Kinematics of lower extremity joint after ankle arthrodesis by retrograde nail

Kinematyka stawów kończyn dolnych po operacyjnym zespoleniu stawu skokowego gwoździem odpiętowym

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Summary

The aim of the study was to assess the variability of parameters characterising the gait of patients after Tibio-talo-calaneal arthrodesis.

The locomotion study evaluated values of angular changes in the hip, knee and ankle joints in three planes of motion, as well as spatio-temporal parameters.

The locomotion examination was carried on 4 patients aged between 45 and 60 years (55±7,6), using Vicon 250, with diagnosed secondary degenerative changes of the left ankle and subtalar joints who had undergone the Tibio-talo-calaneal arthrodesis by retrograde intramedullary nail.

The control group comprised 30 healthy subjects aged 50- 70 years.

Ankle and subtalar arthrodesis have changed the gait stereotype causing a reduction in the economy of patients' locomotion, the influence of the surgery on the function of the neighbouring joints is also distinctly marked.

Key words: meniscus, meniscectomy, meniscus repair, rehabilitation

Streszczenie

Celem badań była ocena zmienności parametrów kinematycznych chodu pacjentów po operacyjnym usztywnieniu stawu skokowo-goleniowego i skokowo-piętowego.

W badaniach lokomocji ocenie poddano wartości zmian kątowych stawów biodrowych, kolanowych i skokowych w trzech płaszczyznach ruchu, a także parametry czasowo-przestrzenne.

Badania lokomocji, z wykorzystaniem systemu Vicon 250, przeprowadzono u 4 pacjentów w wieku od 45 do 62 lat (55±7,6) z zdiagnozowanymi wtórnymi zmianami zwyrodnieniowymi lewego stawu skokowego, u których wykonano artrodezę piszczelowo-skokową i skokowo-piętową z użyciem gwoździa odpiętowego.

Grupę porównawczą stanowiło 30 osób zdrowych w przedziale wieku 50-70 lat.

Artrodeza stawu skokowego zmieniła stereotyp chodu, zmniejszając ekonomiczność ruchu. Wpłynęła również na funkcję pozostałych stawów kończyn dolnych.

Słowa kluczowe: łąkotka, meniscektomia, zszycie łąkotki, rehabilitacja

INTRODUCTION

Secondary degenerative changes in the ankle joint lead to a significant functional limitation of a patient. Non-surgical treatment (with supply of orthosis) is ineffective, and operating procedures are limited to arthrodesis. The aim of the surgery is to reduce pain and correct deformations of the ankle and subtalar joints, as well as its instability which limits patient's locomotion skills. [1]

There are many surgical techniques – external and internal fixation (plates, hindfoot intramedullary nails). [1]

Although the tibio-talo-calaneal arthrodesis by retrograde intramedullary nail provides good initial clinical results – pain alleviation, over time it causes premature degenerative changes in the other joints of lower extremities. [2] This is due to the loss of physiological range of motion of the ankle and subtalar joints and, though the movement in the sagittal plane is taken by the Chopart joint, the kinematics of the knee and hip joints during gait is changed.

On the basis of the recorded values the attempt was made to identify the most essential movement patients' dysfunctions after ankle and subtalar arthrodesis.

Based on the same parameters obtained for healthy subjects in the control group, the performance of both lower limbs was assessed, in order to find symptoms of a compensatory activity of the non-operated leg.

The locomotion study evaluated values of angular changes in the hip, knee and ankle joints in three planes of motion, as well as spatio-temporal parameters.

MATERIALS AND METHODS

A group of 15 patients of the Clinic of Orthopaedics and Traumatology of the Musculoskeletal System, Jagiellonian University Collegium Medicum, with diagnosed secondary degenerative changes of the left ankle and subtalar joints who had undergone the Tibio-talo-calaneal arthrodesis by retrograde intramedullary nail "Hindfoot Nail-EX" were chosen for the examination.

