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Original paper

# Evaluation of the kinematic parameters of normal-paced gait in subjects with gonarthrosis and the influence of gonarthrosis on the function of the ankle joint and hip joint

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The aim of the study was to assess the variability of parameters characterising the gait of persons suffering from degenerative changes of the knee joint and their influence on the ankle and hip joints. The values of the angular changes in the knee, ankle and hip joints in the three planes of motion were assessed.

Locomotion tests were performed on 27 persons, aged between 60 and 74, using Vicon 250, the three-dimensional analysis system. The sharpest deviations from the results of the control group were revealed in the transverse and frontal planes. Degenerative knee joint disease has changed the gait stereotype causing a reduction in the economy of gonarthrosis patients' locomotion, the influence of the disease on the function of the neighbouring joints is also distinctly marked.

*Key words*: *locomotion, three-dimensional motion analysis, gonarthrosis*

## 1. Introduction

Degenerative knee joint disease is defined as a chronic, non-inflammatory disease with multi-factor etiology resulting from an imbalance between regenerative and degenerative processes in the articular cartilage and the subcartilage layer [1]–[4].

The most frequent cause of degenerative changes in the knee is the change of load on the articular surfaces whilst walking [5], which is caused by prior genu varum or genu valgum, joint instability or injury, including damage to intra-articular structures: articular crescents, cruciate ligaments, lateral ligaments, leading to disorders in the knee content, and also by intra-articular fractures and articular cartilage injuries [4], [6]–[9]. Changes in the neighbouring joints and obesity may also promote the development of degenerative changes in knee joints [10].

The main clinical symptom is pain located in the anterior or medial part of the knee and in the upper-medial part of the shinbones [3], which becomes more intense under load; with time the pain also begins to occur at rest [10]. The disease is progressive and causes motion to become restricted in the sagittal plane. Expansion of the joint outline, mostly atrophy of the medial head (*vastus medialis)* of the quadriceps femoris muscle and deformation of the joint, occurs together with its development.

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Changes in the gait stereotype also occur as a result of the disease development. Due to the progressive nature of the disease, locomotion function becomes impaired, and, as a result, various compensation mechanisms are developed in the biokinetic chain consisting of the wing of ilium and joints of the lower extremities.

Lower extremity kinematics involving the movement of joints in the sagittal plane during movement has been examined in a large number of research studies [11], [14]. However, three-dimensional gait analysis [15]–[18] conducted in persons with degenerative changes of knee joints is still an area which has not been fully analysed.

This has become the basis for establishing assumptions and determining the aim of research involving an attempt to assess the variability of parameters characterising the gait of persons suffering from degenerative changes of the knee joint qualified for an arthroplasty procedure.

The values of the angular changes in the knee, ankle and hip joints in the three planes of motion were assessed.

# 2. Material and methods

27 patients participated in the study, including 20 women (74%) and 7 men (26%), aged between 60 and 74, qualified for knee arthroplasty due to degenerative changes of the joint. The criterion for qualification of treatment included, among other things, three and four degree arthrosis, and the duration of arthrosis (from the diagnosis to the knee replacement procedure) was approx. 5 years.

X-ray tests performed within the framework of pre-operative diagnostics at the clinic did not reveal degenerative changes in hip joints. A description of the test group is presented in the table.

Before the procedure, the passive range of motion and the contracture in the knee joints were measured goniometrically for each of the patients. The measurement was performed in the forward horizontal position with a straightened hip joint. The maximum flexion of the joint was on average 86.1° (±8.4) in the affected leg and 94.7° (±12.2) in the healthy leg, and in each person with the contracture of the joints observed, the mean value in the healthy leg was 14.9° (±6.03) and in the affected leg 15.4° (±6.8). The significant limitation of motion both in the affected leg and in the healthy leg may result from pathological lesions and degenerative processes caused by the ageing process in the joints – and, as ZEMBATY [19] states, muscle and tendon flexibility becomes reduced with age, and mobility is reduced by 25% by the age of 85.

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

Table. Characteristics of the examined and control groups

| Feature | Examined group $x \pm$ SD | Control group $x \pm$ SD |
|---|---|---|
| Age | 66±5.2 | 62±7.5 |
| Mass (kg) | 82.3±12.3 | 80±10.6 |
| Height (cm) | 159.0±7.8 | 163±8.6 |
| Speed (m/s) | 0.6±0.2 | 1.2±0.3 |
| Cadence (step/min) | 87±18.8 | 112±15.4 |

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

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

The research was financed from the scientific funds for the years 2008–2009 as a research project.

