ABSTRACT
Osteoarthritis of the knee joint and total knee arthroplasty (TKA) change gait parameters and their variability significantly. This study aims to determine how the variability of parameters of stepping is influenced 1) by osteoarthritis and 2) by the type of operation technique (traditional and minimal invasive exposure) in the early postoperative period.

The variability of different kinematical parameters was measured at 10 patients undergoing knee arthroplasty with a minimal invasive and 10 with a traditional operation technique preoperatively and at 6 and 12 weeks postoperatively, as well as at 10 healthy age-matched control subjects. The decreased variability of angular parameters on the affected side of patients prior to TKA represented a decreased flexibility of joint. This led to an increased variability of cadence, which represents a decreased consistency in the movements of the lower limbs from step to step, and a decreased complexity of movement. During the postoperative period the values of variability of motion approached, but did not return to the values of the healthy group. As regards the minimal invasive group, improvement is quicker. The increased flexibility of the non-affected knee joint, the pelvis and the shoulder produce compensatory patterns to ensure stability in stepping prior to and after TKA.

KEY WORDS
gait, ultrasound-based measuring system, variability of gait, total knee arthroplasty

1. Introduction
Osteoarthritis of the knee joint and total knee arthroplasty (TKA) change gait parameters and variability significantly [1-3]. Since gait parameters may be measured after 3 months postoperatively and long measurements (of minimum 10 minutes) can only be carried out after 6 months, there is no or very little information on gait patterns and the variability of gait in the early postoperative period. A method developed for measurements while stepping by Kiss allows to obtain certain stepping parameters like cadence, motion of the knee joint, the pelvis and the shoulder girdle in the early postoperative period [4]. This study aims to determine how the variability of certain kinematical parameters of stepping is influenced 1) by osteoarthritis and 2) by the type of operation technique (traditional and minimal invasive exposure) in the early postoperative period (6 and 12 weeks after the operation). The variability of cadence was represented by a coefficient of variance (CV), which is a percentage ratio of standard deviation and mean. The variability of knee motion and of angular parameters of the pelvis and the shoulder was modeled by the mean coefficient of variance (MeanCV), which is the average CV over all integer percents.

2. Subjects and Methods
2.1 Subjects
The population of the healthy control group consisted of 5 women and 5 men. The age of the control group was 70.4± 6.22 years, their body weight was 71.5 ± 15.6 kg and their body height was 168.8± 12.4 cm. These subjects had no history of osteoarthritis of the knee or hip joint, knee instability or major lower extremity joint surgery. These individuals had normal strength, full range of motion of the lower extremities and had no neurological or balance deficiencies.

Twenty patients with gonarthrosis had unilateral symptoms (only one knee was affected), with no significant variations of the hip and the lumbar spine as shown by physical examination.
The 20 patients were randomly allocated into two groups by 1:1. Both groups of 10-10 patients had the TKA performed at the Orthopaedic Clinic of Semmelweis University, Budapest, Hungary.

Group I (conventional method) consisted of 6 men and 4 women; their age was 68.4± 7.2 years, their body weight was 87.7 ± 8.2 kg, and their body height was 169.8± 8.6 cm. Group II (minimal invasive technique with computer assisted navigation) consisted of 8 women and 2 men; their age was 67.9± 6.7 years, their body weight was 74.1 ± 11.9 kg, and their body height was 162.2± 12.2 cm. All patients in these groups were seriously limited in their activities due to pain.

The severity of osteoarthritis of the knee joint was determined by the Kellgren and Lawrence radiographic index [5], which was grade 4 in 15 patients and grade 3 in 5 patients. This implies that they had severe osteoarthritis of the knee joint, large osteophytes, marked joint space narrowing, severe sclerosis and definite bone contour deformity. Exclusion criteria included previous surgery to another joint in the lower extremity, and generalized inflammatory polyarthritis with multiple joint involvements, which would compromise mobility.