The requirements for qualification to the examination included age (up to 60 years of age) and lack of accompanying diseases and injuries to the motor organ. X-ray tests performed within the framework of pre-operative diagnosis at the Clinic did not reveal any degenerative changes in knee and hip joints. Finally, 4 patients met these requirements. The locomotion examination was carried on 4 subjects (1 female, 3 males) aged between 45 and 60 years (55±7,6) The characteristics of the study group are shown in Table 1.

Tab. 1. Characteristics of the study and control group

Feature	Study group x ± sd	Min - max
Age	55 ± 7,6	60 - 45
Mass [kg]	92,4 ± 26,8	122,5 - 60,5
Height [cm]	172,5 ± 8,5	181 - 161,5

The control group comprised 30 healthy subjects aged 50- 70 years (18 women, 12 men) without any significant neurological diseases or orthopedic injuries which could affect the individual gait scheme.

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

The Vicon System (Oxford Metrics Limited, Oxford, England) includes 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 type of camera and its settings. The frequency of camera operation is 120 images per second. The recorded, two-dimensional image from one of the cameras is transmitted to the data station, where, together 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 data recorded by the cameras. Markers are plastic balls of 25 mm diameter, covered with a 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 pasted directly to a patient's skin. Their arrangement reflects the pattern of the biomechanical model. They are glued along joint axes at an appriopriate distance from the centre of joints and at characteristic points on the head, chest and pelvis. It allows a spatial representation of these segments of the body and measurement of the individual parameters – the dimensions of 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 posterior markers indicate its location in space. Trunk markers (C7, CLAV, TH10, STRN), together with head markers, determine axes of trunk's coordinate system. Pelvis markers (LASI, RASI), along with the sacrum marker, define axes of the coordinate system of the pelvis. The sacrum marker should be put in the plane perpendicular to the line connecting theASIS markers (LASI, RASI). It is also essential to place knee, thigh and crus markers properly.

Locomotion examination made use of the nomenclature developed in Rancho Los Amigos Medical Center [3] which assumes that one gait cycle accounts for 100%.

Subjects from both groups performed locomotion at the natural walking speed (self-selected speed), along a 25-metre gait path. Out of the recorded gait cycles, 30 strides of similar velocity and frequency of cycle movements were chosen for analysis. On their basis the mean values of individual gait pattern were evaluated and afterwards the mean values of angular changes in particular joints typical for both study groups were calculated. The results of the mean values of the gait pattern of patients after the surgery are shown on the graphs against the results, including the average value and standard deviation (the grey ribbon of double standard deviation), typical for the locomotion of healthy people.

Besides that, the subjects answered questions included in the Mazur Ankle Score [4]. 3 parts of the questionnaire were filled: pain, the range of movement, function.

The research was a part of the scientific project 19/MN/KRK/2011 conducted within the framework of scientific studies or development work and associated works.

RESULTS

Mazur Ankle Score

The mean Mazur Ankle Score value was 76,25 ± 6,5 points (72-86), which, taking into account that the maximum is 90 points, is a good result. Patients after arthrodesis do not reach the maximum range of movement and can only get 90 points. One of the subjects had a very good result, the rest achieved good results. None of the patients reported pain ailment.

After the surgery the plantarflexion and dorsiflexion range of motion from the natural position in the operated leg was 10° for one patient and 0° in other cases. On the basis of Mazur Ankle Score results, antalgic gait was not reported, and there was no necessity to use orthopedic aids, whereas none of the patients could run or climb on his toes. Two people were able to walk upstairs and downstairs only with the use of railing, the rest of the subjects did not have any problems with such activity.