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 and RASI). It is very important to place the knee markers and the thigh and crus markers in the proper manner.

In the analysis of the patients' locomotion, the terminology devised at the Rancho Los Amigos Medical Center [17] was used. It is assumed that one gait cycle amounts to 100%. This distinguishes the following gait phases:

1. Initial contact – 0%.
2. Loading response – 0–10%.
3. Midstance – 10–30%.
4. Terminal stance – 30–50%.
5. Pressing – 50–60%.
6. Initial swing – 60–70%.
7. Midswing – 70–85%.
8. Terminal swing – 85–100%.

Both groups of subjects performed locomotion at a self-selected speed along a 25-metre gait path. 30 steps characterised by a similar speed and frequency of cyclical movements were selected from among the registered gait cycles. The mean values of individual locomotion patterns were devised on their basis and afterwards the mean values of angular changes in the individual joints characterising both groups of subjects were calculated. The results of the mean values of the gait of patients suffering from degenerative disease were presented in the diagrams against the results, including the average and ±s – the grey ribbon of double standard deviation.

# 3. Results

## 3.1. Analysis of angular changes in the hip joints in the sagittal plane

Figure 1 presents angular changes in hip joints in the sagittal plane. The grey ribbon in each diagram shows the variability of the results in the healthy population.

The amplitude of hip joints before knee arthroplasty is slightly shifted in time during the gait cycle compared to the biomechanical norm – by approx. 4%.

Before the procedure, the hip joints are excessively flexed – there is no physiological overextension at the terminal stance and preswing phases. The maximum extension in hip joints was approx. 10° of the flexion at the preswing phase, and the correct values amount to approx. 10° of overextension. Thus, the difference between the test results and the norm amounts to 20° (figure 1).

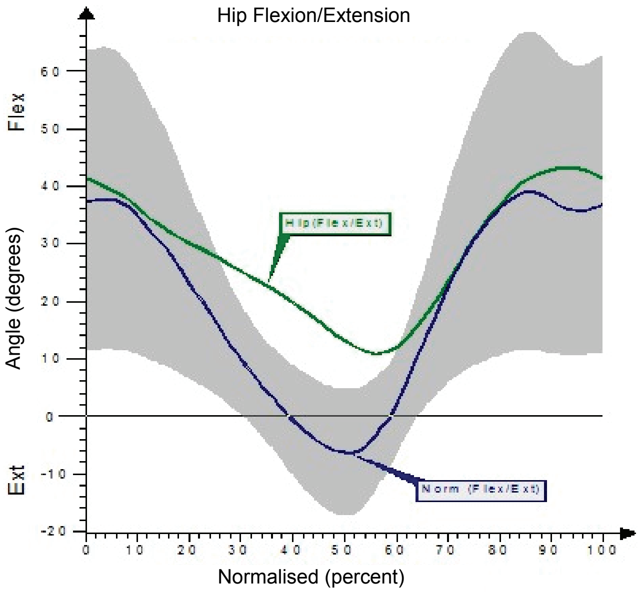


Fig. 1. Angular changes in the hip joints in the sagittal plane: Ext – extension, Flex – flexion, Hip – hip motion before knee arthroplasty, Angle (degrees) – angular degrees in the knee joint (in degrees), Normalised (percent) – normalised time of the gait cycle (in percentages), Norm – angular changes during normal gait in the control group (mean value±SD)

## 3.2. Analysis of angular changes in the hip joints in the frontal plane

Slight abduction of the hip joints was maintained throughout the gait sample. Improper abduction at the stance phase amounted to approx. 2°. On the other hand, the abduction of the hip joints compared to the norm is insufficient at the swing phase – the difference is approx. 2° (figure 2).