2.2 Methods and calculated parameters

Patients underwent motion analysis before surgery and 6 and 12 weeks postoperatively. Control subjects were analyzed at the same time as patients before surgery. The spatial coordinates of certain anatomical points during stepping on a PosturoMed® plate were measured by a ZEBRIS CMS10 (Zebris, Isny, Germany) computer-controlled, ultrasound-based motion analysis system located in the Biomechanical Laboratory of the Department of Orthopaedics of Semmelweis University. The PosturoMed® (Haider-Bioskine, Weiden, Germany) device is a commercial training and therapy device used in Europe. It has a rigid platform (12 kg, 60 cm × 60 cm) connected to a rigid frame by eight 15-cm steel springs of identical strength (Figure 1). The device is designed so that the plate is made stable by the fastening unit. Once the spring is released the plate can move freely. This can be used later to examine dynamic stability.

The measuring head was positioned in front of the individual to be examined; ultrasound-based single markers were to record the motion of anatomical points. The measurement control software (Zebris WinPosture) calculated the spatial coordinates of the anatomical points. The basics of this measurement method are detailed in [4]. A frequency of 100 Hz was used to determine the spatial coordinates of the designated anatomical points.

To simplify the procedure, the motion of the knee joint and the trunk are measured separately. The main criteria of the measurement procedure are standardization and reproducibility. Therefore, the locations on the body of the active sensors that emit the ultrasound signals must be selected so that the possibility of displacement during measurement is excluded; the anatomical points must be properly determinable and palpable through the skin. The active markers are fixed in place, using two-sided plaster tape, to the tuberositas tibiae in order to test the motion of the knee and to the spina iliaca anterior superior and acromion scapulae in the shoulder girdle to test the motion of the trunk (Fig 2). These anatomical points are particularly useful because there is relatively little motion of the skin over osseous anatomical points during gait and other types of motion.

First, a knee motion test was performed in 20 stepping cycles. While testing the motion of the knee joint the cadence of stepping can be determined by the vertical movement of the joint. For each subject in all gait cycles the values of cadence were calculated, followed by the mean, the standard deviation (SD), and the coefficient of variation (CV). During the knee joint tests based on the determined three-direction (x,y,z) spatial coordinates of the tuberositas tibiae the motion of the knee joint (r) was defined by Eq(1) [4]:

\[ r = \sqrt{x^2 + y^2 + z^2} \]  

In the second part of the investigation a test of the trunk was also performed in 20-20 stepping cycles. During the investigation of the trunk, the tilting and rotation of the pelvis girdle were to be calculated from the
spatial coordinates of the anatomical points of the spina iliaca anterior superior and the tilting and rotation of the shoulder girdle from the anatomical points of the acromion scapulae [4].

For knee motion parameters (r), rotation and tilting of the pelvis, and rotation and tilting of the shoulder girdle as angular parameters, all gait cycles of all subjects examined were normalized to 0-100% of cycles. For each subject, angular parameters were calculated at each integer percent of the gait cycle. Then, the mean coefficient of variance (MeanCV) was defined by Eq (2):

\[
\text{MeanCV}(r) = \frac{\text{SD}(i)}{\text{Mean}(i)} \times 100 \quad (i = 0-100\% \text{ gait cycle})
\]

where

\[
\begin{align*}
\text{Mean}(i) & \quad \text{is the mean of the cycles specified at the } i\text{th (integer) percent} \\
\text{SD}(i) & \quad \text{is the standard deviation of the cycles specified at the } i\text{th (integer) percent.}
\end{align*}
\]

MeanCV determined by Eq (2) represents the average CV over all integer percents.

**Statistical analysis**

The group mean and SD were determined from the values calculated (as shown above) for stepping. The CV of cadence and the MeanCV of knee motion and angular parameters were analyzed using a three-factor ANOVA method. Three factors were involved in these experiments: group (healthy patients, patients operated on by the conventional technique, and patients operated on by the minimal invasive technique), time (prior to, 6 weeks and 12 weeks after TKA), and leg (affected and non-affected).

