Variability of gait in the early postoperative period of total knee arthroplasty with different surgical technique

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Abstract

Purpose The purpose of this study was to work out an objective and sensitive method for the early postoperative period following total knee arthroplasty (TKA) in which analysis of the gait parameters is possible and also to investigate the influence of different surgical approaches for TKA on the gait during stepping in the first three months of the postoperative period.

Methods Three groups of patients: age-matched healthy elderly patients as a control group, patients operated upon by the conventional technique and finally by the minimally invasive technique combined with computer-assisted navigation. All three groups included ten patients. The motions of knee, shoulder and pelvis were measured by ZEBRIS ultrasound-based system preoperatively plus six and 12 weeks postoperatively. From the joint motion, the variability of cadence, and the variability of knee joint motion and that of pelvis and shoulder girdle was determined.

Results Osteoarthritis (OA) of the knee joint and TKA using both operation techniques significantly influenced the variability of stepping parameters compared to the controls. In the early postoperative period a significant difference was detected between the two groups of the operated patients in all parameters.

Conclusion Our data prove that our method seems appropriate to provide objective measurement of the gait in the early postoperative period. The variability of motion of the patient groups approaches that of the healthy control group steadily, but does not reach them.

Keywords Total knee arthroplasty · Ultrasound-based measuring system · Variability of gait · Stepping · Minimal invasive technique · Dynamic stability

Introduction

The number of knee replacements is increasing year by year. Selection of adequate rehabilitation, strict follow-up and modification thereof if required are the key points of later success. OA of the knee joint and TKA significantly influence gait parameters [1, 5, 20, 21], as well as the variability and stability of gait [7, 14, 16, 20, 23]. Gait measurements on a treadmill can only be carried out three months after TKA, so there is little or no information on gait patterns and on the variability of gait in the early postoperative period (first three months). In the earlier postoperative period the change in kinematical parameters can be determined only during stepping.

This study aimed to determine how the variability of certain kinematical parameters of stepping is influenced by (1) OA and (2) the type of operation technique (conventional and minimal invasive technique combined with computer assisted navigation) in the early postoperative period (six and 12 weeks after the operation), compared with the controls. It also aimed to analyse the influence of different operation techniques on dynamic stability, which are represented by comparing the data measured during stepping on a fixed and on a released platform. Both OA [14] and TKR [16] and the type of operation technique influence the variability of gait, so it may be postulated that it will also change the variability of stepping.

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Material and methods

Patients

The population of the control group (group I) consisted five women and five men (age 70.4 ± 6.22 years, body mass 71.5 ± 15.6 kg, body height 168.8 ± 12.4 cm). These subjects had no history of OA 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 deficits.

Twenty patients chosen with gonarthrosis (group II and III) had less than 15° varus and less than 10° valgus axis deviation and had less than 15° flexion contracture. Each patient 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 and equally divided into two groups. Group II (conventional method: total anterior exposure with medial parapatellar incision) consisted of six men and four women (age 68.4 ± 7.2 years, body mass 87.7 ± 8.2 kg, body height 169.8 ± 8.6 cm). Group III (minimal invasive technique: quadsparring or midvastus incision depending of the anatomical situation with computer-assisted navigation) consisted of eight women and two men (age 67.9 ± 6.7 years, body mass 74.1 ± 11.9 kg, body height 162.2 ± 12.2 cm). All patients had the TKA performed at the Orthopaedic Clinic of Semmelweis University, Budapest, Hungary. Computer-assisted surgery was performed by the Stryker–Leibinger imageless navigation system. All patients in these groups were seriously limited in their activities due to pain. The severity of OA of the knee joint was determined by the Kellgren and Lawrence radiographic index [11], which was grade 4 in 16 patients and grade 3 in four patients. In both patient groups, full weight bearing was started on the third postoperative day, and all patients were discharged within two weeks after surgery. Thus, all subjects had standard pre- and postoperative management (anaesthesia, pain management, physical therapy protocols).

Each subject examined was informed about the risks and benefits of the study and given the opportunity to withdraw from the study at any time. All patients gave their informed consent prior to inclusion in the study. The study was authorized by the National Science and Research Ethics Committee (184/2007).

Methods and calculated parameters

Patients underwent motion analysis before surgery and six and 12 weeks after TKA. The spatial coordinates of certain anatomical points during stepping were measured by a ZEBRIS CMS10 (Zebris, Isny, Germany) ultrasound-based motion analysis system on a PosturoMed© plate (Haider-Bioswing, Weiden, Germany) [2, 15, 18]. This has a rigid platform

(12 kg, 60 cm×60 cm) connected to a rigid frame by eight 15 cm steel springs of identical strength (Fig. 1). The size and design of the plate permits the measurement of kinematical parameters of stepping on a fixed and a released (non-fixed, moving) platform, respectively [12].