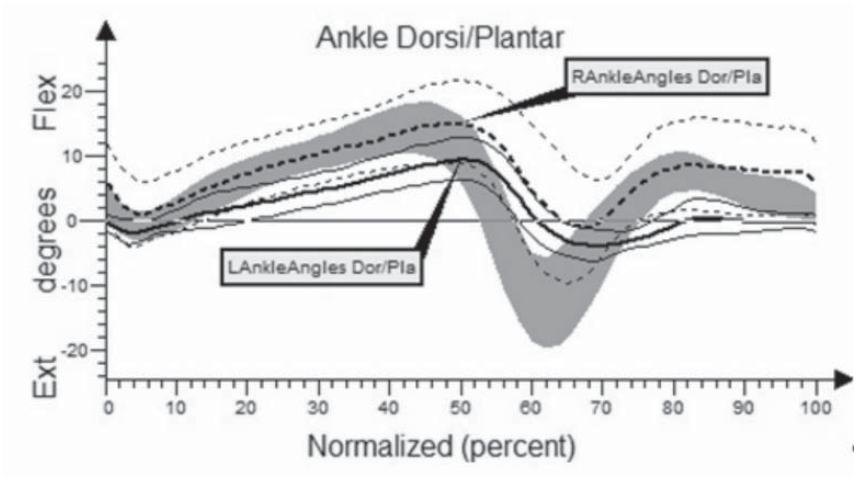


Fig. 1. Angular changes in the ankle joints in the sagittal plane for patients after ankle arthrodesis compared to the control group

Ext – plantarflexion, Flex – dorsiflexion; thick solid line - L Ankle – motion in the arthrodesis ankle; thick dotted line - R Ankle – motion in the healthy ankle; thin solid line – band (mean value ±σ) L Ankle – motion in the arthrodesis ankle; thin dotted line – band (mean value ±σ) R Ankle – motion in the healthy ankle; Angle (degrees) – angular degrees in the knee joint (in degrees); Normalised (percent) – normalised time of the gait cycle (in percentages); Grey band – angular changes during normal gait in the group of healthy subjects (mean value ±σ)

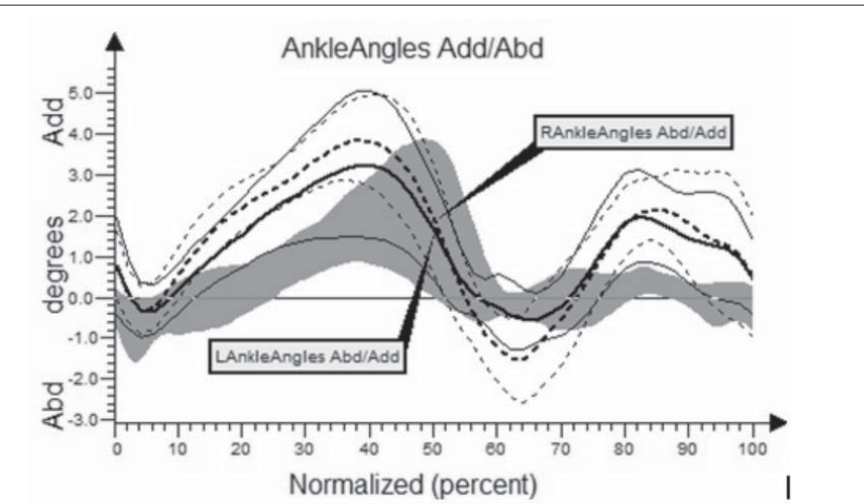


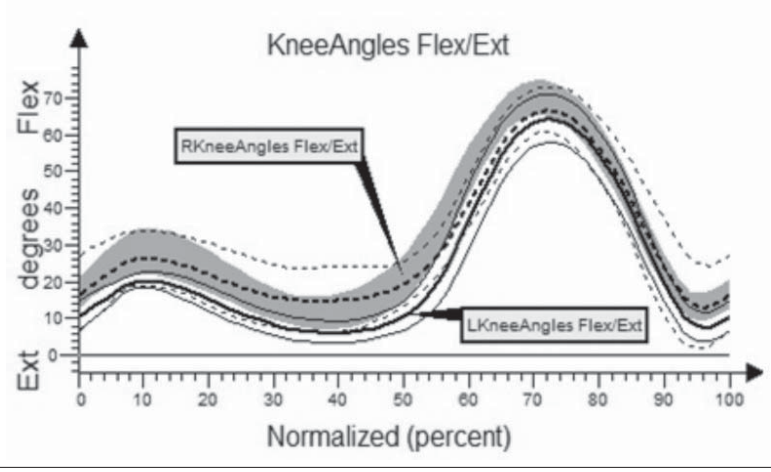
Fig. 2. Angular changes in the ankle joints in the frontal plane for patients after ankle arthrodesis compared to the control group