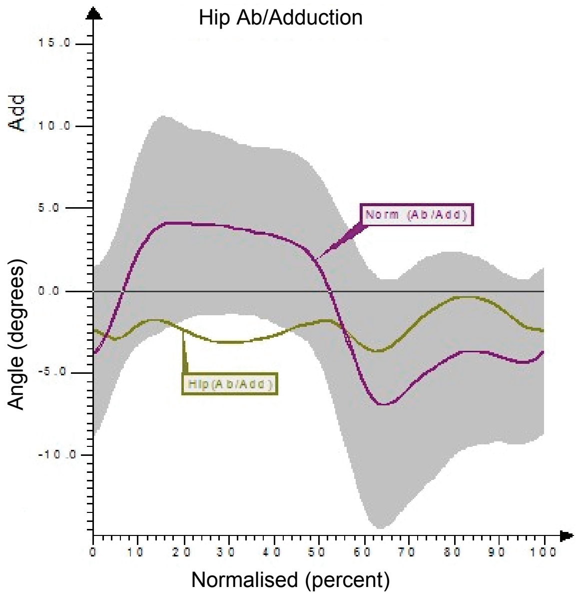


Fig. 2. Angular changes in the hip joints in the frontal plane:
Abd – abduction, Add – adduction

## 3.3. Analysis of angular changes in the hip joints in the transverse plane

Hip joints are arranged in an overnormative external rotation throughout the entire stance phase (approx. 6° rotation at the midstance phase), and at the midswing phase in the internal rotation, the motion pattern was reversed against the terminal swing phase – the external rotation is marked (figure 3).

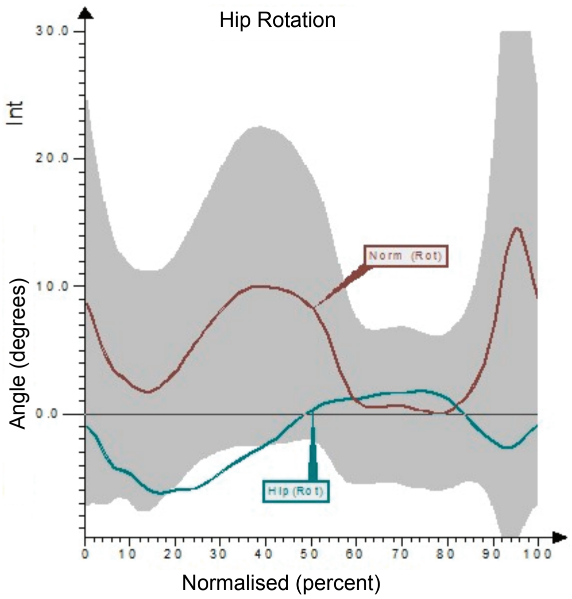


Fig. 3. Angular changes in the hip joints in the transverse plane:
Ext – external rotation, Int – internal rotation

## 3.4. Analysis of angular changes in the knee joints in the sagittal plane

The results of the knee joint examination in the sagittal plane showed no physiological flexion and extension at the midstance and terminal stance phases, and from the pressing phase until the end of the midswing phase, a reduction in joint flexion was distinctly marked (approx. 10° difference in rotation at the midstance phase between the norm and the patients' results) (figure 4).

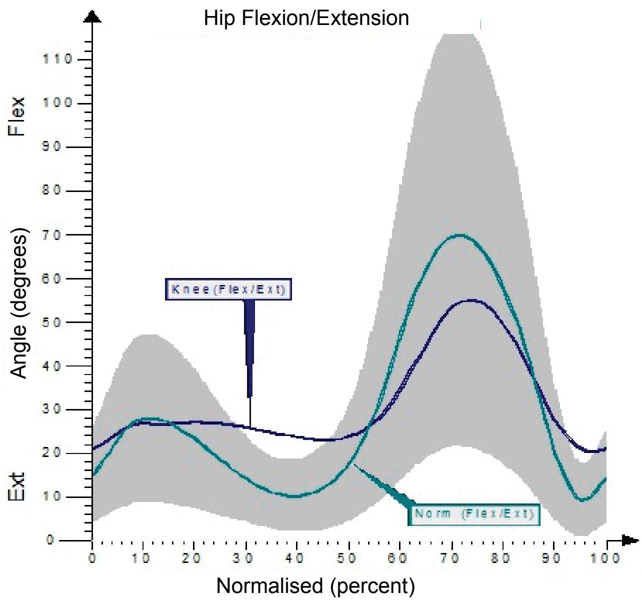


Fig. 4. Angular changes in the knee joints in the sagittal plane:
Ext – extension, Flex – flexion,
Knee – knee motion before knee arthroplasty

## 3.5. Analysis of angular changes in the knee joints in the frontal plane

Excessive bow-leggedness (genu varum) was observed in the frontal plane. The curves of knee joint motion before the procedure are consistent with the bow-leggedness diagnosed on the basis of X-ray images in all patients.

