Effects of ankle arthrodesis on functioning of the knee and hip joints during walking at natural velocity

Wpływ usztywnienia stawu skokowego na funkcjonowanie stawów kolanowych i biodrowych w trakcie chodu z naturalną prędkością

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Keywords
locomotion, ankle arthrodesis, three–dimensional gait analysis

Abstract
Background: Ankle arthrodesis is probably still the safest method of treating painful, lesioned ankle in patients with rheumatoid arthritis or osteoarthritis with significant symptoms that do not respond to conservative treatment. The aim of this study was to present the effects of the ankle arthrodesis on correct functioning of the knee and hip joints during walking at natural velocity.
Materials and methods: The study was conducted in the Biokinetics Laboratory of the Academy of Physical Education in Kraków. Fourteen patients with ankle arthrodesis, aged from 34 to 66 years (mean: 54 years), were enrolled into the study and participated in the testing sessions. Angular changes of the knees and hips in three planes of movement during particular gait phases were evaluated by a three–dimensional motion analysis system: Vicon®. The results of locomotion analysis were compared to a control group that consisted of thirty healthy persons aged 40–60 years.
Results: Significant differences in the movement of the knees and hips in the three planes of motion were observed between the two groups. In the frontal plane, knees moved symmetrically, but during all the gait phases, knees were in a significant valgus deformity. In the transversal plane, knees were in a significant external rotation during all gait phases. In the saggital plane, hips moved with limited extension. There was also a significant external rotation, outside the biomechanical normal range, of both hips in the transversal plane.
Conclusions: The most significant deviations from the biomechanical normal range were found in the frontal and transversal planes for knees and in the saggital and transversal planes for hips.

Słowa kluczowe
lokomocja, artrodeza stawu skokowego, trójwymiarowa analiza ruchu

Streszczenie
Wstęp: Celem badań jest przedstawienie wpływu zabiegu usztywnienia stawu skokowego na prawidłowe funkcjonowanie stawów kolanowych i biodrowych w trakcie chodu z naturalną prędkością.
Materiał i metoda: Badania zostały przeprowadzone u 14 chorych w wieku od 34 do 66 roku życia (średnia wieku 54 lata), u których wykonano zabieg usztywnienia prawego stawu skokowego z wykorzystaniem systemu do trójwymiarowej analizy ruchu Vicon 250. Oceniane były zmiany kątowe stawów kolanowych i biodrowych w trzech płaszczyznach ruchu w poszczególnych fazach chodu. Wyniki lokomocji zostały przedstawione na tle grupy porównawczej 30 zdrowych osób w przedziale wieku 40–60 lat.
Wyniki: U badanych osób odnotowano zmianę schematu pracy stawów kolanowych i biodrowych w trzech płaszczyznach ruchu w porównaniu z wykresami grupy kontrolnej. Największe odchylenia od normy biomechanicznej stwierdzono w płaszczyźnie czołowej i poprzecznej w stawach kolanowych oraz w płaszczyźnie strzałkowej i poprzecznej w stawach biodrowych
Wnioski: Zabieg operacyjnego usztywnienia stawu skokowego ma wpływ na funkcjonowanie stawów kolanowych i biodrowych w trzech płaszczyznach ruchu.

Authors' contribution: A – project of the study, work; B – collection of the data, information; C – statistical analysis; D – data interpretation; E – preparation of the manuscript; F – literature query; G – obtaining funds

Received: 12.05.2007; accepted 25.09.2007

Medical Rehabilitation e ISSN 1896-3250

Introduction

A procedure of transformation of an articulation into a stiff structure, called arthrodesis in medical terminology, is a surgical therapeutic method involving permanent connection of bone ends forming the joint. The bones are placed at a best possible functional position, however, the joint loses its natural range of motion. Dorsal and plantar flexion movements of the foot are possible in Chopart joint, with the range of motion increased sufficiently to correct for arthrodesis-induced dysfunction that becomes insignificant or unnoticeable[1,2,3].

This operation is recommended as a last resort in therapy[4,5]. The arthrodesis of above-described joint is performed, when movement in this joint induces pain or if there is complete lack of control over an unstable articulation (while other surgical therapies are not associated with good prognosis with regard to amelioration of joint function)[6]. For decades, arthrodesis of the ankle joint has been performed as a procedure created for treatment of painful degeneration and irreversible, post-traumatic damage to the tibial-ankle joint[7,8,9]. Arthrodesis of the ankle joint is likely still the safest therapeutic method to treat painful, damaged ankle joint in patients with rheumatoid arthritis or degenerative osteoarthritis. In these patients, advanced form of the disease elicits severe symptoms and signs that result in failure of traditional therapy[6].

