THE EFFECT OF DIFFERENT EXPOSURES OF KNEE ARTHROPLASTY ON STEPPING PARAMETERS, VARIABILITY OF GAIT DURING STEPPING, AND DYNAMIC STABILITY IN THE EARLY POSTOPERATIVE PERIOD

Ph.D. thesis

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1. INTRODUCTION

Articular cartilage damage in the knee (osteoarthritis; OA) is one of the most common musculoskeletal disorders worldwide, affecting 30-40% of the population over 65 years of age. Knee OA not only causes pain but is also associated with limited mobility and deterioration in the quality of life. The number of total knee replacement (TKR) implantations is increasing year by year both worldwide and in our country. After surgery, pains are significantly relieved, and the previously weakened skills and motor functions are partially or fully restored. An accurate assessment of the condition can be obtained by using biomechanical methods. In healthy individuals, gait is a cyclical and symmetrical movement. Knee OA and TKR implantation significantly affect gait parameters, stability, and regularity of gait. In most cases, a treadmill based gait analysis can only be safely conducted at least three months after surgery. Thus, in the early postoperative period, gait parameters can only be tested using our stepping method.

2. OBJECTIVES

The primary objective of this study is to determine how TKRs implanted with different types of surgical exposure techniques (conventional and minimally invasive computer-assisted navigation) affect kinematic parameters and two factors of gait safety, gait regularity, and dynamic balance ability of patients suffering from unilateral knee joint destruction in the postoperative period. Our work also aims to consider the benefits in the early stages of rehabilitation of a more precise prosthetic component insertion solution, which requires a more extensive toolset and a slightly longer surgical time even after the training period, but less tissue damage due to less exploration. An internationally recognized ultrasound-based motion testing method, previously developed by our research group, has made it possible to quantitatively describe the kinematic parameters of stepping, characterize stepping regularity (or, in other words, the opposite of variability), and dynamic balancing ability (ability to overcome unexpected obstacles). We established the following objectives for our research:

1. to determine the kinematic parameters of patients with unilateral advanced cartilage damage - knee OA - awaiting TKR; to describe quantitatively how these parameters change with different surgical techniques from the preoperative period until the end of the postoperative 3rd month in a longitudinal study; and, to compare the values thus obtained with those of healthy controls of similar age with no musculoskeletal complaints on a fixed

plate,

2. to determine the kinematic parameters of patients with unilateral advanced cartilage damage - knee OA - awaiting TKR; to describe quantitatively how these parameters change with different surgical techniques from the preoperative period until the end of the postoperative 3rd month in a longitudinal study; and, to compare the values thus obtained with those of healthy controls of similar age with no musculoskeletal complaints on a non-fixed, moving plate,

3. to measure the variability of stepping parameters (knee motion, and the regularity of angular pelvic and shoulder joint tilt and rotation) in patients with unilateral advanced cartilage damage - knee OA - awaiting TKR on a fixed plate; to compare the variability of the preoperatively-measured stepping parameters with the parameters measured in the early postoperative period in the same patients; and to determine the extent to which the two different surgical techniques, conventional and minimally invasive, affect stepping variability, and to compare the longitudinally followed changes in stepping variability with those of healthy age-matched controls with no musculoskeletal complaints,

4. to measure the variability of stepping parameters (knee motion, and the regularity of angular pelvic and shoulder joint tilt and rotation) in patients with unilateral advanced cartilage damage - knee OA - awaiting TKR on a non-fixed, moving plate; to compare the variability of the preoperatively-measured stepping parameters with the parameters measured in the early postoperative period in the same patients; and to determine the extent to which the two different surgical techniques, conventional and minimally invasive, affect stepping variability, and to compare the longitudinally followed changes in stepping variability with those of healthy age-matched controls with no musculoskeletal complaints,

5. to determine the extent to which different surgical techniques affect Lehr's damping ratio -- an indication of dynamic balancing ability that is closely related to the incidence of falls in old age as measured by the ultrasound-based sudden change of direction test (hereafter referred to as the provocation test) - in the preoperative and the first three months of the postoperative period; and to compare provocation test scores taken at different times during the perioperative period with the mean of Lehr's damping ratio of the healthy controls of similar age with no musculoskeletal complaints.

