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Gait Analysis in Patients with Gonarthrosis Treated by Total Knee Arthroplasty (TKA)

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1. Introduction

The aim of the studies was an attempt to evaluate the variability of kinematic parameters of the lower limb joints of subjects before and after total knee replacement in gait with natural speed. Angular values changes in the knee, ankle, and hip joints were studied in three planes of movement.

2. Gait analysis

Walking and running are natural ways of human locomotion which are shaped during phylogenetic development. According to Zembaty (1987) the walking cycle involves “activities and movements performed by a walking person between the contact of one of the heels with the ground and its subsequent contact with the ground”, another definition assumes that gait means “locomotion consisting in moving the body weight, focused at the centre of gravity, in space, along a rout requiring the least energy expenditure” (Basmajian, 1976).

There are a lot of more definitions which have been devised over several dozen years when thorough research over the methods of human movement was started. First reports on this issue date back to the 1830s when the Weber brothers performed an analysis of time and space parameters of gait, while the locomotion pattern was first determined by means of a photographic technique by Marey and Muybridge (Andriacchi et al. 2000).

On the basis of these long-term and numerous studies individual gait phases were distinguished, their duration was determined and dependencies between gait phases and their mutual changes induced by changing conditions under which motion is executed.

2.1 Gait phases

The constant and characteristic gait feature includes its cyclicity, i.e. the alternating occurrence of two phases (Bober, 1985):

- single support - only one lower limb has contact with the ground, the support time is approx. 0.53 s.
- double support - both feet have contact with the ground, the support time is approx. 0.15 s.

In each gait cycle the alternating phases of lower extremity movements listed in Table 1 can be distinguished.

General division	Detailed division	Indirect positions
support	shock-absorption	initial contact mid stance
	rebound	toe off
swing	pre swing	pre swing mid swing
	terminal swing	terminal swing

Table 1. Step phases (Bober, 1985)

The first application of gait analysis for clinical needs was described at Rancho Los Amigos Medical Center in Los Angeles. Dr Jacqueline Perry used film cameras and a dynamometric platform to determine the gait stereotype in children with lower extremity orthopedic problems, such as the monitoring of surgical treatment results (Minns 2004). It was also there that a gait division system commonly used today was devised (Fig. 1) (Perry, 1992).

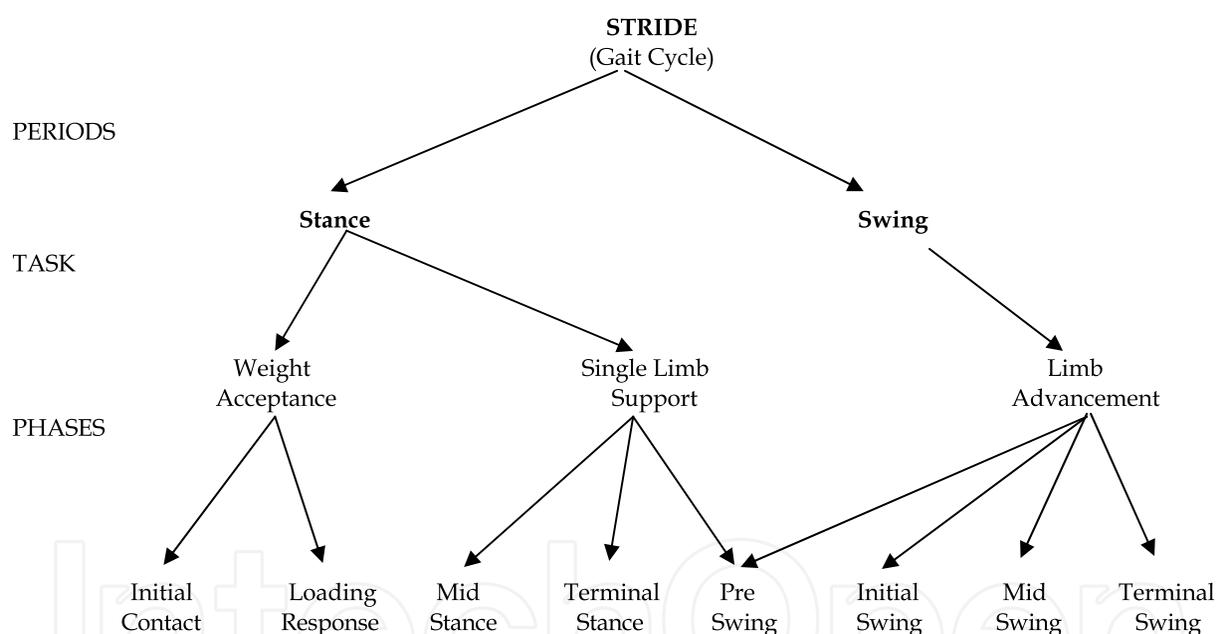


Fig. 1. Gait phases worked out by Rancho Los Amigos Medical Center (Perry, 1992)

On the basis of this division, the gait cycle is divided into the support phase and the swing phase. The support phase consists of:

- the weight acceptance period which includes the initial contact period, which lasts approx. 0-2% of the gait cycle and the loading response period, which lasts 0-10% of the gait cycle. It begins when the heel comes in contact with the ground and ends when the other leg is lifted up and enters the limb advancement period;
- during the single limb support phase the midstance period is distinguished, which lasts for 10-30% of the gait cycle. This period starts when the other leg is lifted from the ground and it ends when the forefoot touches the ground and, next, it enter the terminal stance period. This period lasts 30-50% of the gait cycle and it starts when the

lateral and medial ankles are lifted and it ends when the other foot touches the ground. This is the end of the support phase.

- The swing phase:
- the limb advancement period including the last support period (preswing) (50-60% of the gait cycle); this is the moment when both feet have contact with the ground;
- the initial swing period (60-73% of the gait cycle) begins at toe off and ends when the leg is at the level of the support foot);
- the midswing phase (73-87%) begins when the foot is at the level of the support foot and ends when the tibia is vertical to the ground (the knee and the hip in flexed position);
- the terminal swing period (87-100%) constitutes the continuation of the previous period and ends when the heel touches the ground;

While describing gait periods attention should also be paid to the changing range of motion in the individual lower extremity joints (Fig. 2):

- initial contact (*F1*) - 20° hip joint flexion, extended knee joint, slightly dorsi-flexed foot;
- loading response (*F2*) - hip and ankle joints in flexed position, plantar flexion of the foot until the forefoot is placed on the ground;
- mid stance (*F3*) - hip and ankle joints in extended position, dorsi-flexed foot - approx. 20°;
- terminal stance (*F4*) - extended hip joint, flexed knee joint;
- preswing (*F5*) - hip in intermediate position, flexed knee joint, plantar flexion of the foot;
- initial swing (*F1*) - hip and knee joints in flexed position, dorsi-flexed foot;
- midswing (*F7*) - hip joint flexion, extended knee joint, slightly dorsi-flexed foot;
- terminal swing (*F8*) - slight hip flexion, extended knee joint, foot in intermediate position (Fig. 2)

