height 168.8± 12.4 cm). The orthopaedic examination performed before motion analysis established that the motion range and stability of joints in the lower limbs as well as the axial position, muscular strength, and muscular tension of the lower limbs were physiologically adequate at healthy subjects. Inclusion and exclusion criteria for the analysis corresponded to those for the OA, except for the existence of OA.

2.2 Methods

Balancing ability after sudden unidirectional perturbation was examined by provocation tests, using the platform of the PosturoMed© device (Figure 1). The easiest setting used was where four springs worked and four springs were fixed. Sudden perturbation was simulated by releasing the unit fixed 20 mm away from the central position. After realeasing the unit the rigid plate suddenly started to move and the participant had to balance and re-equilibrate as the plate moved. The motions of the rigid plate were recorded using a single ultrasound-based marker of ZEBRIS CMS10 (ZEBRIS, Medizintechnik GmbH, Isny, Germany) computer-controlled, ultrasound-based motion analysis system (Fig. 1), which were attached on the side of the plate. The measurement frequency was 100 Hz. Tests were performed at the Department of Orthopaedics of Semmelweis University. Each test had three parts (stance on double leg - double leg scenario; stance on dominant leg – dominant leg scenario; and stance on non-dominant leg – non-dominant leg scenario) at healthy subjects and three scenarios (stance on double leg - double leg scenario; stance on unaffected/healthy leg – unaffected leg scenario; stance on affected leg – affected leg scenario) at patients. Each was repeated three times. Details of provocation tests and measuring method are included in [17].

![Figure 1: Measurement arrangement](image)

The second-order damped motion of the rigid plate parallel with the direction of motion is modeled by the Lehr’s damping ratio. Calculation of the Lehr’s damping ratio from the movement of the plate is summarized in [17].

The mean and the standard deviation were calculated for each group from the results of the Lehr’s damping ratios for individuals. The data were statistically analyzed using the MS Excel Analysis Tool Pak software. A one-sample t-test applying a symmetrical critical range was used for the comparison of results in the same group, and a two-sample t-test applying a symmetrical critical range was used for the comparison of results in different groups.

3. Results

The results are summarized in Table 1 in the form of average±SD. All three parts of the tests (standing on both, on right and left limb) were completed by each participant, nobody was to be excused for incomplete testing.

The analysis of the results of healthy subjects and patients before THA can be found in [3]. In this research the effect of TKA was analyzed in the early post-operative period (6 and 12 weeks after the surgery).

For patients 6 and 12 weeks after TKA, the Lehr’s damping ratio calculated from the results of standing on the affected leg was significantly smaller compared to the parameters calculated from the results of standing on both legs ($p_{6\text{weeks}} = 0.0008; p_{12\text{weeks}} = 0.004$) and to the parameters calculated from the results of standing on the unaffected leg ($p_{6\text{weeks}} = 0.0007; p_{12\text{weeks}} = 0.005$) (Table 1). The difference was not significant between the Lehr’s damping ratio calculated from the results of the unaffected leg scenario and the parameters calculated from the results of the double leg scenario ($p_{6\text{weeks}} = 0.07$ $p_{12\text{weeks}} = 0.14$) (Table 1).

For patients 6 weeks after TKA the Lehr’s damping ratio was significantly smaller compared to the values calculated from the results of all three test parts in healthy elderly subjects ($p_{6\text{weeks}} = 0.007, p_{12\text{weeks}} = 0.008, p_{\text{non-dominant}} = 0.0004$), and there was no significant difference compared to the values prior to TKA ($p_{\text{both}} = 0.14, p_{\text{dominant}} = 0.09, p_{\text{non-dominant}} = 0.07$) (Table 1). No significant difference was found comparing the results of male and female subjects ($p_{\text{both}} = 0.06, p_{\text{dominant}} = 0.07, p_{\text{non-dominant}} = 0.24$) (Table 1).

For patients 12 weeks after TKA the values of the Lehr’s damping ratio determined from the results of all three test parts were significantly smaller ($p_{\text{both}} = 0.01, p_{\text{dominant}} = 0.009, p_{\text{non-dominant}} = 0.0007$) than the same parameters at healthy elderly subjects (Table 1). The Lehr’s damping ratio calculated from the results of all three scenarios was significantly higher than the parameters measured prior to the surgery ($p_{\text{both}} = 0.007, p_{\text{dominant}} = 0.003, p_{\text{non-dominant}} = 0.0009$) and 6 weeks after the surgery ($p_{\text{both}} = 0.0006, p_{\text{dominant}} = 0.001, p_{\text{non-dominant}} = 0.0002$) (Table 1). No significant difference was found comparing the results of
male and female subjects ($p_{both} = 0.05$, $p_{dominant} = 0.09$, $p_{non-dominant} = 0.14$) (Table 1).

4. Discussion

The discussion of results in healthy subjects and in patients prior to surgery is included in [3]. In summary, it can be stated that at healthy subjects the Lehr’s damping ratio calculated from the results of standing on the non-dominant leg was significantly smaller than the values determined from the results of standing on the dominant leg and on both legs (Table 1). The Lehr’s damping ratio of female subjects was significantly higher than that of male subjects. This means that dominance and gender significantly influence balancing ability after sudden perturbation [3].