Abd – abduction, Add – adduction

Gait kinematics

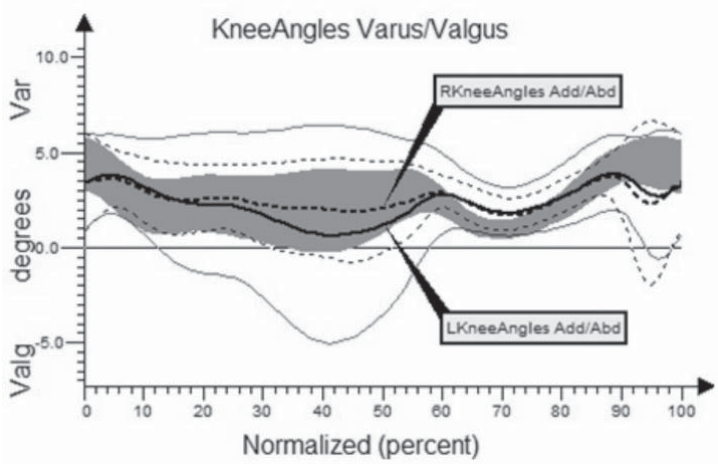
Figures 1 and 2 present average values of the ranges of angular changes in the ankle joints in the sagittal and frontal plane for patients after ankle arthrodesis.

Figures 3-5 show average values of the ranges of angular changes in the knee joints in three planes of motion for patients after ankle arthrodesis.



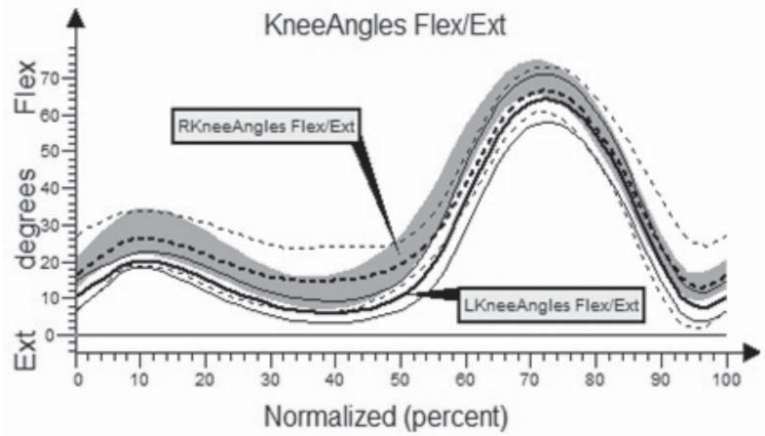
Ext – extension, Flex – flexion

Fig. 3. Angular changes in the knee joints in the sagittal plane for patients after ankle arthrodesis against the control group



Val – valgus knee, Var – varus knee

Fig. 4. Angular changes in the knee joints in the frontal plane for patients after ankle arthrodesis against the control group

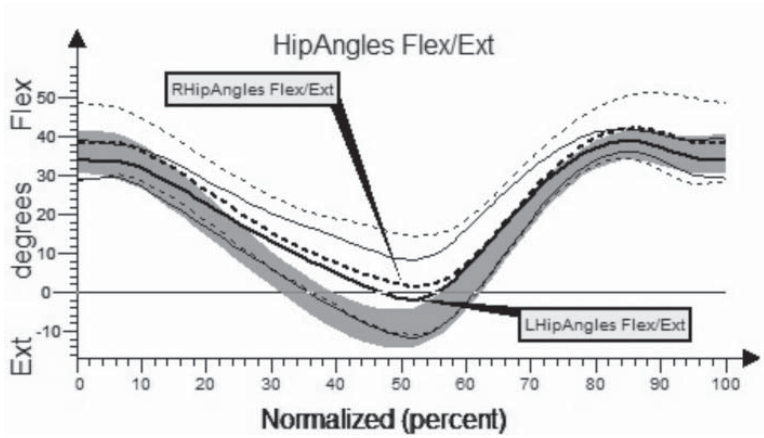


Ext – external rotation, Int – internal rotation

Fig. 5. Angular changes in the knee joints in the transverse plane for patients after ankle arthrodesis against the control group