Before the measurement, ultrasound-based single markers were attached to record the motion of the designated anatomical points. The measuring head was positioned in front of the individual to be examined. The WinPosture (Zebris, Isny, Germany) measurement control software calculated the spatial coordinates of the anatomical points from the propagation time of the ultrasound as recorded by the measurement system. The measurement frequency was 100 Hz. The intraobserver variation of the spatial position of anatomical points was less than one millimetre; their inter-observer variation was less than 1.5 mm. More details about the measuring method are summarised in [12].

Our aim was standardisation and attaining reproducibility. Therefore, the locations of the active, single markers on the body had to be selected to exclude the possibility of displacement during measurement; the anatomical points had to be properly determinable and palpable through the skin. The active markers were fixed in place, using two-sided plaster tape, to the tibial tuberosity in order to test the motion of the knee and to the anterior superior iliac spine in the pelvis and scapular acromion in the shoulder girdle to test the motion of the trunk (Fig. 2). These anatomical points are particularly adequate because there is relatively little motion of the skin over these osseous anatomical points during gait and other types of motion.

To simplify the procedure, the motion of the knee joint and the trunk were measured separately. The motion of the knee was measured both on a fixed and a non-fixed plate for 20

Fig. 1 PosturoMed® is a rigid plate which is connected in different directions by springs with the same tension. The plate can be fixed to the frame by a fastening unit

Fig. 2 Investigated anatomical points. **a** Tibial tuberosity to test knee motion. **b** Anterior superior iliac spine and acromion scapulae in the shoulder girdle to test the motion of the upper body

stepping cycles each. For each subject in all gait cycles the values of cadence were calculated from the vertical movement of knee, and the motion of the knee joint (r) was calculated from three-directional (x, y, z) spatial coordinates of the tibial tuberosity [1, 12] (Fig. 2a) as:

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

The trunk motion test (motion of pelvis and shoulder) was also performed in 20 stepping cycles on both fixed and non-fixed plates. From the trunk motion test, the tilting and rotation of the pelvis could be calculated using the spatial coordinates of the anatomical points of the anterior superior iliac spine and the tilting and rotation of the shoulder from the anatomical points of the scapular acromion [1, 12] (Fig. 2b).

The knee motion parameter (r) and the angular parameters (rotation and tilting of pelvis and shoulder) changed constantly over time. To calculate these parameters, all motion cycles of all subjects were normalised to 0–100 % of cycles. So the mean coefficient value (*mean CV*) calculated is the average of all integer percent standard deviation figures [12].

Statistical analysis

The CV of cadence, and the mean CV of knee joint motion and angular parameters were all available for all patients. From these data the average and the standard deviation of the different groups (control group and both patient groups) were calculated. The CV of cadence and the mean CV of angular parameters were analysed using multi-variable ANOVA method, supplemented, if necessary, by a Tukey post-hoc test. As regards the controls, variables included laterality (dominant and non-dominant) and gender (male or female). In the patient group, variables included laterality (non-affected and affected), gender (male or female), testing time (preoperatively, and six and 12 weeks postoperatively), and type of operation (conventional technique, and patients operated upon by the minimally invasive technique). Data were processed by SPSS 14 software (SPSS, Chicago, IL USA). Significance levels (p) were set at 0.05 in each case.

Results

All healthy subjects and patients involved in the examination were able to complete the tests during stepping on both the fixed and non-fixed plate. The results are summarised in Table 1.

To examine the static stability the variability of parameters was analysed during stepping on the fixed plate (Table 1). Prior to surgery for OA the mean CV of the affected knee joint motion decreased significantly ($p < 0.0008$) and the CV of cadence, the mean CV of non-affected healthy knee joint motion, and of pelvis and shoulder girdle motion increased significantly ($p < 0.001$) compared to that of the control (Table 1) (Fig. 3). In the early postoperative period the variability of stepping parameters showed constant improvement as soon as six weeks after the operation compared to preoperative values. However, 12 weeks after the operation the variability of parameters still showed significant difference and did not reach the normal values of the healthy control subjects ($p < 0.04$), except for the mean CV of shoulder tilting in group III ($p = 0.09$). The operation technique significantly influenced the variability of stepping parameters six and 12 weeks postoperatively in all measured parameters, except for the pelvis rotation 12 weeks postoperatively ($p = 0.09$), where there was no significant difference between the two patient groups (Table 1). The stepping parameters of the patients operated upon by minimally invasive surgery showed a faster recovery towards the normal values compared to those operated upon by conventional technique.