At patients prior to surgery the Lehr’s damping ratio calculated from the results of standing on the affected leg was significantly lower than the values determined from the results of standing on both limbs and on the unaffected limb (Table 1). This means that the non-affected side was always the dominant side. The values of the Lehr’s damping ratio calculated from all three test parts in patients prior to TKA was significantly smaller than those of healthy subjects. No significant difference was found in the comparison of results of female and male patients. This means that balancing capacity after sudden perturbation deteriorated following knee osteoarthritis, but balancing capacity after unidirectional sudden perturbation was not influenced by gender [3].

6 weeks after TKA, the Lehr’s damping ratio determined from the results of standing on both limbs, on the unaffected and on the affected limb did not differ significantly from the results determined prior to TKA, but were significantly smaller compared to the results of controls. It was established by earlier research [11] that balancing capacity during standing on both limbs deteriorated in the early postoperative period after TKA. Our research established that balancing capacity after sudden perturbation deteriorated after TKA compared to healthy subjects and did not improve compared to the results prior to TKA. Decreased balancing ability increases the risk of falling [18]. Between the 6th and 12th week of the postoperative period the Lehr’s damping ratio calculated from the three parts of the test increased significantly (Table 1); however, it did not reach normal values. The results show that the deterioration of the balancing ability of the affected limb cannot be compensated by the balancing capacity of the unaffected limb, and the risk of falls is high 12 weeks after TKA [18]. Such deterioration of balancing ability after sudden perturbation can be caused by the weakness of muscles around the knee joints [19].

Our results show that the Lehr’s damping ratio determined from the results of standing on both limbs and on the unaffected limb was significantly smaller compared to the results of controls. This confirmed the statements by Gage et al. [20] that the kinematical answer to unilateral lesion and surgery should be bilateral. The limitation of this study was that balancing ability after sudden perturbation in patients was analyzed only during the first three months after TKA. Muscle activation during the provocation test was not analyzed; it should also be analyzed in the future.

5. Conclusion

In patients 12 weeks after TKA, the unaffected leg was always the dominant leg and balancing capacity after unidirectional sudden perturbation improved to the state before TKA, but did not reach normal values. Decreased balancing ability after unidirectional sudden perturbation may also indicate an increased risk of falling. This could be taken into account in the use of different aids. The rehabilitation protocol should be extended by equilibrium exercises and the strengthening of muscles around the knee joint.

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References


### Table 1
The mean ± standard deviation of Lehr’s damping ratio (D) calculated from the results of the provocation test

<table>
<thead>
<tr>
<th>Gender</th>
<th>Standing on</th>
<th>both limbs</th>
<th>dominant/ unaffected limb</th>
<th>non-dominant/ affected limb</th>
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<tbody>
<tr>
<td><strong>Male</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>4.65 ± 0.33</td>
<td>4.47 ± 0.30</td>
<td>2.90 ± 0.039&lt;sup&gt;a,b&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>4.99 ± 0.29&lt;sup&gt;g&lt;/sup&gt;</td>
<td>4.83 ± 0.28&lt;sup&gt;g&lt;/sup&gt;</td>
<td>3.41 ± 0.031&lt;sup&gt;a,b,g&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>3.25 ± 0.49&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.05 ± 0.42&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.84 ± 0.049&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>3.21 ± 0.34&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.17 ± 0.39&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.05 ± 0.039&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>3.62 ± 0.37&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
<td>3.57 ± 0.35&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
<td>1.87 ± 0.035&lt;sup&gt;a,b,c,d,e&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td></td>
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<td></td>
<td></td>
<td>3.20 ± 0.41&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.12 ± 0.49&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.88 ± 0.047&lt;sup&gt;a,b,c&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>3.08 ± 0.37&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.04 ± 0.37&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.08 ± 0.033&lt;sup&gt;a,b,c,d&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>3.67 ± 0.35&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
<td>3.60 ± 0.37&lt;sup&gt;c,d,e&lt;/sup&gt;</td>
<td>1.91 ± 0.033&lt;sup&gt;a,b,c,d,e&lt;/sup&gt;</td>
</tr>
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</table>

OA osteoarthritis

dominant/unaffected limb: dominant limb in healthy subjects and unaffected (healthy) limb in patients

non-dominant/affected limb: non-dominant limb in healthy subjects and affected limb in patients

<sup>a</sup> Significant differences in values of D compared to parameters measured while standing on both limbs

<sup>b</sup> Significant differences in values of D compared to parameters measured while standing on dominant/unaffected limb

<sup>c</sup> Significant differences in values of D of patients with OA compared to parameters of the healthy control group

<sup>d</sup> Significant differences in values of D of patients after TKA to parameters of patients prior to TKA

<sup>e</sup> Significant differences in values of D of patients 12 weeks after TKA compared to parameters of patients 6 weeks after TKA

<sup>f</sup> Significant differences in values of D between the genders