The shape of the affected joint motion at the stance phase remains at a 6° level almost all the time, and at the swing phase, it is reduced to approx. 4° (figure 5).

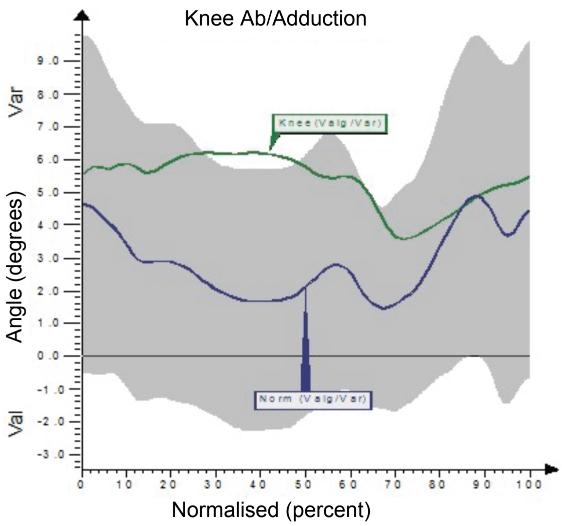


Fig. 5. Angular changes in the knee joints in the frontal plane:
Var – varus, Val – valgus

## 3.6. Analysis of angular changes in the knee joints in the transverse plane

The crus motion in the transverse plane was characterised by a shift of the range of angular changes in the direction of external rotation throughout the gait cycle (figure 6).

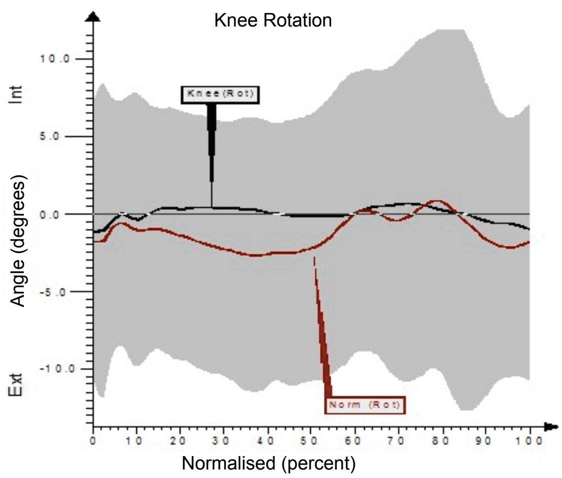


Fig. 6. Angular changes in the knee joints in the transverse plane
Ext – external rotation, Int – internal rotation

## 3.7. Analysis of angular changes in the ankle joints in the sagittal plane

Degenerative changes in knee joints also caused a change of the gait pattern in ankle joints. Up to the middle of the preswing phase, the curve of changes falls within the biomechanical norm (within its upper limits), and excessive dorsiflexion occurs from the second half of the preswing phase to the end of the initial swing phase. There is no natural plantar flexion at the gait transition phase (figure 7).

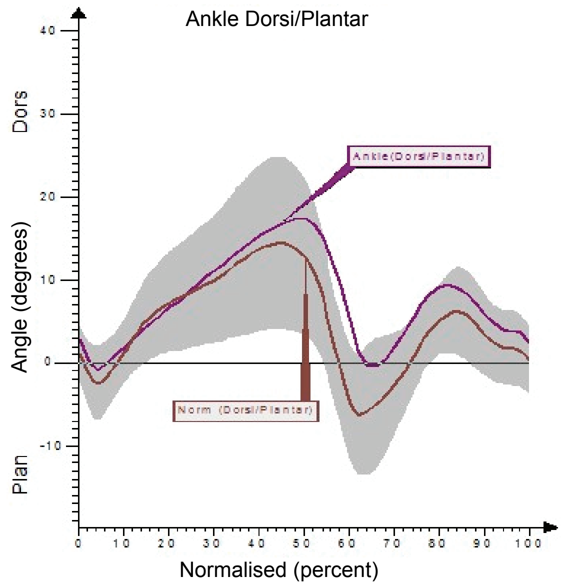


Fig. 7. Angular changes in the ankle joints in the sagittal plane
Plan – plantar flexion, Dors – dorsal flexion

## 3.8. Analysis of angular changes in the ankle joints in the frontal plane

The results of the ankle joint examination in the frontal plane showed adduction of the joints throughout the gait cycle. The ankle joints become slightly abducted only at the end of the stance phase (figure 8).