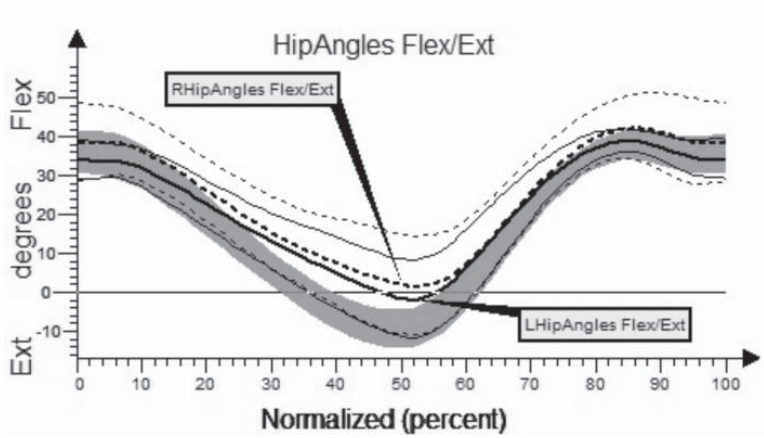
Figures 6-8 show average values of the ranges of angular changes in the hip joints in three planes of motion for patients after ankle arthrodesis

Spatio-temporal parameters (tab. 2)



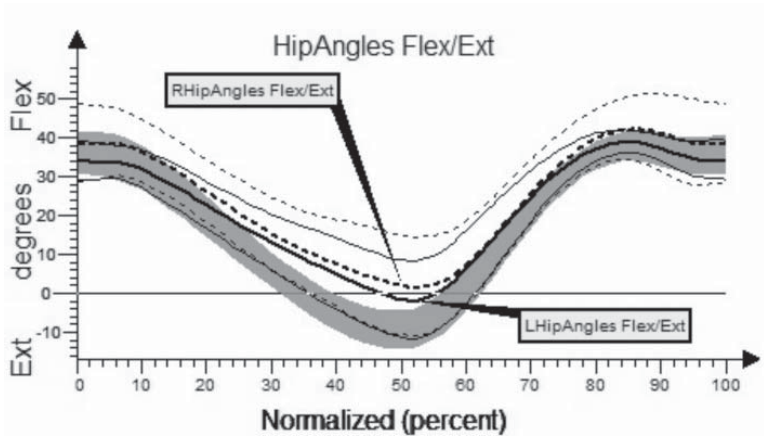
Ext – extension, Flex – flexion

Fig. 6. Angular changes in the hip joints in the sagittal plane for patients after ankle arthrodesis against the control group



Abd – abduction, Add - adduction

Fig. 7. Angular changes in the hip joints in the sagittal plane for patients after ankle arthrodesis against the control group



Ext – external rotation, Int – internal rotation

Fig. 8. Angular changes in the hip joints in the sagittal plane for patients after ankle arthrodesis against the control group

DISCUSSION

The main cause of deformative changes in the ankle joint are post-injury states which proceed together with ischemia and deformations in the area of joint surface. The instability related to the advanced degenerative process leads to a significant limitation of a joint function. Ankle arthrodesis as an ultimate method of treating the secondary degenerative changes is regarded as a satisfactory technique, as it eliminates pain in the joint, but increases risk of development of overload changes in the forefoot [2,1].

Ankle fusion causes changes in the locomotion scheme, thus the technical requirements for arthrodesis by retrograde nail are aimed at obtaining the optimal angular setting – so that patient's gait after surgery is similar to physiological values [2].

Locomotion tests carried out on a group of 4 patients after arthrodesis show variations in the normative values, especially the individual parameters of gait, which consequently may lead to the development of overload changes in the joints of lower limbs.

Analysis of limb movement in the sagittal plane

During the whole stride the range of motion of the stiffened ankle joint (Fig. 1) is lowered. In the stance phase the stiffened joint has reduced plantarflexion (by approximately 6°) over the comparison group. Additionally, the extension of the support phase by 6% of the stride is observed, compared to the results of the control group. In the pre-swing phase a reduced range of foot dorsiflexion is noted (by approximately 11%), caused by a detachment of the heel of the supporting limb from the ground. In the swing phase, after releasing the load from the limb, the foot is set in an intermediate position - 0°. The range of motion of the stiffened ankle joint is shifted about 4-6° towards a neutral position in relation to the results of the healthy limb.