3. METHODS

Participants

The healthy control group (Group I) consisted of five voluntary women and men with similar age. These people/subjects had no history of OA of the knee or hip joints, spinal deformities, or clinical history of other musculoskeletal disorders affecting their lower limb or lumbar spine.

Twenty patients with severe knee OA associated with pain and limited range of motion were included in our study from the waiting list for TKR who had already no or minimal response to conservative treatment. Each patient had unilateral symptoms (only one knee was affected).

The 20 patients, who had no significant differences in anthropometry, functional tests, and in the grade of OA, were randomly and equally allocated into two groups based on the different surgical techniques: conventional method (Group II.) and computer-assisted minimal invasive technique (CAS) was performed by the Stryker–Leibinger imageless navigation system. (Group III.). All subjects had standard pre-and postoperative management (anaesthesia, pain management, physical therapy protocols and permission time of full weight-bearing). Each subject underwent motion analysis before surgery as well as 2, 6, and 12 weeks after TKR. The study was authorized by the National Science and Research Ethics Committee (184/2007).

Ultrasound-based motion analysis during stepping

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). 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 signals as recorded by the measurement system. Further expectations were the standardization and attaining reproducibility. The active markers were fixed in place, using two-sided plaster tape, to the tibial tuberosity 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. 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. First, the motion of the knee joint was measured both on fixed and non-fixed plates for 20 stepping cycles each. In the second part, the motion of the trunk (motion of shoulder and pelvis) was measured.

The measurement of clinical parameters during stepping

From the three directional *(x, y, z)* spatial coordinates of the given anatomical points the following clinical parameters could be calculated: motion of the knee joint, trunk-pelvis motion (rotation and tilting), shoulder motion (rotation and tilting). It is worth performing the measurements not only on fixed but also on non-fixed plate, because the patients' balance control is very important during the early postoperative period.

Calculated parameters
For each subject in all gait cycles the values the cadence were calculated from the vertical movement of knee, while the motion of the knee joint *(r)* was calculated from three-directional *(x,y,z)* spatial coordinates of the tibial tuberosity (Equation 1.).

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

Equation 1

From the trunk motion test (motion of pelvis and shoulder) the tilting and rotation of pelvis and shoulder could be calculated using the spatial coordinates of the anatomical points of the anterior superior iliac spine and scapular acromion.
The obtained data were analyzed 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 and female), testing time (preoperatively, and six and 12 weeks postoperatively), and type of operation technique (conventional and 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.

Examination of the variability of stepping
The knee motion parameter *(r)* and the angular parameters (rotation and tilting of the shoulder and pelvis) changed constantly over time. After breaking down the parameters into cycles, the maximum and minimum values of the parameter can be defined for each cycle. If it is known for all gait cycles, then the mean,

standard deviation, and relative standard deviation of a given parameter for a given person can also be calculated from the variable defined for that person. The relative standard deviation thus calculated characterizes the variability of the maximum and minimum values of a given characteristic, which is the joint angle, rather than that of the particular joint motion. To avoid this, for the spatial movement of the knee joint as well as for the tilting and rotation of the pelvis and shoulder girdle, all gait cycles of all subjects examined were normalized to 0-100% of cycles. For each subject, angular variables were calculated as all integer percent of the gait cycle. In the next step, for all gait cycles of the individual subject, the mean [*Mean (i)*] and standard deviation [*SD (i)*] were calculated from the characteristic determined at the i-th whole gait cycle percent. Calculation of the mean coefficient value *(MeanCV)* characterizing the variability of the total joint motion is presented in equation 2*).*

$$MeanCV(\%) = \frac{\sum_{i=1}^{10e} \frac{SD(i)}{Mean(i)}}{100} \times 100 i\epsilon\{0 - 100\% gaitcycle\}$$

Equation 2.

Where: *i* represents {0–100% of the gait cycle} thus the mean coefficient of variation *(MeanCV)* represents the mean of all relative standard deviations determined in integer percent.