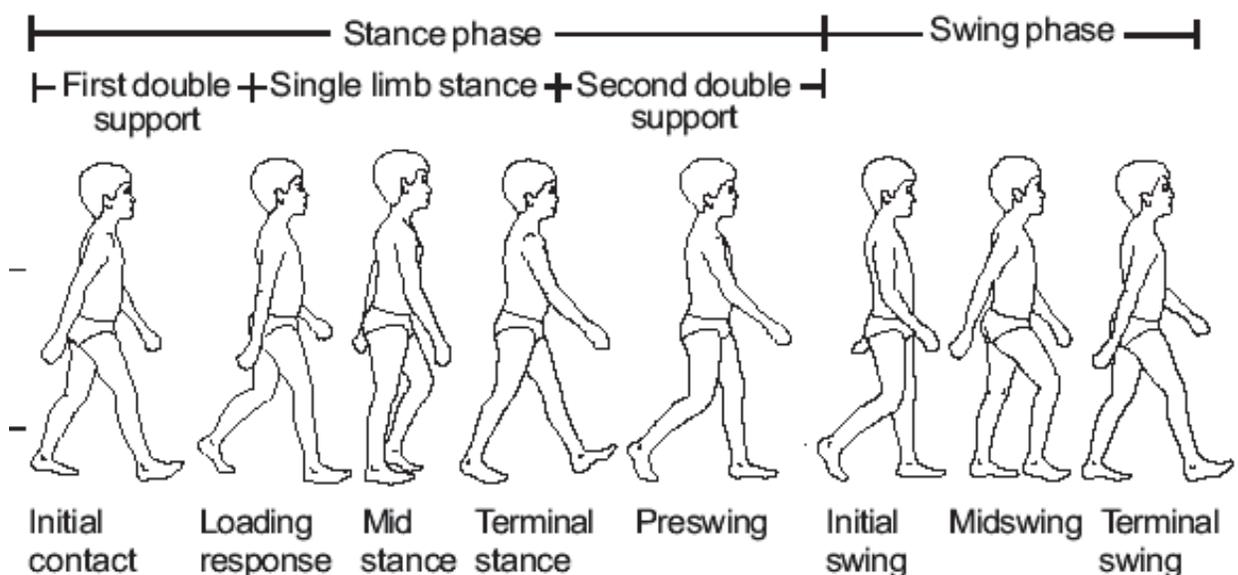


Fig. 2. Angular placing of joints during gait cycle (Perry, 1992).

3. Gait analysis in patients with gonarthrosis before and after total knee arthroplasty based on own research

The literature on the subject (Baliunas et al. 2002, Manetta et al. 2002, Fantozzi et al. 2003, Wu et al. 2007) provides a broad description of the work of the knee joint before and after knee replacement, but these studies are mostly limited to the presentation of the joint movement in the sagittal plane, without considering the other planes or the influence of the disease on the ankle and hip joints and the side which was not operated on. Therefore, research was undertaken to assess the change in kinematic parameters of the gait of persons with degenerative knee joint changes before and after arthroplasty of the joint, to present the three planes of the operated and unoperated knee – in search of compensation mechanisms and to devise a biokinematic chain of the lower limb before and after the surgical procedure.

3.1 Material and method

27 patients participated in the study, including 20 women (74%) and 7 men (26%), aged 60 to 74 (average of the age 66,29 ($\pm 5,2$)), qualified for knee arthroplasty due to degenerative changes of the joint. X-ray tests performed within the framework of pre-operative diagnostics at the Clinic did not reveal degenerative changes in hip joints. The gonarthrosis evoked an apparent flexion contraction in the affected knee joint in all patients (mean angle value: 6°)

Locomotion tests included measurements of biomechanical parameters of the gait on the basis the three-dimensional analysis using the Vicon system. The analysis took into account angular changes in the three planes of knee joint motion and in the sagittal plane of the ankle and hip joints, as well as time and spatio-temporal parameters.

First examination was done before knee arthroplasty and the second 6 months after the operation when patients mobile without orthopedic support devices.

The control group consisted of 30 healthy persons aged 50-70 (18 women and 12 men) in whom no significant neurological diseases or orthopaedic injuries which might affect the individual gait pattern were found.

Results of control group are a part of a conducted research project through Dr. Wiesław Chwała, being aimed at creating the norm of the locomotion of healthy persons in an all sorts age brackets.

Locomotion tests were conducted at the Biokinetics Laboratory, Department of Anthropometrics, University School of Physical Education in Cracow.

The research project was approved by the Bioethics Committee at the Regional Chamber of Physicians.

The gait was examined using the Vicon 250 computer system for three-dimensional gait analysis. This system consists of five cameras with a set of luminescent diodes and a data station. The cameras work in the infrared band, and the speed of image recording depends on the setting and type of camera. The frequency of camera operation is 120 images per second. The recorded two-dimensional image from one of the cameras is then transmitted to the data station, where, after being combined with the images from the other cameras, it creates a three-dimensional representation of markers.

The data station is a specialised computer which collects and processes the data recorded by the cameras. Markers are plastic balls with a diameter of 25 mm covered with fluorescent material. The system determines the three-dimensional location of the markers in the form

of points and registers their changes in space. The so-called passive markers are glued directly on the patient's skin. Their arrangement reflects the pattern of the biomechanical model. They are glued along the joint axes at an appropriate distance from the centre of the joints and at characteristic points on the head, chest and pelvis. In this way, it is possible to create a spatial representation of these segments of the body and to measure the individual parameters – the dimensions of the pelvis and the span of the chest.

It is important to place the markers of the head, trunk and the lower half of the body in a precise manner. Anterior head markers define the beginning and the scale of the head as a body part, and the posterior markers indicate its location in space. Trunk markers (C7, CLAV, TH10, STRN), together with head markers, determine the axes of the coordinate system of the trunk. The pelvic markers (LASI, RASI), together with the sacrum marker, define the axes of the coordinate system of the pelvis. The marker of the sacrum should be placed in the plane perpendicular to the line joining the ASIS markers (LASI i RASI). It is very important to place the knee markers and the thigh and crus markers in the proper manner.

The Microsoft Excel software and the statistical package SPSS 14 were used for statistical analysis of the research results. The statistical analysis of the data collected was performed on the basis of descriptive and mathematical methods of statistics.

Descriptive methods of statistics were used to present the results in tables containing arithmetic means, standard deviations (s) and the range (min-max).

Mathematical methods of statistics involved significance analysis of the means for repeated measurements by means of Student's t-test for repeated measures.

Both of the aforementioned techniques assumed that the dependent variable distribution is not distant from normal. However, the legitimacy of this assumption cannot be verified using such a small sample. Therefore, it was decided to use parametric tests as the application of non-parametric tests (which do not require a normal distribution) would additionally reduce the strength of the analysis and, in this way, also the chance of obtaining statistically significant results.