In the non operated joint the limb works correctly in the first double support phase (LR) and in the single support phase (MST and TST), while the plantarflexion in the second double phase (PSW) is not observed. A prolonged support phase in this leg and the delay of movement in comparison with the control group in the whole stride is also visible. It has to be added that dispersion of individual values around the curve representing the mean of the results obtained in the study is bigger than the one of the healthy group.

Due to the stiffening of the ankle and subtalar joints, the range of motion in the sagittal plane is clearly reduced. Although during the surgery the joint stiffens in neutral position, flexion and extension is taken by the Chopart joint. Therefore, the limited range of motion is natural.

In the knee joint (fig.3) of the limb with a fused ankle a shift of the range of motion towards a neutral position is observed during the whole stride in the sagittal plane, which results in the reduced flexion of the knee by appr. 6° in the LR phase, and a slight shift in a phase, comparing to the control group. Other characteristic peaks of arches illustrating angular changes in the knee joint reach lower values of flexion compared to the norm, in the range of 4 – 6°. The knee joint in the non operated leg works in the range of values obtained in the healthy group, with the tendency to a slight reduction of the extension range of the knee in the single support phase. It is confirmed by a wide ribbon of dispersion of individual values in this fragment of the motion of the joint in the non operated limb.

According to the analysis of hip joints in the sagittal plane (fig.6), it should be noted that the motion ranges of both joints are shifted in the direction of increased flexion relative to the results of the control group in the terminal stance phase. It is manifested by the lack of hyperextension in the right hip joint and only minimal hyperextension in the left limb joint. In this phase the average differences of both analyzed joints in comparison with the mean values of the angle in the control group reach several degrees. Individual scores of people classified for the study clearly shift towards flexion pattern of joints also in other phases of stride, though the mean values are within the limit of variation of the results obtained in the healthy group.

The flexion movement pattern observed in the terminal single support phase may have an adverse effect on the acceleration of the centre of gravity and it also overloads extensor muscles. The flexion pattern causes extension of arms' gravity, balanced by extensor moments, which may lead to overextension of those muscles. As a result of that mechanism, a disorder in the acceleration of the centre of gravity occurs.

Tab. 2. Results of spatio-temporal parameters of gait for patients after arthrodesis and the control group

Spatio-temporal parameters	Not operated limb $\bar{x} \pm sd$	Operated limb $\bar{x} \pm sd$	Control group $\bar{x} \pm sd$
Step cadence [step/min]	109 ± 10.80	110 ± 10.80	121 ± 7.20
Double support time [s]	0.32 ± 0.10	0.36 ± 0.07	0.22 ± 0.04
Single support time [s]	0.40 ± 0.02	0.37 ± 0.04	0.39 ± 0.02
Step length [m]	0.57 ± 0.09	0.57 ± 0.12	0.70 ± 0.06
Step time [s]	0.55 ± 0.07	0.57 ± 0.06	0.50 ± 0.032
Stride length [m]	1.14 ± 0.21	1.14 ± 0.20	1.40 ± 0.12
Stride time [s]	1.12 ± 0.12	1.10 ± 0.11	1.00 ± 0.06
Velocity [m/s]	1.05 ± 0.27	1.06 ± 0.26	1.21 ± 0.16

Summary of the movement of the biomechanical chain in the operated limb in the sagittal plane indicates a functional limitation resulting from the lack of foot dorsiflexion in the swing phase and functional shortening of the leg (fig.1), which leads to an increased flexion of the hip joint, aimed at compensating this negative phenomenon (fig.6).