Statistical analysis

We had the relative standard deviation of the gait frequency for each subject tested as well as the value of the mean coefficient of variation *(MeanCV)* pertaining to the spatial motion of the knee joint as well as to the tilting and rotation of the pelvis and shoulder girdle. For the groups of subjects (healthy elderly people; patients operated on with conventional surgical technique and minimally invasive technique), the mean and standard deviation were calculated from the values of the parameters (determined as above) that characterize the variability of the subjects' stepping.

The data obtained were analyzed using the bivariate ANOVA method, while for the necessary post-hoc testing the Tukey method was used. The laterality of the lower limb (dominant and non-dominant) was used as the variable for the healthy group, while for the patient group the time of testing (preoperative, 6 and 12 weeks after surgery) and laterality (affected and non-affected) were used as variables. Data were processed with the SPSS 14 software (SPSS, Chicago, IL USA).

Measurement of dynamic stability using a sudden perturbation

The plate of the PosturoMed© (Haider-Bioswing GmbH, Weiden, Germany) device could be suspended by releasing the fastening unit, so it provides an unstable platform for walking. The springs allow the rigid plate to move freely in the horizontal plane. After the spring-suspended rigid plate is displaced from its middle position, the plate can be fixed again with the help of a fixing-releasing unit belonging to the device.

Once the fixing device is released, the rigid plate intends to return to its original position, which models the sudden change of direction. When no person is stand on the rigid plate, the rigid plate performs undamped free oscillation. The person standing on the plate set in motion loses their balance; this person can regain their balance by damping the moving plate. In this case, the rigid plate performs damped free oscillation and damping characterizes the balancing ability of the subject. During the balancing process after the sudden change in direction, an arbitrary number of anatomical points could be recorded with an ultrasound-based motion analysis system. The question emerges: to what extent can the person tested dampen the movement of the oscillating plate, i.e. what damping coefficient does the balancing ability of the person tested represent? If this question is raised, the movement of the rigid plate has to be recorded by a ZEBRIS CMS10 (Zebris Medizintechnik GmbH, Germany) ultrasound-based measuring system equipped with individual specific markers attached to the side of the rigid plate.

Calculated characteristics

In characterizing dynamic balancing, the question was how the subject can damp the motion of the rigid plate set into oscillation by their balancing; therefore it is expedient to characterize the balancing ability exhibited after an abrupt change of direction with one oscillation parameter of the damped oscillation. It is called the Lehr's damping ratio, which we can be easily obtained from the data. It corresponds to the balancing ability of the subject, the Lehr's damping number (D) is a suitable for characterizing the balancing ability. The value of Lehr's damping ratio can be between 0 and 1. If $D = 0$, there is no damping, undamped oscillation develops and the subject loses their balance. If $D = 1$, damping is equal to the critical damping, no oscillation occurs, and the balancing ability is ideal. The higher Lehr's damping ratio is, the better the actual damping is, i.e. the better the subject's balancing ability will be. The damped free oscillation can be determined from the movement of the rigid plate.

4. RESULTS

4.1. Effect of exposure method of knee arthroplasty on kinematic parameters characterising knee motion

We aimed to determine how the knee arthroplasty conducted with different exposures affects the clinical parameters characterizing knee motion during stepping. In the case of minimally invasive exposure, the motion range of the affected knee joint is significantly greater than the preoperative values and the range of vertical motion reaches the values of the healthy side already in the postoperative 6th week. The same cannot be said for conventional exposure. The motion range of the knee joint operated on with conventional exposure is reduced in comparison to the contralateral healthy knee, mainly due to the decrease of motion in the anteroposterior direction.

4.2. Effect of exposure method of knee arthroplasty on stepping regularity

The second objective of our study was to establish how knee arthroplasty performed with different exposures affects the regularity of gait. If the variation in the length and temporal parameters of gait results in a reduced value, then the subject's lower extremity is performing a similar movement from stride to stride, with each step occurring similarly with minimal variation. Mean coefficient of variation (*Mean CV*), which describes the regularity of joint motion, is a variability parameter that reflects the adaptability of joints.

The gait is harmonious if the variability of the spatial and temporal parameters characterizing the regularity of the gait pattern is small, but the mean standard deviation of the angular parameters characterizing the flexibility of the joint is high.