4. Results

4.1 Comparison of angular changes in knee joint in sagittal plane

The values of the range of angular changes in the knee are presented in figures 3-7 in three planes of motion (sagittal, frontal and transverse), in patients before and after knee arthroplasty. The grey ribbon in each diagram shows the variability of the results in the healthy population (the mean + 2sd). In the sagittal plane, both in the operated and unoperated leg, a limitation of the knee extension at the stance phase is distinctly marked in the 1st and 2nd examination, while insufficient flexion can be noticed at the swing phase. (Fig. 3)

I bad op – examination before arthroplasty, operated knee

I bad n/op – examination before arthroplasty, not operated knee

II bad op – examination after arthroplasty, operated knee

II bad n/op – examination after arthroplasty, not operated knee

Ext – extension, Flex – flexion

Angle (degrees) – angular degrees in the knee joint (in degrees)

Normalised (percent) – normalised time of the gait cycle (in percentages)

Norm – angular changes during normal gait in the comparative group (mean value±SD)

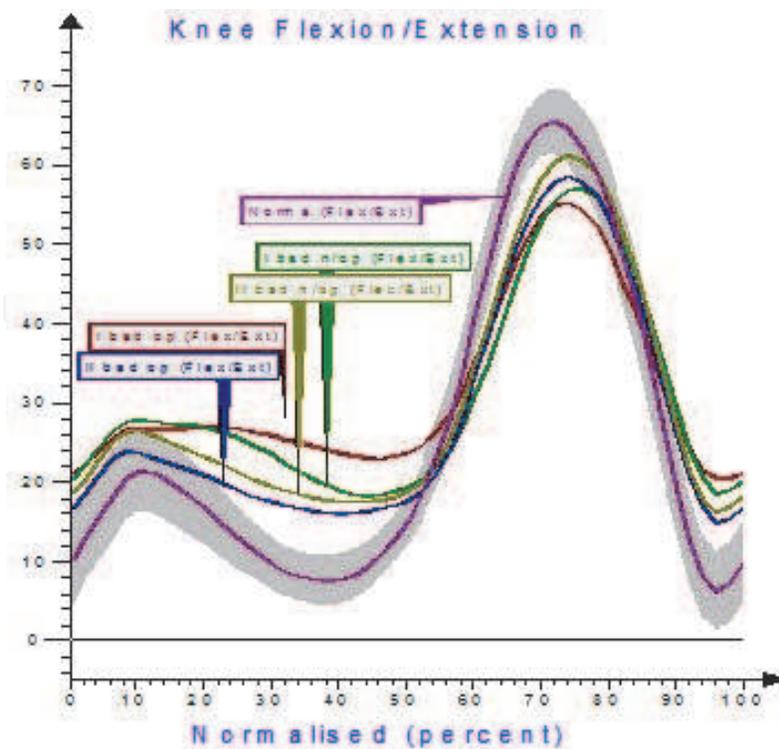
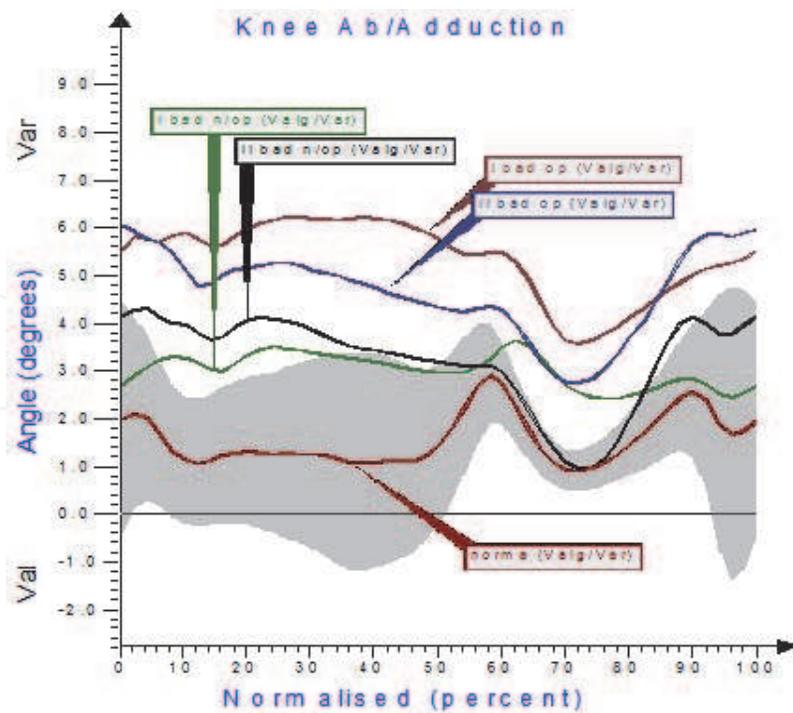


Fig. 3. Angular changes in the knee joints in the sagittal plane

4.2 Comparison of angular changes in knee joint in frontal plane

During the 1st examination excessive genu varum is revealed at the stance and swing phases. After the procedure this position changes slightly. On the operated side, increased



Var - varus knee, Val - valgus knee

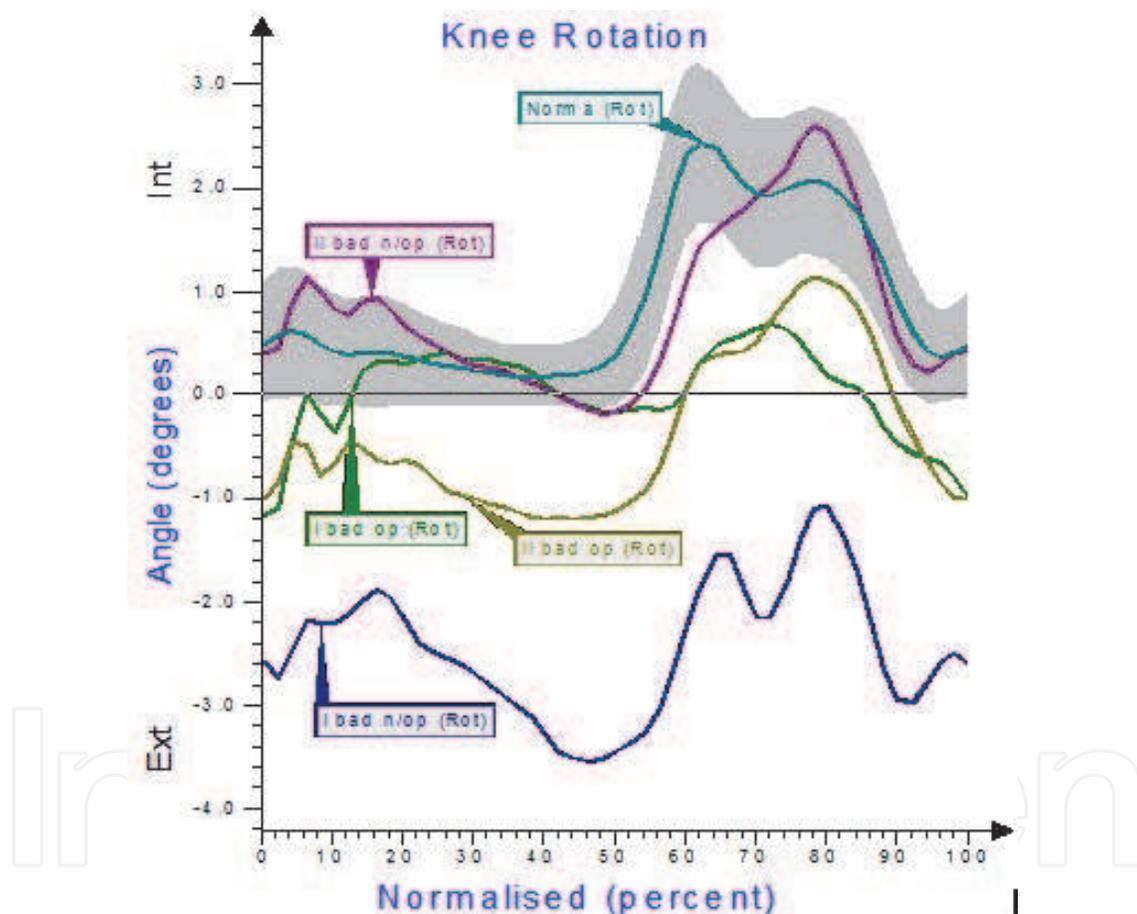
Fig. 4. Angular changes in the knee joints in the frontal plane

genu varum is marked during the mid stance, initial swing and mid swing periods. After the procedure, genu varum deteriorated during mid stance period; however, it improved during the swing period (Fig. 4).