Processing was carried out using an SPSS 14 software (SPSS, Chicago, IL USA). The significance level of statistical analysis (p) was set at 0.05. A Tukey post-hoc test was performed for ANOVA.

### 3. Results

All healthy subjects and patients involved in the investigation were able to complete the tests during stepping on the stable PosturoMed plate prior to as well as 6 and 12 weeks after TKA performed by different surgical approaches (conventional and minimal invasive technique) and to compare these variables with healthy controls and with each other.

The variability of cadence, as a temporal parameter, represented by CV, characterizes the consistency of the motion of the lower limbs from stride to stride [6]; the variability of knee motion (r), and the variability of tilting, and rotation of the pelvis, tilting, and rotation of the shoulder girdle as angular parameters represented by MeanCV, characterize the flexibility of lower-limb joint movement [7]. A decrease in the variability of joint motion can produce an increase in the variability of temporal parameters, both of them together represent a worsening of the complexity [7] and stability of movement [6].

The effects of the osteoarthritis of the knee joint and total knee arthroplasty (TKA) on the variability of stepping parameters are as follows: osteoarthritis of the knee joint and total knee arthroplasty (TKA) performed in both ways significantly change the variability of gait parameters compared to that of the healthy control group (Table 1). The variability of cadence is significantly higher than that of the control group both in the preoperative period and at the end of the early postoperative period (12 weeks after surgery). On the basis thereof it can be assumed that the consistency of limb movement and the stability of gait deteriorated compared to the healthy group [6]. In the earlier study [2] increased variability of cadence was recorded when gait...
parameters were measured during treadmill walking 6 months after TKA [2]. In both the preoperative and at the end of the early postoperative period the variability of affected knee joint motion decreased significantly compared to that of the values of the healthy group (Table 1). During the postoperative period the values of knee joint motion variability increased significantly compared to preoperative values, but they did not reach the values of the healthy group even 12 weeks after the operation (Table 1). The decrease in the gait variability of the affected joint suggests a rigidity of joints [7]. In the preoperative period, this is the result of osteoarthritis and consequent pain while in the postoperative period it is because of pain on the one hand and on the other hand it might be a consequence of weakened muscles and deteriorating proprioception. Before and in the early postoperative period of TKA the increase in the variability of cadence and the decrease in the variability of affected knee joint motion together lead to decreased coordination and consistency of movement [6,7]. In the early postoperative period the coordination and consistency of movement improved steadily compared to the preoperative period but did not return to the figures of the healthy group even after 12 weeks postoperatively. The increased variability of cadence and the decreased variability of affected joint motion measured in the present study jointly show that after TKA, independently of the chosen exposure technique, the joint flexibility, the complexity and consistency and functional responsiveness of motion all decrease [6,7]. These figures also predict an increased risk of falling [6]. The tendency is similar in the variability of gait determined during treadmill walking preoperatively and 6 months postoperatively [2,3].

Our study shows that the variability of motion of the non-affected knee joint, the pelvis and the shoulder girdle significantly increased compared to the figures of the healthy group both in the preoperative and the early postoperative periods (Table 1). The parameters were steadily decreasing compared to the figures of the preoperative period. 12 weeks postoperatively the only figures returning to the original values were the rotation and tilting of the shoulder girdle and the rotation of the pelvis girdle in group II.

Increased variability of joint motion demonstrated that these joints play an important role in compensation and thereby in the ability to have a secure, safe gait. [6].

It follows from this study that the non-affected knee joint, the pelvis and the shoulder girdle are also parts of the compensation mechanism to ensure gait stability.

This confirms earlier statements that both the non-affected knee joint and the pelvis girdle play an important role in compensation before and after the operation [1-3]. It also draws attention to the importance of the shoulder girdle in compensation and ensuring gait stability.