The increased relative standard deviation in the cadence of the operated patients (Groups II and III) in the pre-and postoperative periods shows a deterioration in limb motion regularity compared to Group I used as control, which correlates with previous literature. In the pre-operative and early postoperative period, the *Mean CV* of the affected knee decreased compared to the age-matched control group of healthy subjects. This suggests that the joint is stiffer, which is influenced by the pain caused by an OA in the preoperative period. In the postoperative period, stiffness may develop due to pain, reduced muscle strength, and proprioceptive deficits. Based on the results obtained, it can be stated that both before surgery and at the postoperative week 12, an increase in the coefficient of variation of cadence and a decrease in the mean coefficient of variation (Mean CV) of the affected knee motion led to decreased coordination and increased variability of motions.

Prior to surgery, no significant difference was detected between the parameters of groups II and III, which confirms the random selection conditions. In the early postoperative period, a significant difference was found between the groups in all the parameters studied. The values of the patients operated on with minimally invasive technique (group III) improved faster than the values of the patients operated on with the conventional method (group II), but the standard deviation of the gait and the mean coefficient of variation (Mean CV) of the affected knee joint motion were still significantly different from the control group even at 12 weeks after surgery.

4.3. Effect of knee arthroplasty performed with different exposure methods on the dynamic balancing ability of the knee

In the further part of our studies, we investigated the deterioration of balancing ability after a sudden change of direction, which is closely associated with an increased risk of tragic falls in the elderly, in the preoperative period and the early period after TKA. The values obtained were compared with those of the age-matched control group. The question arose as to whether the method of TKR exposure influenced the faster convergence of the response to the sudden change of direction compared to the control.

After TKR performed with any operation technique (Group II. and III.), the Lehr's damping ratio at week 6, determined by all three test methods, was not significantly different from the preoperative values and was significantly lower than the values in the control group. The results of our research have demonstrated that in the early postoperative period after TKR surgery, the values of the provocation test conducted during standing on the operated side and on the unaffected contralateral side do not improve significantly compared to the preoperative period, i.e. the risk of falling is very high throughout the early postoperative period. In the next stage of the postoperative period, the Lehr's damping number characterizing the balancing ability increases steadily for all the three test methods but does not reach the values of the control group for any of the test methods at week 12 postoperatively. This high risk of falling may be because the non-operated side is not yet able to compensate for the reduced balancing capacity of the operated side. The presumed reason for this is that the muscles are not yet able to take over the role that the affected joint capsule and the removed ligaments play in balancing, or the joint capsule and the damaged muscles have not yet regenerated properly and movement provokes pain. The Lehr's damping number calculated from the values recorded during standing on the unaffected side and standing on both limbs also decreased compared to the values of the control group, which is in line with

Gage's finding suggesting that kinematic responses in unilateral diseases and in the case of surgeries are bilateral.
In patients undergoing minimally invasive knee arthroplasty, the Lehr's damping number characterizing the dynamic balancing gradually improves over the entire postoperative period compared to preoperative values, and the improvement is faster than that in patients undergoing conventional surgery but does not reach the values of the control group in any of the test methods at week 12 postoperatively.
The presumed reason for the difference between the two exposure methods is that the minimally invasive technique entails much less joint capsule involvement than the conventional technique. In both groups of patients, the sex of the subject did not affect the ability to balance after an abrupt change of direction, i.e. the physiological difference between the sexes disappears. In addition to increasing joint motion and muscle development, rehabilitation protocols should also focus on developing dynamic balancing ability. It should be taken into consideration that at week 12 postoperatively, the dynamic balancing ability is worse for both exposure methods than for the control group, which indicates that the risk of falling is high. In other words, the ability to adapt to unexpected situations, e.g. walking on uneven or slippery ground, is still significantly lower in the early postoperative period compared to the age-matched control group, so prolonged physiotherapy and the use of walking aids should be considered at postoperative follow-up examinations to prevent accidents, after assessing the effect of age and comorbidities.