4.3 Comparison of angular changes in knee joint in transversal plane

As a result of the disease external rotation is marked on the operated side during the initial contact and loading response periods and throughout the swing phase. After the treatment, on the other hand, the crus undergoes external rotation throughout the stance phase and the internal rotation is insufficient at the swing phase.

Distinct external rotation appeared on the unoperated side throughout the gait cycle, crus rotation occurred after the procedure towards proper internal rotation (Fig. 5).

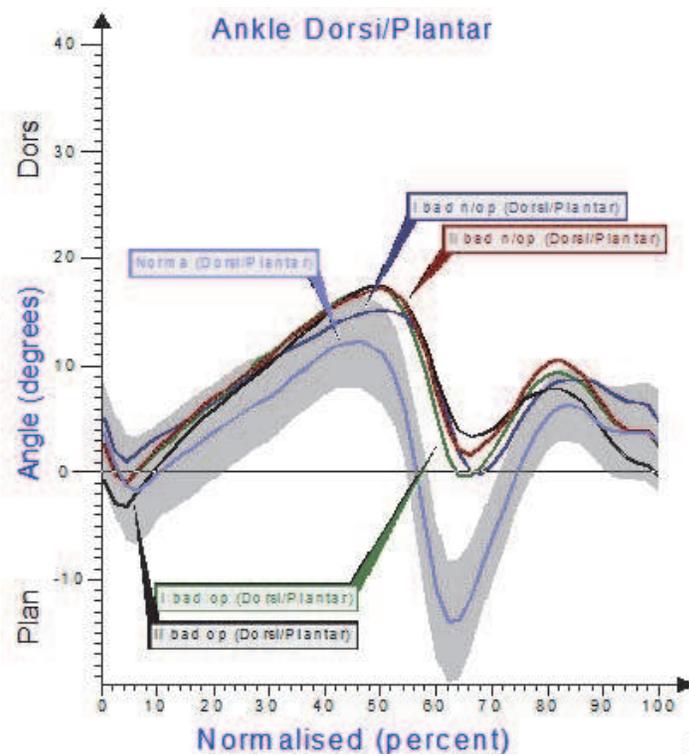


Ext - external rotation, Int - internal rotation

Fig. 5. Angular changes in the knee joints in the transversal plane

4.4 Comparison of angular changes in ankle joint in sagittal plane

The 1st and 2nd examinations revealed that the position of the ankle joints was correct at the stance phase, while no plantar flexion of the joints occurred during the preswing period (Fig. 6).

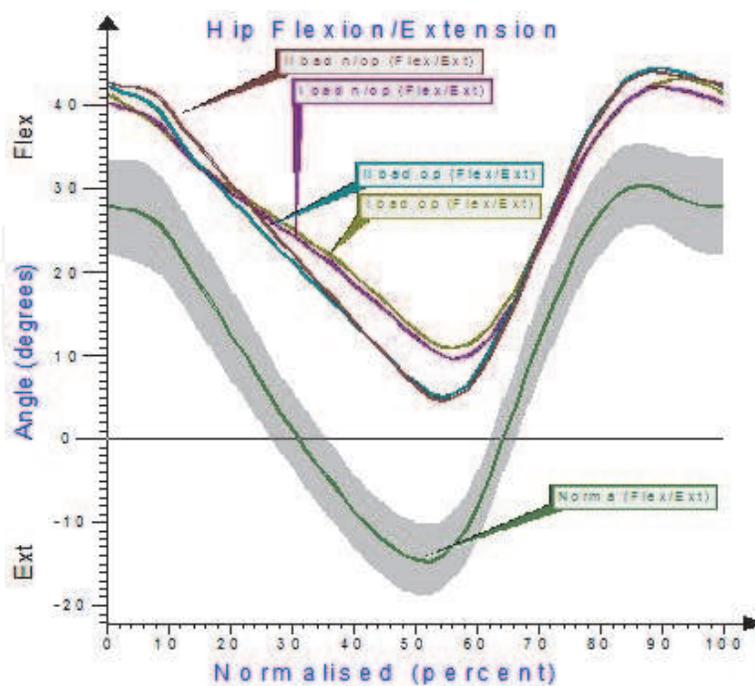


Plan – plantar flexion, Dors – dorsal flexion

Fig. 6. Angular changes in the ankle joints in the transversal plane

4.5 Comparison of angular changes in hip joint in sagittal plane

Flexion contracture of the hip joints was marked on both sides in the 1st and 2nd examination. It was slightly reduced after the procedure (Fig. 7).



Ext – extension, Flex – flexion

Fig. 7. Angular changes in the hip joints in the transversal plane

4.6 Analysis of spatio-temporal parameters

The table below presents a comparison of the average values of time and space parameters obtained before and after the endoprosthetic replacement for the control group. (Tab.2)

The following parameters were measured for all persons:

Cadence – number of steps within the minute

DS – double support

Foot Off – end of stance phase

SS – single support

StrL – stride length

StrT – stride time

WS – walking speed

spatio-temporal parameters	I examination		II examination		control group
	operated knee	not operated knee	operated knee	not operated knee	
Cadence [steps/min]	87,0	86,7	88,8	87,9	112,0
Foot Off [%]	68,3	70,7	68,0	68,5	62,8
DS [s]	0,6	0,6	0,5	0,5	0,3
SS [s]	0,4	0,4	0,4	0,5	0,4
StrL [m]	0,8	0,8	0,9	0,9	1,3
StrT [s]	1,5	1,5	1,4	1,4	1,0
WS [m/s]	0,6	0,6	0,7	0,7	1,2

sides: operated knee – knee before and after arthroplasty; not operated knee – healthy knee

Table 2. Comparing temporary-spatial values at patients before and after the arthroplasty with results of the control group

On the basis of the analysis of the time and space parameters it can be noticed that patients move with a reduced frequency of steps and at a slower rate. Thus, the double support phase and cycle duration are longer for them; similarly, the stance phase ends later.

Time and space parameters were also compared between the operated and unoperated side in the 1st and 2nd examination. Tables 3 & 4.

Statistical analysis also revealed a significant difference between the operated and unoperated side for the Foot Off parameter in the 1st and 2nd examination. No statistically significant differences between the analyzed parameters were found in the 2nd examination.