Analysis of limb movement in the frontal plane

Under load a repetitive movement of toward the upper leg occurs, which is reflected on the chart of angular changes in the ankle in the frontal plane (fig.2)

Loading of the stiffened foot begins with a slight decrease in supination in the initial loading response phase, so that in its second part, as well as in the mid stance and the first stage of the terminal stance (up to app.40% of the cycle), it turns into a clear supination. It should be noted here that the supination peak of both extremities is reached about 10 % stride earlier than for the control group. From approximately 40 % of the gait cycle another movement towards pronation is observed. It lasts until the end of the support phase. In the swing phase an alternating movement occurs, first towards foot's supination, then - in its second stage, a motion reverse to the neutral setting. There are distinct differences in comparison with the healthy group, where subjects have feet set in the neutral position throughout the whole swing phase. It may indicate a lack of sufficient muscle control of the unloaded foot for supination and pronation in the swing phase. The range of motion on the unaffected side is similar.

The varus/valgus performance of the knee joint (fig.4) shows a distinctly higher dispersion of values around the mean than for healthy subjects. This is particularly evident in relation to the left, operated knee. The biggest deviation occurs in the single support phase and the terminal swing phase. Weak repeatability of motion pattern in the left knee joint may indicate a lack of sufficient muscle control of movement of the loaded limb. This may result from post-surgery disorder in previous coordinate joint motion pattern. Average values of angular changes in gait cycle of both knee joints are, however, in the area of variability of the results from the control group.

The analysis of hip joints' movement in the frontal plane (fig.7) shows a distinct dispersion of individual results around the mean in the left joint in the whole stride. The single support generates individual motion patterns shifted towards abduction, particularly in the loading response phase (LR) and the single support phase MST and TST. Lack of repeatability of movement in the left joint is probably a result of the unsteady motion pattern observed in the lower joints. This demonstrates the difficulty in exercising muscle control of the lower limb's biomechanical axis.

Even the unloaded leg in the swing phase exhibits a widely increased variability of results as compared with the control group. After averaging the results, however, no significant differences in comparison with the average values of the control group were found.

The aforementioned pattern of limb's performance in the frontal plane comes down to a supinal setting of the operated leg, valgus knee joint and abduction in the hip joint, particularly visible in the single support phase.

Technical indications for the procedure assume that due to the necessity of keeping a natural locomotor pattern after the surgery, the ankle has to be fusioned in 0-5° of pronation and 5 to 10° of external rotation of the joint towards the upper leg.

However, author's own research indicates that in the full load phase (stance phase) of the stiffened joint the foot is set in supine position. This may mean that, despite achieving the indicated angular values of the ankle during the procedure in the single support phase, and therefore while external forces charging the joint (body mass) are working – supination occurs. It is, yet, forced by the movement of thigh and upper leg (valgus knee and abduction of tight), caused by the lack of sufficient muscle control of these joints and loosening of the pre-surgery motion pattern. This leads to a location disorder of bio-mechanical loading axis of lower extremities.

Analysis of limb movement in the traverse plane

Movement of knee joints in the transverse plane (fig.5) has a similar tendency to the one observed in the frontal plane. The mean values of angles are within the range of variations in the control group in individual gait stages. Directions of angular changes also do not vary from the norm, in comparison with joint's motion pattern of healthy subjects. Dispersion of individual results around the curve representing mean values shows, however, an increased alternation in relation to the control group. This is mostly visible in the swing phase, where the range of motion is shifted towards internal rotation.

Internal rotation of the hip joint (fig.8) in the operated limb in the stance phase reaches the upper limit of normative values, in the terminal swing and initial contact phase, internal rotation exceeds the results of the control group by approximately 2°.The range of rotation of the hip joint in the non operated leg oscillates in the range of values for the comparison group.

The ribbon of double standard deviation for both examined joints is much wider than parallel results of the control group. The range of motion is evidently shifted in the direction of internal rotation. Particularly two areas-the support and terminal swing phase indicate distinct dislocation towards aforementioned direction.

In the dimensional gait analysis rotation of the ankle is connected with the rotation of the upper leg towards the thigh. Based on this, it can be assumed that the obtained internal rotation of the knee joint corresponds to foot's rotation, which in the stance phase rotates itself inwards relatively to the body axis. Therefore, under load of the joint whilst walking a reverse setting of foot may occur, in comparison with technical premises for the

procedure. However, values of the rotation are very small (1-2°) and are not visible during clinical examination.