5. CONCLUSIONS

Knee joint endoprosthesis implantation is one of the most frequently used orthopaedic procedures. However, 20 percent of the patients who underwent the operation are dissatisfied with the outcomes. The reason for this is not clear, but a mechanical alignment beyond 3° of varus-valgus can represent the most important cause of failure of TKR and consequently patient dissatisfaction. Neutral mechanical alignment is the main goal in every TKR. This can be achieved through different tools, such as extramedullary and intramedullary guides, patient-specific instrumentation (PSI), and computer-assisted surgery (CAS). The use of an intramedullary guide may lead to fat embolism, there is an increased risk of fatty embolism and it is impossible to use in cases of bone deformity and post-traumatic deformities (sequelae of trauma). Regarding the extramedullary guide, it becomes more difficult to use in cases of great obesity or increased soft-tissue volume around the tibia. Meta-analysis suggests that surgeries conducted with patient-specific instrument

(PSI) fail to improve the mechanical axis and implant survivorship. Computer-assisted total knee arthroplasty (CAS) has provided a useful tool in assisting the surgeon to achieve a more accurate mechanical axis through precise bone cuts and ligament balancing. Early follow-up after CAS showed a more accurate mechanical axis and better functional outcomes, and two meta-analyses demonstrated a better mechanical axis and longer implant. Besides the better mechanical axis of the components, the quality of life parameters are also better compared to the traditional surgical method, but the operative time is longer and thus the use of a tourniquet also lasts longer.

The main objective of the research conducted with biomechanical methods and summarized so far was to determine how the knee joint prosthesis implanted with different surgical techniques (conventional and navigation-assisted minimally invasive approaches) affects kinematic parameters characterizing the knee motion, gait regularity, and dynamic balancing ability of the knee joint in the event of an abrupt change of direction.

For safe, harmonious walking, it is essential that motion is performed within the correct range and with adequate accuracy, and that the person always regains balance in the event of a sudden stumble or fall. Based on the statistical processing of the results of the motion studies carried out, the following new scientific findings can be concluded:

Thesis 1: The kinematic parameters (range of motion of the knee joint, range of motion of the pelvic girdle rotation, range of motion of the pelvic girdle tilt, range of motion of the shoulder girdle rotation, and range of motion of the shoulder girdle tilt) that characterize stepping were significantly influenced by the method of exposure of the total knee arthroplasty on fixed. The anteroposterior gait amplitudes of the healthy subjects used as age-matched controls without musculoskeletal disorders were significantly higher compared to the patients with knee osteoarthritis. In the early postoperative period, the kinematic parameters of the motion of the knee joint of the non-operated side, i.e. those characterizing the motion of the relatively healthy knee joint, are back to the pre-operative level by the end of the 3rd month. With minimally invasive exposure, the motion range of the affected knee joint is significantly greater than the preoperative values and the vertical range of motion reaches the values of the healthy side already in the postoperative 6^{th} week. In the case of conventional exposure, this cannot be said even at the end of the 12^{th} week. Increasing the tilt of the pelvic and shoulder girdles compensates for the reduced knee joint motion. The explanation for the differences between the two methods could be that the surgical damage of the adjacent tissues around the joint in case of minimal invasive exposure is much less.

Thesis 2: The above-mentioned observations are valid on non-fixed, moving plates as well. There are no significant alterations compared with the results measured on fixed plate. It may prove that different circumstances influence the motion range of the knee much less than the different methods of exposure.

Thesis 3: The increased coefficient of variation of the cadence observed pre- and postoperatively in patients operated on by different methods (navigated minimally invasive and conventional methods) shows that the regularity of limb movements deteriorates compared to the age-matched healthy controls without musculoskeletal disorders. The results obtained suggest that both before surgery and at postoperative week 12, an increase in the variation of the cadence of the affected knee motions led to decreased coordination of motions and increased variability of motions. In the early postoperative period, the values of CV for the patients operated on with navigation-assisted minimally invasive technique (group III) decreased significantly faster than those for the patients operated on with the conventional method (group II), but the coefficient of variation characterizing gait regularity and the mean coefficient of variation (*Mean CV*) of the affected knee joint motion were still significantly different from the control group even at week 12 postoperatively.