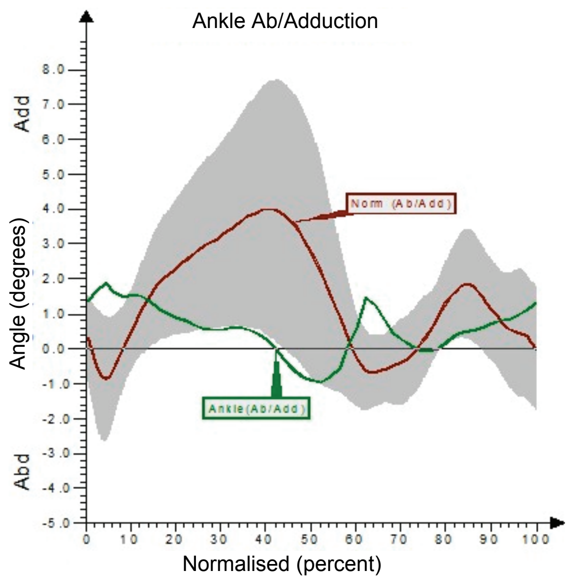


Fig. 8. Angular changes in the ankle joints in the frontal plane:
Abd – abduction, Add – adduction

### 3.9. Analysis of angular changes in the ankle joints in the transverse plane

In the transverse plane, the amplitude of ankle joint movement corresponds to the upper limit of the biomechanical norm – the joints are at an approx. 5° external rotation throughout the gait cycle (figure 9).

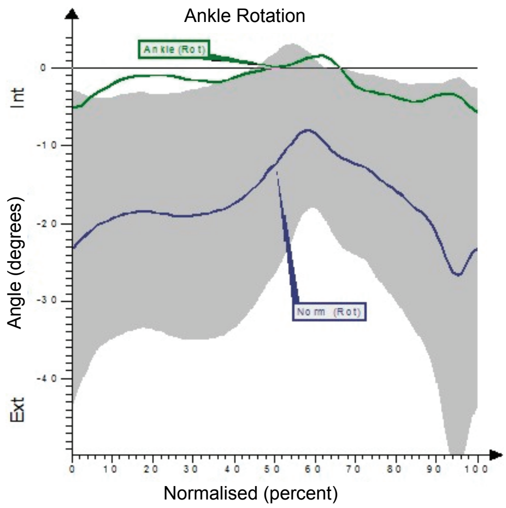


Fig. 9. Angular changes in the ankle joints in the transverse plane: Ext – external rotation, Int – internal rotation

## 4. Summary of the results

### 4.1. Analysis of angular changes in the hip joints

Due to knee joint disease, distinct changes in the position of the hip joints in all planes of motion occurred. Hip joints are excessively flexed and abducted. At the stance phase, the joints are externally rotated, while internal rotation occurs at the swing phase.

### 4.2. Analysis of angular changes in the knee joints

Knee joints are excessively flexed at the stance phase, and this flexion is insufficient at the swing phases. Additionally, bow-leggedness and external rotation of the joints are marked.

### 4.3. Analysis of angular changes in the ankle joints

Degenerative changes in knee joints also caused dysfunction of ankle joints. Ankle joints are dorsally flexed, adducted and slight external rotation occurs.

## 5. Discussion

Advanced degenerative changes of knee joints significantly affect the gait stereotype, resulting in a patient's functional limitation. To assess the scope and degree of dysfunction, an accurate and thorough gait analysis is necessary, as this shows and illustrates the motor disorders in these patients. Three-dimensional motion analysis, presenting spatial arrangement of body segments in three planes, offers such a possibility. Literature on the subject [20], [21] provides a comprehensive description of the work of the knee joint before knee replacement, but these studies are mostly limited to the presentation of joint movement in the sagittal plane without considering the other planes or the influence of the disease on the ankle and hip joints.