I examination									
spatio-temporal parameters	operated knee				not operated knee				statistical significant differences (p)
	x	s	min	max	x	s	min	max	
Cadence [steps/min]	87,0	18,8	34,4	118,0	86,7	18,8	34,2	117,4	0,622
DS [s]	0,6	0,4	0,3	2,3	0,6	0,4	0,2	2,2	0,318
Foot Off [%]	68,3	5,5	59,8	81,8	70,7	5,4	63,6	84,3	0,013
SS [s]	0,4	0,05	0,3	0,5	0,4	0,1	0,3	0,8	0,194
StrL [m]	0,8	0,2	0,6	1,3	0,8	0,2	0,5	1,2	0,630
StrT [s]	1,5	0,5	1,0	3,5	1,5	0,5	1,0	3,5	0,932
WS [m/s]	0,6	0,2	0,2	1,0	0,6	0,2	0,2	1,0	0,639

sides: operated knee – knee before and after arthroplasty; operated knee – healthy knee

Table 3. Comparing temporary-spatial values at patients before the arthroplasty on the operated and not operated side.

II examination									
spatio-temporal parameters	spatio-temporal parameters				spatio-temporal parameters				spatio-temporal parameters (p)
	x	s	min	max	x	s	min	max	
Cadence [steps/min]	88,8	18,4	46,8	115,5	87,9	18,6	45,9	116,7	0,188
DS [s]	0,5	0,3	0,3	1,4	0,5	0,3	0,3	1,4	0,585
Foot Off [%]	68,0	4,5	52,8	78,3	68,5	6,2	60,6	84,3	0,500
SS [s]	0,4	0,08	0,3	0,8	0,5	0,1	0,3	0,8	0,342
StrL [m]	0,9	0,2	0,6	1,2	0,9	0,2	0,5	1,3	0,169
StrT [s]	1,4	0,4	0,7	2,6	1,4	0,4	0,7	2,6	0,208
WS [m/s]	0,7	0,3	0,2	1,4	0,7	0,3	0,2	1,4	0,943

sides: operated knee – knee before and after arthroplasty; operated knee – healthy knee

Table 4. Comparing temporary-spatial values at patients after the arthroplasty on the operated and not operated side

5. Discussion

5.1 Locomotion of patients with gonarthrosis

Gait analysis in osteoarthritis patients indicates that as a result of degenerative knee disease, limitation of hip joint movement occurs - marked flexion contracture can be observed in these patients.

On the basis of the research conducted by the present authors, it can be concluded that the patients taking part in the study walk with their knees bent. Additionally, the joints assume the genu varum position and are considerably externally rotated. There is no plantar flexion of the ankle joints occurs at the beginning of the limb advancement period.

Considerable bow-leggedness is also observed in the authors' own research, especially on the affected side.

Similar results were obtained by Gök et al. 2002 who analyzed the gait of 13 patients suffering from knee arthritis. Their results were compared with 13 healthy persons. The analysis was performed using the Vicon 370 system and it involved kinetics, kinematics and time and space parameters of the gait. Significant movement limitation was discovered in the saggital plane, as well as genu valgum at the support phase.

One of the reasons may be the patients' reduced daily physical activity caused, among other things, resulting in lower flexibility and reduced active range of motion in the joints.

On the basis of the research conducted it can also be concluded that due to pain the support phase is extended and thus, the limb advancement period is shortened in patients suffering from degenerative knee disease. A similar conclusion was reached by Andriacchi et al. (1997) who found that an extended gait cycle can be observed in patients waiting form endoprosthetic replacement. The knee function was not completely restored, despite good clinical results, which is confirmed by the authors' own research.

Astephen et al. (2007), on the basis of locomotion tests of persons with degenerative changes of knee joints, concluded that changes in ankle and knee joints are marked in the saggital plane. However, they did not determine the direction of the changes in the joints.

Similar results for the saggital plane were obtained by Baliunas et al. [21], who discovered there existed a restriction of the range of motion throughout the gait cycle.

This is yet another confirmation of the results of the author's own studies, where a clear restriction of the active range of motion was found in the knee joint in the saggital plane.

Manetta et al. (2002), on the other hand, examined 10 persons suffering from degenerative knee joint disease and compared the results with the control group. They determined the kinetics and kinematics of the gait on the basis of a motion analysis system. It turned out that the maximum flexion at the support stage was lower in the patients. As the values of the maximum flexion at the support phase were similar among the patients compared to the norm and no weakening of the quadriceps femoris muscle was observed, they concluded that this pattern was caused by a compensatory reduction in gait speed.

These reports are not fully consistent with the results of the author's own research, as extension limitation was observed in the examined patients (increased flexion) at the support phase.

Results similar to Manetta et al. (2002), and not fully consistent with the results of the author's own research, were obtained by Childs et al. (2004), who found that flexion during loading response was limited in patients suffering from articular disease compared to the norm.

Bajek et al. (2006a) analyzed the gait of 20 patients suffering from degenerative knee disease and compared with a control group consisting of 20 persons. The analysis included the time and space parameters and the range of motion in the saggital plane of the knee and hip joints in both legs and the three-dimensional pelvic function.

The results obtained indicate a considerably higher limitation of flexion during the limb advancement period than the results of the present authors' research. Flexion contracture of the hip joints was also visible, which confirms the results of the authors' own research.

The authors assumed that the limitation of motion in the affected knee joint will be compensated by an increased range of motion in the hip joint, however, the results of their research show that this range of motion becomes reduced, in particular, on the side of the affected joint.

Similar results are presented in this study. However, on the basis of the present authors' own research it can be concluded that the reason for such position of the hip joints is the flexion contracture in the knee joints, which leads to excessive hip flexion potentially accompanied by increased anterior pelvic tilt.

No study describing the gait stereotype before and after endoprosthetic knee replacement presents such an interpretation.

A change in the leg axis is a characteristic feature of degenerative disease. Changes located within the medial range cause a varus deformity of the leg, while changes in the lateral section lead to its valgosity (Wierusz-Kozłowska et al. 2004, Kwiatkowski et al. 2004). This alignment results in a dominating varum or valgum deformity. In the present study, a varus deformity of knee joints was observed both before and after the arthroplasty procedure. The fact that the situation does not change after the procedure may result from changes in lower extremity biomechanics consolidated as a result of the disease.

Similar conclusions were reached by Rudolph et al. (2007), who, while evaluating the gait pattern in patients, found that a varum deformity of the knees and the weakening of the quadriceps femoris is a characteristic feature.

A study by Al-Zahrani et al. (2002) describes the influence of the disease on the gait stereotype. The analysis involved the function of the lower extremity joints in the saggital plane, time and space parameters and the bioelectric activity of the knee joint muscles. The test was performed using an optoelectronic system for three-dimensional gait analysis combined with a dynamometric platform and an electromyograph. 58 persons participated in the study. The results were compared with a control group consisting of 25 (average age: 69).

Gait analysis performed in the patients revealed a restriction of the active range of motion was found in the knee joint in the saggital plane. All these results corroborate the findings of previous studies and are interpreted as the result of pain and a change of the joint proprioception. However, the weakening of the proprioception of the knee joint is not a fully objective explanation of the changes in the gait stereotype. Despite the fact that the proprioception of the joint was not studied directly, no neurological changes were found in any of the patients.