Effect of operation techniques on the variability of stepping: Preoperatively, no significant difference was measured between the two groups since the groups were randomly chosen. (Table 1). In the early postoperative period there were significant differences between the two groups in all the measured parameters (Table 1). The patients operated on by the minimal invasive technique approached the figures of the healthy control group faster. However, the values characterizing the consistency of movement and the flexibility of the affected knee joint still differ significantly from those of the healthy group even 12 weeks postoperatively.

These data suggest that even in the case of the minimal invasive technique gait consistency, stability and functional responsiveness are worse than in the healthy group. 12 weeks postoperatively, compensatory patterns show great differences in the patient group operated on by the minimal invasive technique compared to the group operated on in the traditional way. Neither the rotation of the pelvis girdle nor the tilting and rotation of the shoulder girdle have a role in compensation; the respective values do not differ significantly from those of the healthy group. A possible explanation is that the flexibility of the affected knee, together with the increased role of the non-affected knee joint and of the tilting of the pelvis girdle, are sufficient to ensure gait stability.

Limitations of this study are as follows: only a few kinematic parameters can be measured because of simplified measurement techniques and the use of single markers. Secondly, in the early postoperative period, only 20 motion cycles were taken into account when gait variability was calculated instead of the 400 motion cycles proposed by Owings and Grabnier [8] because of the patients’ condition.

5. Conclusion

This study showed that osteoarthritis of the knee joint and total knee arthroplasty in the early postoperative period worsen the flexibility of the affected knee joint, resulting in inconsistent step-by-step movement repetitions. The decreasing flexibility and consistency of movement is associated with an inability to adapt to movement due to decreased complexity and reduced stability of gait [6,7]. The non-affected knee joint, the pelvis and the shoulder girdle all take part in stabilizing gait. There is a significant difference in the variability of movements between the two groups operated differently: in case of the minimal invasive technique the values approach those of the control group faster than in the case of the traditional technique. It should also be mentioned that 12 weeks postoperatively the only values similar to those of the control group were pelvis rotation and shoulder tilting and rotation. The results also show that during rehabilitation the flexibility of the non-affected side, the pelvis and the shoulder girdle should also be increased to ensure better gait stability.

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References


Table 1

The mean ± standard deviation of CV of cadence and MeanCV of knee motion, pelvis tilting and rotation and shoulder tilting and rotation.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Control</th>
<th>Group I</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>preop</td>
<td>6 weeks postop</td>
<td>12 weeks postop</td>
</tr>
<tr>
<td>Cadence</td>
<td>8.7±0.9</td>
<td>23.8±1.7</td>
<td>16.4±1.2</td>
</tr>
<tr>
<td>Knee motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nd</td>
<td>6.9±0.7</td>
<td>2.8±5.2</td>
<td>3.5±0.3</td>
</tr>
<tr>
<td>d</td>
<td>6.8±0.6</td>
<td>32.7±3.0</td>
<td>27.7±2.8</td>
</tr>
<tr>
<td>Pelvis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nd</td>
<td>21.8±1.8</td>
<td>41.4±3.9</td>
<td>35.6±3.3</td>
</tr>
<tr>
<td>d</td>
<td>23.7±2.0</td>
<td>45.7±4.3</td>
<td>39.3±4.0</td>
</tr>
<tr>
<td>Shoulder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>nd</td>
<td>13.2±1.5</td>
<td>29.4±2.5</td>
<td>23.5±2.0</td>
</tr>
<tr>
<td>d</td>
<td>17.1±1.9</td>
<td>35.7±3.3</td>
<td>30.4±3.3</td>
</tr>
</tbody>
</table>

Comments: preop: data measured preoperatively; postop: data measured postoperatively; nd: non-dominant leg at healthy subjects and affected leg at patients; d: dominant leg at healthy subjects and non-affected leg at patients; *significant difference compared to healthy control subjects; †significant difference compared to preoperative patient value; #significant difference comparing the healthy (contralateral) side to the affected side; ◊significant difference between the patient groups (conventional and minimal invasive technique)