In the authors' own research, in accordance with the adopted aims of the study, an assessment of changes in kinematic gait parameters was carried out in persons with degenerative changes of the knee joint based on three-dimensional motion analysis using the Vicon 250 system. This analysis included angular changes of knee, ankle and hip joints in the three planes of motion.

The results of locomotion tests in patients suffering from degenerative changes corroborate that the pattern of ankle, knee and hip joint movement is distinctly influenced by the disease in the three planes of motion.

At the stance phase, the hip joints were flexed, abducted and externally rotated at the same time. Flexion contracture and external rotation occur in knee joints, while dorsiflexion, external rotation and adduction are characteristic of ankle joints.

At the swing phase, the hip joints are internally rotated. Knee joints are not sufficiently flexed, and the feet remain dorsally flexed.

A wrong range of motion in the knee joints in the sagittal plane while walking 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.

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 the straightening of the joint, which is characteristic of the beginning and end of the stance phase. Flexion contracture of knee joints is the result of long-term knee flexion.

There are numerous reports in literature referring to the influence of knee joint degenerative disease on the three-planar range of motion of the remaining lower extremity joints. They are mostly limited to statements that the single-support phase becomes shortened as a result of the disease [11], [12].

ASTEPHEN et al. [22], 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 sagittal plane. However, they did not determine the direction of the changes in the joints.

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

This is another one confirmation of the results of the authors' own studies, where a clear restriction of the active range of motion was found in the knee joint in the sagittal plane.

MANETTA et al. [22] 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 authors' own research, as extension limitation was observed in the patients examined (increased flexion) at the support phase.

Results similar to those reported by MANETTA et al. [22], and not fully consistent with the results of the authors' own research, were obtained by CHILDS et al. [23], who found that flexion during loading response was limited in patients suffering from articular disease compared to the norm.

In view of the analysis of the locomotion test results presented above and detailed interpretation of angular changes in lower extremity joints in persons before knee arthroplasty, with reference to the entire biomechanism, it seems justified to undertake research aimed at determining the pattern of knee joint movement in patients with degenerative changes using the results of three-dimensional motion analysis, focusing on presenting mutual conditioning of body segments in the three planes.

The evaluation of gait parameters during walking is helpful in assessing abnormal gait, in quantifying improvements resulting from intervention, or in predicting subsequent events such as ageing or falls [24].

Considering the controversial results obtained by some authors, who determine the gait stereotype in persons suffering from osteoarthrosis, a thorough verification of changes occurring in the knee joint before knee arthroplasty seems necessary, as it will be significant in the planning and selection of appropriate rehabilitation treatment in these patients.

# 6. Conclusions

1. Degenerative knee joint disease significantly affects the correct gait stereotype, causing deviations from the biomechanical norm as regards angular changes in lower extremity joints in the three planes of motion.

2. A changed motion pattern was most distinct in the frontal and transverse planes.

## References


[1] LEE J.A., *Choroba zwyrodnieniowa stawów kolanowych u dorosłych. Przywrócenie sprawności i utrzymanie zdrowego stawu. Wytyczne Institute for Clinical Systems Integration, Minneapolis*, Medycyna po Dyplomie, 2000, 9 (4), 115–128.

[2] WIDUCHOWSKI J., *Kolano, endoprotezoplastyka – całkowita wymiana stawu*, Sport & Med. s.c., 2001, Katowice.

[3] WIERUSZ-KOZŁOWSKA M., MARKUSZEWSKI J., *Choroba zwyrodnieniowa stawów*, [w:] *Wiktora Degi ortopedia i rehabilitacja*, Marciniak W., Szulc A. (red.), PZWL, Warszawa, 2004, tom 2.

[4] MESSIER S.P., DEVITA P., COWAN R.E., SEAY J., YOUNG H.C., MARSH A.P., *Do older adults with knee osteoarthritis place greater loads on the knee during gait? A preliminary study*, Arch. Phys. Med. Rehabil., 2005, 86, 703–709.

[5] ANDRIACCHI T.P., LANG P.L., ALEXANDER E.J., HURWITZ D.E., *Methods for evaluating the progression of osteoarthritis*, J. Rehabil. Res. Dev., 2000, 37(2), 163–170.

[6] GOLEC E., CZABAŃSKI P., GOLEC J., *Ocena wyników ruchowego usprawniania chorych z zaawansowanymi zmianami zwyrodnieniowymi stawów kolanowych*, Fizjoterapia, 1999, 7(3), 20–23.