Marks et al. (1993) concluded that there was no relationship between the locomotion possibilities in patients suffering from degenerative disease and the weakening of the proprioceptive function of the joint. Differences in the gait kinematics between the patients and the control group may also result from different gait speed, however, the authors did not study this influence. Many authors emphasize the importance of proprioception changes both before and after the procedure. Proprioception decreases with age and causes a change in the muscle pattern when the joint is under load, thus contributing to the development of degenerative disease (Cash et al. 1996, Barret et al. 1991, Sharma et al. 1997).

5.2 Locomotion of patients after arthroplasty

After arthroplasty gait parameters do not change significantly. A slight improvement is marked in the range of motion of the knee joints – the flexion contracture decreased during the mid stance and terminal stance periods. External rotation of the joint became more marked with a simultaneous reduction of the varus deformity on the operated side.

No distinct changes in the ankle joint function were observed – the restriction of plantar flexion during the initial swing period increased slightly.

Thus, knee arthroplasty changes the three-dimensional picture of the joint function but these changes do not fully correspond to the biomechanical norm. This may be caused by the fact that the second locomotion examination was performed only 6 months after the procedure, when the previously developed compensation mechanisms still persisted and the results obtained are just an intermediate stage before returning to the correct values (Ogrodzka et al. 2008). It also needs to be emphasized that all patients were rehabilitated for only 2 weeks after the procedure. Thus, it turns out that it is too short a period for the disease-induced changes in the gait stereotype to subside. Therefore, it is important to underline that long-term rehabilitation (emphasizing the correct gait function) after the procedure could accelerate the patient's return to full mobility.

Lack of the required range of motion in the knee joints in the sagittal plane while walking before and after arthroplasty results in a lack of plantarflexion in the ankle joints at the initial swing phase and persistent contracture of the hip joints. This makes it possible to move the lower extremity without "catching" the ground.

Slight changes in the patients' gait stereotype before knee arthroplasty may primarily result from their long-standing locomotor habits. Increasing pain makes the patients change their way of walking – if the knee joint is straightened, the pressure on the joint surface increases and the pain becomes more intense. As a result, these patients try to avoid straightening of the joint, which is characteristic for the beginning and end of the stance phase. Flexion contracture of knee joints is the results of long-term knee flexion.

As degenerative disease is progressive in nature the procedure will not bring about sudden changes in the joint position. Despite good clinical results, the patient's consolidated habits prevent a quick change of the gait stereotype.

Consequently, tests performed 6 months after the procedure make it possible to capture the direction of the changes, but this period is still too short to determine the locomotion stereotype in this group of patients in an unambiguous manner.

Such conclusions are also supported by the literature on the subject (Chao et al. 1980, Andriacchi et al. 1982, Kramers-de Quervain et al. 1997 and Sukru Solak et al. 2005).

A comparison of the results of the authors' own research with reports found in the literature it can be concluded that there exist certain similarities in the results obtained, but also some conclusions differ.

It was found in the authors' own research that patients walk with their knees bent - hip joints are excessively flexed at the support phase and this flexion is insufficient during the advancement period.

Ishii et al. (1998) examined locomotion at natural walking speed using an electrogoniometer attached to the knee joint. In this way, they obtained information about three-dimensional knee function in 20 patients (11 with posterior cruciate ligament retention and 9 with PCL removal) after arthroplasty. The analysis was performed 18-20 months after the procedure.

On this basis a conclusion was formulated that in persons after total knee replacement (in both groups) the range of motion of the knee joints is limited, mostly in the sagittal and transverse planes.

They also found that despite correct passive range of motion in the joint, limited flexion during the limb advancement period is clearly marked in the gait, which may result from the consolidated gait stereotype from before the procedure which has not improved to date. Such conclusions partly corroborate the results of the authors' own research where insufficient flexion of the knee joint was also observed during the limb advancement period.

Börjesson et al. (2005) and Astephen et al. (2005) also confirm that, as a result of the disease, changes in the gait stereotype occur, but despite good results they continue to walk more slowly and do not regain the correct gait stereotype after the procedure.

Such an interpretation also confirms the results of the present study, as, despite satisfactory results, the biomechanical picture of the knee joints during gait changed only slightly.

Total knee replacement improves the function of the hip joints only slightly - the contracture is reduced mostly during the terminal stance and preswing periods.

Numerous authors conclude that the gait stereotype after arthroplasty does not change despite reduced pain and the achievement of sufficient range of motion. This is probably caused by patients' habits developed before the procedure, as well as by changes in proprioceptive sensations in the joint occurring before and after the operation, which also corresponds to the results of this study; however, no significant lengthening of the support phase was observed before or after the procedure in the authors' own research.

On the basis of the results of the authors' own research conducted after the total knee replacement it can be concluded that, despite good clinical conditions, the pattern of the lower extremity joint function changes to an insignificant degree during gait. The range of motion in the individual planes improves, but consolidated habits developed before the operation do not allow for a complete change of the gait stereotype in this group of patients. Such conclusions are presented by, among others, Sukru Solak et al. (2005), who assessed the locomotion of 24 women with the average age of 67/ The examination was performed before the procedure and 1 and 2 years after the procedure. There were no differences between the examination 1 and 2 years after the procedure.

The authors concluded that the limitation of the range of motion after total knee arthroplasty (TKA) results from the joint contracture consolidated before the procedure. Andriacchi et al. (1982) and Chao et al. (1980) are of a similar opinion. They believe that the stereotype of the patients' gait after the TKA procedure results from the locomotion method consolidated before the procedure, caused by pain, changes in the joint proprioception and lack of full extension which would protect the patients' against pressure on joint surfaces and, in consequence, pain avoidance.

Kramers-de Quervain et al. (1997) analyzed the gait of 5 patients after bilateral total knee replacement. The authors conclude, that despite the procedure, the changed locomotion pattern persists, just like disturbed proprioception of the joint.

In another study of the locomotion of patients after knee replacement, Wu et al. (2007) discovered that the range of knee flexion is reduced throughout the gait cycle. Reduced plantar flexion of the ankle joint at the end of the preswing period was also observed, compared to the unaffected leg and the control group.

The results of the authors' own research also revealed limitation of the range of motion of knee joints and considerably reduced plantar flexion of ankle joints during the preswing period. The limitation of plantar flexion may be caused by the fact that patients do not achieve sufficient flexion at the knee joint, so to be able to move the limb under the pelvis they must flex the foot to compensate for this.

16 persons (average age: 69) after arthroplasty were examined (Wilson et al. 1996). The analysis encompassed the gait and isokinetic measurement of flexors and extensors (Cybex 6000 dynamometer). The Vicon system with 5 cameras was used for gait analysis. The patients walked at their natural walking speed.

No statistically significant differences were observed in the results of time and space parameters, however, significantly lowered (statistically significant) values were noted for gait kinematics - limited range of motion of the knee joints in the sagittal plane throughout the gait cycle.