In order to examine the change of dynamic stability, the variability of parameters was also measured during stepping on a non-fixed plate (Table 1). The variability of stepping on a non-fixed plate was significantly influenced by OA ($p < 0.02$) and TKA ($p < 0.04$) compared to that of the controls (Table 1). Only in group III did the mean CV of shoulder tilting not show significant differences 12 weeks after the operation ($p = 0.08$) compared to the control. The variability of parameters changed significantly by six weeks after the operation compared to preoperative values ($p < 0.03$). In favour of the minimally invasive operation technique the variability of all stepping parameters on a non-fixed plate throughout the early postoperative period showed a faster recovery to the normal

Table 1 The mean $\pm$ standard deviation of CV of cadence and mean CV of knee motion, tilting and rotation of pelvis and shoulder

Parameters	Non-fixed plate											
	Fixed plate			Non-fixed plate								
	Group I			Group II			Group III			Group II		
	preop	Six weeks postop	Twelve weeks postop	preop	Six weeks postop	Twelve weeks postop	preop	Six weeks postop	Twelve weeks postop	Preop	Six weeks postop	Twelve weeks postop
Cadence	8.7 $\pm$ 0.9	23.8 $\pm$ 1.7	16.4 $\pm$ 1.2	12.4 $\pm$ 1.1	24.3 $\pm$ 1.6	15.1 $\pm$ 1.3	10.7 $\pm$ 1.1	11.3 $\pm$ 0.9	29.3 $\pm$ 1.9	18.7 $\pm$ 1.5	15.8 $\pm$ 1.3	13.2 $\pm$ 1.3
Knee motion												
nd	6.9 $\pm$ 0.7	2.8 $\pm$ 0.2	3.5 $\pm$ 0.3	4.6 $\pm$ 0.4	2.9 $\pm$ 0.2	4.1 $\pm$ 0.3	5.7 $\pm$ 0.5	8.2 $\pm$ 0.8	2.9 $\pm$ 0.3	3.7 $\pm$ 0.3	5.1 $\pm$ 0.4	6.2 $\pm$ 0.5
d	6.8 $\pm$ 0.6	32.7 $\pm$ 3.0	27.7 $\pm$ 2.8	22.4 $\pm$ 2.2	31.4 $\pm$ 2.9	23.8 $\pm$ 2.5	17.1 $\pm$ 2.0	8.1 $\pm$ 0.7	39.3 $\pm$ 3.6	33.9 $\pm$ 2.9	26.4 $\pm$ 2.4	25.1 $\pm$ 2.1
Pelvis girdle												
Tilting	21.8 $\pm$ 1.8	41.4 $\pm$ 3.9	35.6 $\pm$ 3.3	30.8 $\pm$ 2.7	42.4 $\pm$ 4.1	30.8 $\pm$ 2.8	27.6 $\pm$ 2.6	27.9 $\pm$ 2.1	46.5 $\pm$ 4.1	40.1 $\pm$ 3.9	35.5 $\pm$ 3.3	32.3 $\pm$ 3.0
Rotation	23.7 $\pm$ 2.0	45.7 $\pm$ 4.3	39.3 $\pm$ 4.0	31.6 $\pm$ 3.6	46.6 $\pm$ 4.6	33.3 $\pm$ 3.9	25.9 $\pm$ 3.1	29.1 $\pm$ 2.5	49.3 $\pm$ 4.1	43.8 $\pm$ 4.3	33.2 $\pm$ 4.1	32.4 $\pm$ 3.3
Shoulder girdle												
Tilting	13.2 $\pm$ 1.5	29.4 $\pm$ 2.5	23.5 $\pm$ 2.0	19.9 $\pm$ 1.8	27.9 $\pm$ 2.4	20.3 $\pm$ 1.7	13.9 $\pm$ 1.5	17.0 $\pm$ 1.8	33.4 $\pm$ 2.2	27.3 $\pm$ 2.7	24.6 $\pm$ 2.6	18.2 $\pm$ 1.9
Rotation	17.1 $\pm$ 1.9	35.7 $\pm$ 3.1	30.4 $\pm$ 3.3	25.7 $\pm$ 3.1	34.8 $\pm$ 3.2	26.7 $\pm$ 2.9	19.8 $\pm$ 2.3	26.4 $\pm$ 2.3	39.1 $\pm$ 3.5	34.9 $\pm$ 3.4	31.4 $\pm$ 3.2	29.7 $\pm$ 3.1