[7] LEE J.A., *Choroba zwyrodnieniowa stawów kolanowych u dorosłych. Przywracanie czynności i zmniejszanie objawów chorobowych. Wytyczne Institute for Clinical Systems Integration, Minneapolis*, Medycyna po Dyplomie, 1998, 7(6), 105–113.
[8] WOLNY T., SAULICZ E., MOLICKA D., RYNGIER P., *Terapia wtórnych skutków zmian zwyrodnieniowych stawu kolanowego – ocena skuteczności różnych sposobów postępowania*, Medycyna Sportowa, 2002, 10, 40–43.
[9] BECKER R., BERTH A., NEHRING M., AWISZUS F., *Neuromuscular quadriceps dysfunction prior to osteoarthritis of the knee*, J. Orthop. Res., 2004, 22, 768–773.
[10] JEZIERSKI C., *Wpływ kriostymulacji i usprawniania na wydolność chodu w gonarthrosis*, Fizjoterapia, 1996, 4(1–2), 44–47.
[11] DELUZIO K.J., WYSS U.P., ZEE B., COSTIGAN A., SORBIE C., *Principal component models of knee kinematics and kinetics: Normal vs. pathological gait patterns*, Hum. Mov. Sci., 1997, 16, 201–217.
[12] YU S., STUART M.J., KIENBACHER T., GROWNEY E.S., AN K.-N., *Valgus–varus motion of the knee in normal level walking and stair climbing*, Clin. Biomech., 1997, 12(5), 286–293.
[13] ROGIND H., BIBOW-NIELSEN B., JENSEN B., MOLLER H.C., FRIMODT-MOLLER H., BLIDDAL H., *The effect of a physical training program on patients with osteoarthritis of the knee*, Arch. Phys. Med. Rehabil., 1998, 79, 1421–1427.
[14] ROSSI M., BROWN L., WHITEHURST M., CHANI C., HANKINS J., TAYLOR C., *Comparison of knee extensor strength between limbs in individuals with bilateral total knee replacement*, Arch. Phys. Med. Rehabil., 2002, 83, 523–526.
[15] HOCHBERG M.C., ALTMAN R.D., BRAND K.D., CLARK B.M., DIEPPE P.A., GRIFFIN M.R., MOSKOWITZ R.W., SCHNITZER T.J., *Guidelines for medical management of osteoarthrosis*. Part II. *Osteoarthrosis of the knee*, Arthritis Rheumatism, 1995, 11, 1541–1546.
[16] ANDRIACCHI T.P., ALEXANDER E.J., *Studies of human locomotion: past, present and future*, J. Biomech., 2000, 33, 1217–1224.
[17] PERRY J., *Gait analysis*, Thorofare, SLACK, 1992.
[18] ALLARD P., CAPPOZZO A., LUNDBERG A., VAUGHAN C.L., *Three-dimensional analysis of Human Locomotion*, Wiley and Sons, New York, 1997.
[19] ZEMBATY A., *Fizjoterapia*, PZWL, Warszawa, 1987.
[20] MANETTA J., FRANZ L.H., MOON C., PERELL K.L., FANG M., *Comparison of hip and knee muscle moment in subjects with and without knee pain*, Gait Posture, 2002, 16, 249–254.
[21] BALIUNAS A.J., HURWITZ A.B., RYAL A.B., KARRAR A., CASE J.P., BLOCK J.A., ANDRIACCHI T.P., *Increased knee joint loads during walking are present in subjects with knee osteoarthritis*, Osteoarthritis and Cartilage, 2002, 10, 573–579.
[22] ASTEPHEN J.L., DELUZIO K.J., CALDWELL G.E., HUBLEY-KOZEY C.L., DUNBAR M.J., *Gait and neuromuscular changes associated with knee OA severity*, J. Biomech., 2007, 40(S2), 287–294.
[23] CHILDS J., SPARTO P., FITZGERALD K., BIZZINI M., IRRGANG J., *Alterations in lower extremity movement and muscle activation patterns in individuals with knee osteoarthritis*, Clinical Biomech., 2004, 19, 44–49.
[24] KISS R., *Variability of gait characterized by normalized deviation*, Acta Bioeng. Biomech., 2010, 12(1), 19–23.