67° range of motion is required while walking, which becomes reduced as a result of knee joint degeneration. In the research conducted by Dorr et al. (1988) the range of motion after the procedure was 52° and similar results were obtained by Steiner et al. (1989). In a study by Wilson et al. (1996) the range of motion was 53°. The restriction of the range of motion after the treatment may result from both the structure of the prosthesis and the weakening of the muscles, a change in the proprioception or a locomotion pattern consolidated before the procedure.

In the authors' own research the maximum knee joint flexion was approx. 58° on the operated side and 60° on the unoperated side, so these values are higher than those obtained by other authors, but they are still lower than the correct values, so the change in the range of motion in other joints will compensate for deficiencies of the knee joint position. However, the interpretation of these results may be similar to the interpretation presented by Wilson et al. (1996).

McClelland et al. (2006, 2007) and Smith et al. (2006) as well as Webster et al. (2003) found that patients after the procedure walk with restricted range of motion in the knee joint compared to the norm. The flexion is reduced both at the support and swing phase. The results of the authors' own research are confirmed again, as, according to them, patients do not achieve full knee flexion during the limb advancement period, but also it can be noticed that the results are diversified if we consider the function of the knee joint at the stance phase - the patients' knees are excessively bent compared to the biomechanical norm.

Benedetti et al. (2003) analyzed the gait of 15 persons after the knee endoprosthesis procedure. No degenerative changes were observed in any of the patients in the other joints, each person underwent a rehabilitation treatment after the procedure, during which continuous passive movement, exercises of flexors and extensors of the knee joint and proprioception exercises were used, the patients were able to put their weight on the leg after two weeks. The locomotion test was performed 6, 12 and 24 months after the procedure.

Despite rehabilitation, changes in the patients' gait persisted. The results of the tests show that 6 months after the procedure the length of the cycle is reduced and restricted flexion of the knee joint persists during the loading response period.

These results are slightly different from the results obtained in this study. No restriction of knee flexion was observed during the loading response period and the length of the cycle after the procedure increased.

5.3 Three-dimensional stereotype of the move of joint of lower limbs before and after the treatment

The literature does not refer to results similar to the results obtained in the authors' own research in which it was attempted to evaluate the position of knee joints in the sagittal and transverse planes before and after an arthroplasty procedure.

While devising a biomechanical gait pattern in persons before and after knee replacement it is important to take into account all planes of motion. This allows to present the stereotype of motion in a spatial way and, at the same time, it draws attention to the

existing, pathological position of the joints, which may lead to other strains and diseases of the locomotor system. On the basis of test results presented in this study, it can be concluded that three-dimensional gait analysis determines the scope of changes in lower extremity joints and their dysfunctions in the three planes of motion in an unambiguous way.

The interpretation of other authors' results presented above confirms that the determination of the locomotion pattern in patients before and after knee arthroplasty on the basis of the description of movement only in the sagittal plane is not sufficient. Before and after the procedure patients develop their own way of walking adjusted to their needs. Therefore, to be able to determine the scope of changes and deviations from correct values, the gait stereotype must be analyzed in all three planes. Such an analysis is presented in the present study, which broadly describes biomechanics of lower extremities during gait.

Due to a very small number of reports on the joint function in the unoperated leg, one of the aims of this study was to determine the biomechanical chain of the unoperated side.

Other authors (Wilson et al. 1996, Al-Zahrani et al. 2002) limit their conclusions to the statement that the range of motion in the unoperated knee joint is also restricted and the ankle joint works properly (Wu et al. 2007). In their study, Bajek et al. (2006a) also describe flexion contracture in hip joints.

These are, however, only statements which are narrow in their scope and which do not take into account the function of all joints in the unoperated leg during all gait periods.

On the basis for the first part of the discussion of the unoperated leg movement analysis throughout the gait cycle, it can be concluded that:

- the function of the hip joint on the unoperated side does not differ from the operated side - considerable flexion contracture of the joint.
- the knee joint in the sagittal plane both before and after the procedure works in a similar way and its function is not different from the operated joint
- the varum deformity is considerably smaller in the frontal plane (close to normal values)
- the biggest differences were revealed in the transverse plane - the unoperated joint was positioned in considerable external rotation before the procedure, after the treatment the external rotation of the opposite joint changed into correct internal rotation (such differences were not observed on the operated side)
- the ankle joint on the unoperated side worked in a way similar to the ankle joint on the operated side.

On this basis it can be concluded that as a result of degenerative knee changes, the joints of the other leg begin to function in a different way. The direction of these changes corresponds to the changes in the affected leg (mostly in hip and ankle joints), apart from the transverse plane of the knee joint where the rotation values are significantly higher than the rotation on the operated side.

After the knee replacement procedure the change of the gait stereotype is slight, which results from the patterns consolidated before the procedure, but the direction of these changes is similar to the changes on the operated side. The biggest difference is marked again in the transverse plane of the knee joint, where correct internal rotation has already appeared.

This kind of analysis has not been presented in the literature.

5.4 Spatio-temporal parameters

The analysis of time and space parameters revealed that before the treatment the patients' step frequency was reduced, the length of the cycle was lowered and their walking speed was lower, while the double support phase and the cycle duration were lengthened.

On the basis of the statistical analysis performed in the authors' own research, no statistically significant differences were found – apart from the StrL parameter (length of the cycle) – between the mean values of the time and space parameters in the 1st and 2nd examination on the operated side. On the unoperated side, on the other hand, statistically significant differences occurred between the DS (double support time), StrL (length of the cycle) and the WS (walking speed) parameters. No such differences were observed for the remaining values.

Time and space parameter values were also compared between the operated and unoperated side in the 1st and 2nd examination. Statistical analysis also revealed a significant difference between the operated and unoperated side for the Foot Off parameter in the 1st and 2nd examination. No statistically significant differences between the analyzed parameters were found in the 2nd examination.

It was also attempted to evaluate the strength of the relationship between time and space parameters before and after the knee replacement procedure.

Moderate correlation is revealed between the 1st and 2nd examination as regards the single support time (SS). Considerable dependence was discovered among the other parameters and this dependence was very strong for step frequency values.

Moderate correlation also occurred on the unoperated side in the SS parameter values (single support time). High correlation also occurred for the cycle length and duration and the walking speed parameters, while very high correlation was observed between step frequency and the values of double support time.

Correlation was also analyzed between the operated and unoperated side in the 1st and 2nd examination.

Moderate correlation was observed between the sides in the 1st examination as regards the values of the single support time (SS) and the Foot Off parameters. The correlation was very high for the remaining parameters.

After the operation significance dependence occurred between the sides for the SS variable (single support time). Very high correlation was revealed in the evaluation of the strength of the relationship between the parameters step frequency, double support time, cycle length walking speed on both sides.

This may mean that the gait pattern of both legs under analysis, both in the 1st and in the 2nd examination, are mutually dependent and changes occurring in one leg must be compensated by the other leg.

These results are consistent with the majority of the existing studies on the locomotion in persons with degenerative knee joint changes (Kaufman et al. 2001, Manetta et al. 2002, Astephen et al. 2005, Bejek et al. 2006b, Ogrodzka et al. 2007).