Group I: control group, Group II: patients operated upon by conventional technique, Group III: patients operated upon by minimally invasive technique

preop data measured preoperatively, postop data measured postoperatively, nd non-dominant leg at controls and affected leg at patients, d dominant leg at healthy subjects and non-affected leg at patients

‡ Significant difference between fixed and non-fixed plate

^a Significant difference compared to healthy control subjects

^b Significant difference compared to preoperative patient value

^c Significant difference between the patient groups (group II vs group III)

^d Significant difference comparing the healthy (contralateral) side to the affected side

Fig. 3 Knee motion on fixed plate

values, but did not reach them even 12 weeks postoperatively. Only the mean CV of knee motion of the non-operated side 12 weeks after TKA ($p > 0.07$), the mean CV of pelvis tilting ($p > 0.06$), pelvis rotation ($p > 0.06$), shoulder rotation ($p > 0.06$) six and 12 weeks postoperatively and the mean CV of shoulder tilting ($p > 0.07$) six weeks postoperatively did not show significant differences between the two patient groups (groups II and III) (Table 1).

Discussion

The variability of knee motion (r), the variability of tilting and rotation of the pelvis and shoulder as angular parameters are presented by mean CV, which represents the flexibility of lower-limb joint movements [9, 17, 22]. A decrease in the variability of angular parameters produced an increase in the variability of temporal parameters and they together can lead to the deterioration of the complexity [6, 22] and stability of movement [4, 9].

The increased CV of cadence (groups II and III) in the preoperative and postoperative period shows that the consistency of limb movement and the stability of gait worsened compared to the controls (group I) [3, 19], which is similar to results established during treadmill walking six months after TKA [16]. In both the preoperative and the early postoperative period the mean CV of affected knee joint motion decreased significantly compared to that of the values of controls (Table 1) (Figs. 3 and 4). During the postoperative period the mean CV of the affected knee joint increased significantly, but it did not reach the values of the control group even 12 weeks after TKA (Table 1) (Figs. 3 and 4). This suggests a stiffness of the joint [13, 22], which is the result of OA and the pain in the preoperative period. During the postoperative period the stiffness results partly from pain and partly from the weakness of muscles and deteriorating proprioception [10]. On the basis of these results it can be stated that the increase in the CV of cadence and the decrease in the mean CV of affected knee joint motion together led to decreased coordination and consistency of movement [3, 9, 19, 22] prior to and three months after TKA. These figures also predict an

Fig. 4 Knee motion on non-fixed plate

increased risk of falling [4, 8]. It is worth taking this finding into consideration when planning rehabilitation, or when prescribing and suspending Zimmer frames and crutches.

The increased mean CV of the non-affected knee joint and the pelvis and the shoulder joint (Table 1) motion demonstrated that these joints play an important role in the compensation mechanism to ensure gait stability, which confirms earlier statements [1, 14, 16]. It also draws attention to the importance of the shoulder in compensation and ensuring gait stability.

Preoperatively no significant difference was found between the two groups in the measured parameters since patients were randomly chosen. In the early postoperative period there were significant differences between groups II and III in all measured parameters (Table 1). The patients operated upon by the minimally invasive technique (group III) approached the values of the healthy control group (group I) faster than those operated upon by conventional technique (group II), but the CV of cadence and the mean CV of affected knee joint motion still significantly differed from controls 12 weeks after the operation (Table 1) (Figs. 3 and 4).

In case of stepping on a non-fixed plate, the mean CV of non-affected knee motion, as well as pelvis and shoulder tilting were higher than the values measured on a fixed plate (Table 1). It can be concluded that the non-affected knee joint and the tilting of both the shoulder and pelvis have an important role in compensation and in the maintenance of stability. These findings correspond to the results of previous treadmill measurements [14, 16]. In the literature available we could not find an accurate and precise measurement technique for gait analysis which could be used in the early postoperative period of TKA. The data and results presented here underline the usefulness of our method also for evaluating the different stepping parameters relating the static and dynamic stability of the patients.

Limitations of the present study are that measurements were taken only in the early postoperative period and the CV of just one temporal parameter and the mean CV of only few angular parameters were calculated in the early (three-month) postoperative period from the results of 20 motion cycles. Further studies should analyse the variability of all kinematical parameters during stepping.

Conclusion

We presented that in the early postoperative period (12 weeks) the minimal invasive surgical technique, the less invasive approach to the knee results in a faster recovery. In such an early period after TKR no other objective measurement technique is known so far which can prove our statement since subjects cannot take part in a treadmill measurement where they have to walk for a much longer distance in order to show the deviations in gait variability [24].

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