Three-dimensional gait analysis implies the presence of changes in the locomotion pattern, which may also result from the compensatory performance of joints in lower extremities caused by ankle fusion.

The knee joint on the operated side has not reached sufficient flexion neither in the stance nor the swing phase as compared with the control group. In order to move the limb, the lack of a full flexion of the knee was compensated by an increased internal rotation of the hip joint and incomplete hyperextension at the end of the stance phase.

The analysis of spatio-temporal parameters

The values of spatio-temporal parameters indicate a reduced cadence of steps as well as length and speed of gait compared to the control group. Double support time, length and velocity of step and stride are also extended. Gait is slower and performed with the lower frequency of steps. This means the fear of full loading and persistence of the antalgic locomotion pattern formed in the pre-operative period, what may cause a slight, but only ostensible contradiction with the results of Ankle Mazur Score.

Comparing the values of spatio-temporal parameters in group of operated people the attention should be paid to shortening of the single support phase and extension of the double support phase on the operated side, relative to the non operated leg. It is caused by the avoidance of longer loading of the fused joint, due to a reduced control over the joint axis observed in the kinematic analysis, and deterioration of leg stability in the single support phase.

The results of the Mazur Ankle Score (76,25 points) obtained from the study group indicate that the clinical results of ankle arthrodesis by a hindfoot nail are good, which means that the patients did not feel pain an did not report any significant troubles connected with daily life activities, which supports a pre-operative consolidated pathologic gait scheme. The results are consistent with the studies of Mazur et al. [4]

According to Glazebrook [2], after the ankle and subtalar arthrodesis the motion of the ankle in the sagittal plane is limited and compensated by midfoot joints. The gait speed and stride duration are also reduced. It partially confirms the results of the author's own research.

Buck et al. [5] carried out locomotion tests by the use of electrogoniometer among 19 patients who had undergone ankle arthrodesis. On the basis of those studies they presumed that, in order to minimize deviations from the normative values of gait parameters, the optimal position for joint's arthrodesis is a neutral position of the ankle joint in the sagittal plane, slight valgus (angulation) and external rotation of the joint. Such a setting reduces the risk of development of compensative changes in the locomotor system.

The patients who participated in the author's own research had joints stiffened in such a position throughout the surgery. However, the gait analysis revealed that, probably under the influence of forces during free locomotion, there is a reverse setting of a foot on the ground at loading time.

Wen-Lan et al. [6] conducted research among 9 patients after ankle arthrodesis. Gait analysis was performed with the use of six three-dimensional cameras during walking on the flat surface and stairs. The values of angular changes in the hip joint during a walk on a flat ground have shown limited extension in the stance phase, whereas the knee joint in the same phase has achieved a bigger range of flexion.

A different movement pattern is indicated by the research of Weiss et al. [7] who assessed locomotion of 14 people after a complex arthrodesis, before and after the procedure, also with the use of the Vicon system. The outcome clearly shows that in both- the hip and knee joint the range of mobility has been improved. The extension in the hip joint has risen by 9° and flexion of the knee joint by 5°.

The probable cause of such a pattern may also be adverse locomotor habits developed before the surgery, characterized by an acute pain resulting from degenerative changes in the joints which are difficult to change, even after a surgical removal of their cause. The results of the non operated extremity, which slightly differ from the data of the control group, may be another confirmation of this hypothesis.

CONCLUSION

1. During the analysis it has been observed that the range of motion of the ankle and hip joints in the sagittal plane is limited in comparison with the control group.
2. The performance of joints in the frontal and transverse plane indicates a loosening of their movement pattern in the stride, what points to the lack of sufficient muscle control and a consolidated antalgic motion pattern.
3. Although the results of the Mazur Ankle Score have been assessed as good, the obtained values of space and time parameters demonstrate the consolidation of the habit of antalgic gait.
4. During the stance phase the ankle stiffened by a hindfoot nail positions itself in the supination and internal rotation.
5. The performance of joints of both lower limbs is symmetric and their mean values slightly differ from the admissible variability of the results in the healthy group.

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