Gök et al. (2002) also studied time and space parameters in their work. The authors observe reduced values of the walking speed, step frequency, length of the cycle and automatically extended duration of the cycle and the double support phase. Based on their result, Andracchi et al. (1982) conclude that reduced walking speed and length of the cycle as well as the delay of the Foot Off period are a part of an adaptation mechanism aimed at pain reduction. Additionally, authors conclude that the shortened length of the cycle may result from the avoidance of full load, which is typical of gonarthrosis patients.

Al-Zahrani et al. (2002) performed a gait analysis in patients suffering from degenerative knee disease which showed that the length of the cycle and the walking speed were reduced for such persons while the support phase is extended.

After the procedure the values of time and space parameters improved only slightly, which may be corroborated by a study by Börjesson et al. (2005) who found that patients suffering from degenerative knee disease walk at a lower speed, with lower step frequency and the single support phase is shortened. Despite good results they continue to walk more slowly and do not regain the correct gait stereotype after the procedure.

Similar results, pointing to slight changes in time and space parameters before and after the procedure were observed in research conducted by Sukru Solak et al. (2005).

Fantozzi et al. (2003) studied locomotion in two groups – endoprosthesis with PCL retention and with PCL removal. The extension of the DS period and a reduced walking speed were observed in both groups, compared to the control group.

The results obtained by these authors confirm the results of the authors' own research presented in this study.

Wu et al. (2007) found in their study of patient locomotion after knee replacement that the walking speed is reduced, which is connected with the reduction of the length of the cycle and a reduction in step frequency, especially in the operated leg. The DS period was lengthened.

However, the results were not compared before and after the procedure. Such an analysis presented in this study shows a clear improvement of these parameters after the procedure and their values become close to the control group.

6. Significance of the three-dimensional gait analysis in therapy of patients with gonarthrosis before and after arthroplasty

Degenerative changes in the knee joint lead to its deformation resulting in genu varum or genu valgum. They also cause changes in intra- and peri-articular soft tissues. Cruciate ligaments, collateral ligaments, the quadriceps femoris and other lower extremity muscles influencing the joint function under incorrect conditions. Compensation mechanisms are developed to make it possible for the system to function under normal conditions. All this causes nerve impulses from the end organs of the ligaments of the joint capsule, and especially those responsible for the proper position of the joint surface and joint kinematics reach the central nervous system from damaged locations or from locations which do not function properly. In this way, the stimuli reaching the central nervous system consolidate incorrect patterns of motion.

During the knee replacement procedure, the cruciate ligaments are removed, fat is removed from the joint capsule, the condyles of the femur and tibia are trimmed together with the subcartilage layer. Main end organs informing the central nervous system about the position of the joint are removed. A prosthesis without nerve connections is implanted.

After the surgical procedure, the central nervous system is not properly informed about the position of the individual elements of the joint, so, during gait, it uses the patterns consolidated during the disease.

It is important to capture all deviations caused by the developing disease in the gait analysis performed before the procedure. As both legs are used for walking, changes occurring in the affected joint often influence the function of the healthy joint.

All deviations captured in the gait analysis performed before the procedure should be used for the planning of rehabilitation treatment to eliminate them after the operation.

Kinezytherapy planning should emphasize the use of end organs in the remaining joint structures which are responsible for proprioception to open a new route for information flowing from these elements to the central nervous system.

Selection of appropriate exercises may help eliminate motion patterns consolidated before the procedure to achieve the correct gait pattern. Without being familiar with locomotion patterns before the procedure it will be difficult, which is confirmed by results of research conducted even two years after the procedure.

The patients taking part in the study were rehabilitated for only two weeks after the procedure and the results of locomotion examination show that changes consolidated in the gait stereotype resulting from the progressive nature of the disease were not considerably improved after the procedure. Thus, on the basis of the research conducted it should be concluded that physiotherapeutic procedures should include changes in the gait pattern and should be conducted until normal values are reached in follow-up examinations. The rehabilitation program should include elements of correct gait learning, dominated by exercises teaching the correct function of the pelvis and the lower extremity joints. This will make it possible to reconstruct the biomechanical locomotion pattern changed as a result of the disease. This will also extend the endoprosthesis life.

Compensation mechanisms developing in the locomotor system due to disease make it possible to reduce pain, however, they cause strain changes in other locomotor segments with time - in the pelvis, ankle and hip joints. Knee replacement reduces articular pain, however, it will not reverse these mechanisms. It will be possible only by proper rehabilitation based on three-dimensional gait analysis.

The gait analysis presented in this study may be an example of locomotor disturbance examination in a group of patients before and after knee replacement. Thus, the application of more and more accurate measuring instruments in gait analysis becomes a necessity to achieve the best clinical results. On the basis of the presented three-dimensional gait analysis, a change in the locomotor pattern in patients after joint replacement can be noticed and the degree and scope of these dysfunctions can be determined. So one of the possibilities offered by the method is the monitoring of the treatment after surgical procedures. The results obtained can be used to evaluate and verify the effectiveness of the treatment methods used.

Owing to the application of three-dimensional gait analysis it is possible to adjust the therapeutic programme to individual changes in the locomotor stereotype and to monitor the direction of the rehabilitation as well as walking reeducation processes.

Advanced gonarthrosis affects significantly gait stereotype with a limitations in function of a patients. Knee arthroplasty is a method of therapy which allows to improve the gait pattern, although it demands time and proper rehabilitation to record correct pattern. A detailed analysis of gait cycle is necessary of optimal results, since it illustrates and presents various disturbances in individual gait pattern. This can be reached in 3D motion analysis, which presents spatial arrangement of body segments in three planes of motion

Application of more and more exact hardware for motion analysis is necessary to obtain best clinical results. Changes in gait pattern is apparent in 3D analysis of patients motion after arthroplasty of knee joint, estimation of these changes and range of dysfunction can thus be measured. As so, one of applications of the presented method is monitoring of the

patients after the surgery. The obtained result can be used for validation and verification of the efficacy of applied therapy.

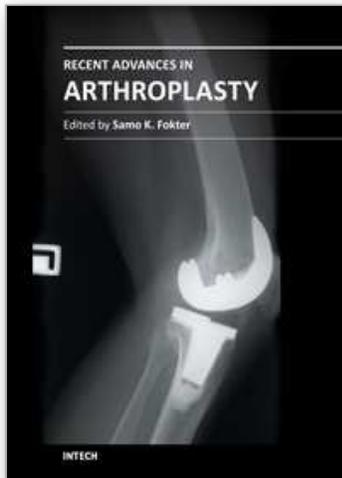
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Recent Advances in Arthroplasty

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The purpose of this book was to offer an overview of recent insights into the current state of arthroplasty. The tremendous long term success of Sir Charnley's total hip arthroplasty has encouraged many researchers to treat pain, improve function and create solutions for higher quality of life. Indeed and as described in a special chapter of this book, arthroplasty is an emerging field in the joints of upper extremity and spine. However, there are inborn complications in any foreign design brought to the human body. First, in the chapter on infections we endeavor to provide a comprehensive, up-to-date analysis and description of the management of this difficult problem. Second, the immune system is faced with a strange material coming in huge amounts of micro-particles from the tribology code. Therefore, great attention to the problem of aseptic loosening has been addressed in special chapters on loosening and on materials currently available for arthroplasty.

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