Thesis 4: The above-mentioned observations are valid on moving non-fixed plates as well. There are no significant alterations compared with the results measured on fixed plate. The explanation could be that the different circumstances influence the regularity of cadence much less than the different methods of the exposure. When gait testing was performed on an unstable, non-fixed plate, the mean coefficient of variation (*Mean CV*) of the non-affected knee joint motion as well as the pelvic and shoulder tilt values were greater than those measured on a fixed plate. This may suggest that contralateral knee motions as well as shoulder and pelvic tilt may play an important role in compensation and maintaining stability.

Thesis 5: In the early period after total knee arthroplasty (3 months), the response to sudden change of direction during standing, i.e. the provocation test values on both extremities, on the operated side and on the non-affected contralateral side, do not improve significantly compared to the preoperative status, i.e. the risk of falling is very high throughout the early period after surgery. The Lehr's damping number increases steadily but does not reach the values of the control group at week 12 after surgery (Table 6.). The Lehr's damping number calculated from the values measured during standing on the unaffected side and on both limbs also decreased compared to the values of the control group, which is in line with Gage's finding: kinematic responses in unilateral diseases and surgery manifest bilaterally. The presumed reason for

the difference between the two exposure methods is that the minimally invasive technique causes much less surgical damage to the joint capsule than the conventional technique. The other reason is that in medial parapatellar exposure, the vastus medialis muscle adhering to the patella and part of the rectus femoris muscle radiating into the quadriceps tendon are also virtually detached from the patella, as a result, not only the muscle function but also the proprioception is impaired in the early immediate postoperative period until the muscle heals. In addition to increasing joint motion and muscle development, rehabilitation protocols should also focus on developing dynamic balancing skills.

A summary of my results: I have found that the exposure method of TKR significantly influenced the kinematic parameters characterizing stepping and the two factors characterizing safe gait: gait regularity and dynamic balancing ability (response to the abrupt change of direction). By the 3rd month of the postoperative period, the values of the patients operated on with minimally invasive exposure combined with navigation were closer to those of the control group than the values of the patients operated on with conventional exposure, but they failed to reach the values of the control group. Due to my research, I can formulate the next statements:

1. The kinematic parameters (range of motion of the knee joint, range of motion of the pelvic girdle rotation, range of motion of the pelvic girdle tilt, range of motion of the shoulder girdle rotation, and range of motion of the shoulder girdle tilt) that characterize stepping were significantly influenced by the method of exposure of the total knee arthroplasty on fixed plates.
2. With minimally invasive exposure, the motion range of the affected knee joint is significantly greater than the preoperative values and the vertical range of motion reaches the values of the healthy side already in the postoperative 6^{th} week. In the case of conventional exposure, this cannot be said even at the end of the postoperative 12^{th} week.
3. Different circumstances (fixed or non-fixed plates) influence the motion range of the knee much less than the different methods of the exposure.
4. An increase in the variation of cadence and the decreased knee motion of the affected knee led to decreased coordination of motions and increased variability of motions preoperatively and still at the postoperative week 12
5. In the early postoperative period the coefficient of variation characterizing gait regularity for the patients operated on with navigation-assisted minimally invasive technique (group III) decreased significantly faster than those for the patients operated on with the conventional method (group II).

6. The coefficient of variation and the mean coefficient of variation (*Mean CV*) of the affected knee joint motion was still significantly different from the control group even at week 12 postoperatively.
7. The mean coefficient of variation (*Mean CV*) of the non-affected knee joint motion as well as the pelvic and shoulder tilt values were greater than those measured on a fixed plate. This may suggest that contralateral knee motions as well as shoulder and pelvic tilt may play an important role in compensation and maintaining stability.
8. In the early period after total knee arthroplasty (3 months), the response to sudden change of direction during standing, i.e. the provocation test values on both extremities, on the operated side, and on the non-affected contralateral side, do not improve significantly compared to the preoperative status.
9. The Lehr's damping number calculated from the values measured during standing on the unaffected side and on both limbs also decreased compared to the values of the control group, which indicates that kinematic responses in unilateral diseases and surgery manifest bilaterally.

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