The majority of authors are consistent in their opinion that damaging, post-traumatic degenerative disease is the most common indication for arthrodesis[6,8,9,10]. Apart from the above indication, pain and deformations resulting from: infections, osteo-cartilaginous defects, aseptic necrosis of talus, inflammatory arthropathy and rheumatoid degeneration are also, yet less frequently, listed as indications for arthrodesis.

According to studies conducted by Beyaert C. et al.[11], Thomas R. et al.[12] and Wen-Lan W. et al.[13], significant impairment of the locomotor function resulting from changes in ranges of motion in three planes occurs in patients who underwent arthrodesis.

Table 1

Characteristics of the evaluated group		
parameter	**x̄ ± sd**	**min – max**
age [years]	54.7±10.5	34-66
weight [kg]	85.3±13.5	62-100
height [cm]	166.6±7.9	160-180

However, analysis and interpretation of results of locomotion studies with regard to the whole biomechanism is lacking. The aim of the study was, therefore, to attempt to assess the effects of ankle arthrodesis on functioning of the knee and hip joints during walking.

The evaluation included spatial position and ranges of motion of these joints in particular planes during subsequent gait phases.

Material and method

Assessment of locomotion was conducted in 14 patients (10 women and 4 men), aged from 34 to 66 years (mean age: 54 years), following right ankle joint arthrodesis due to secon-

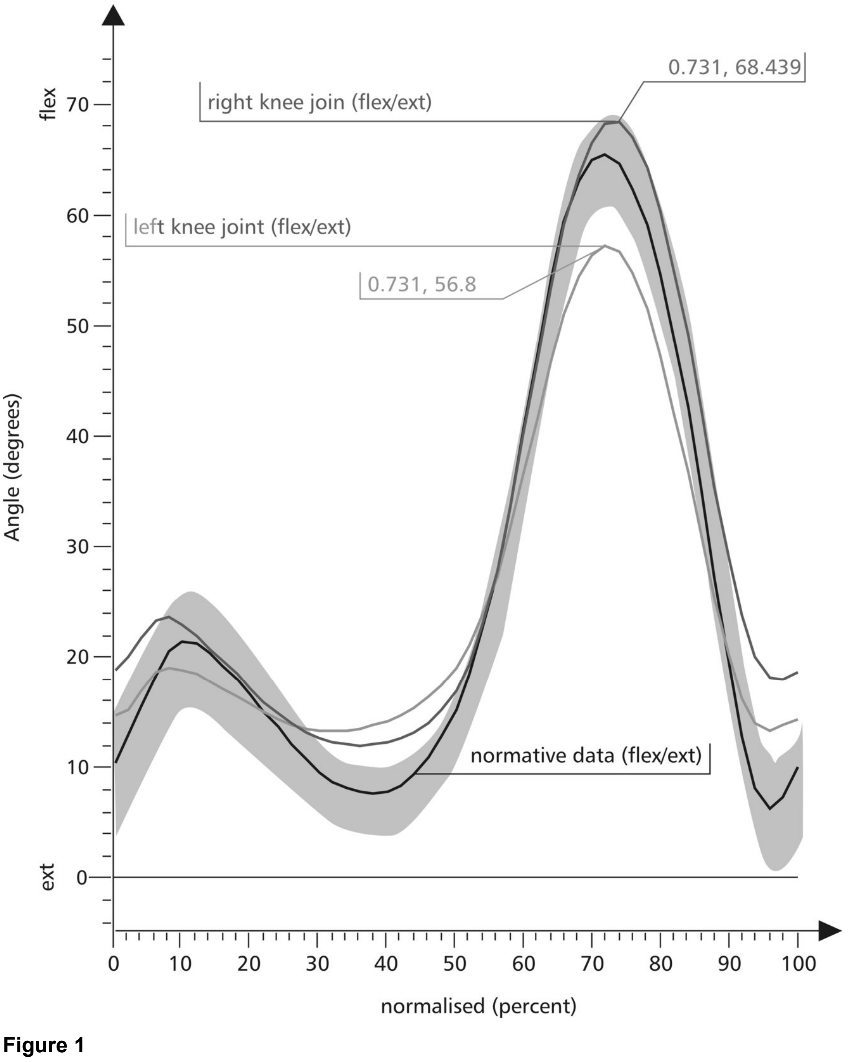

Figure 1

Angular changes in the knee joints in the sagittal plane

Ext. – extension, **Flex.** – flexion; **Angle (degrees)** – angular values in the evaluated joints (expressed in degrees); **Normalised (percent)** – normalised duration of the complete gait cycle (expressed as percent valules); **normal** – angular changes observed during normal gait, represented by the comparison group (mean and 2 SD)

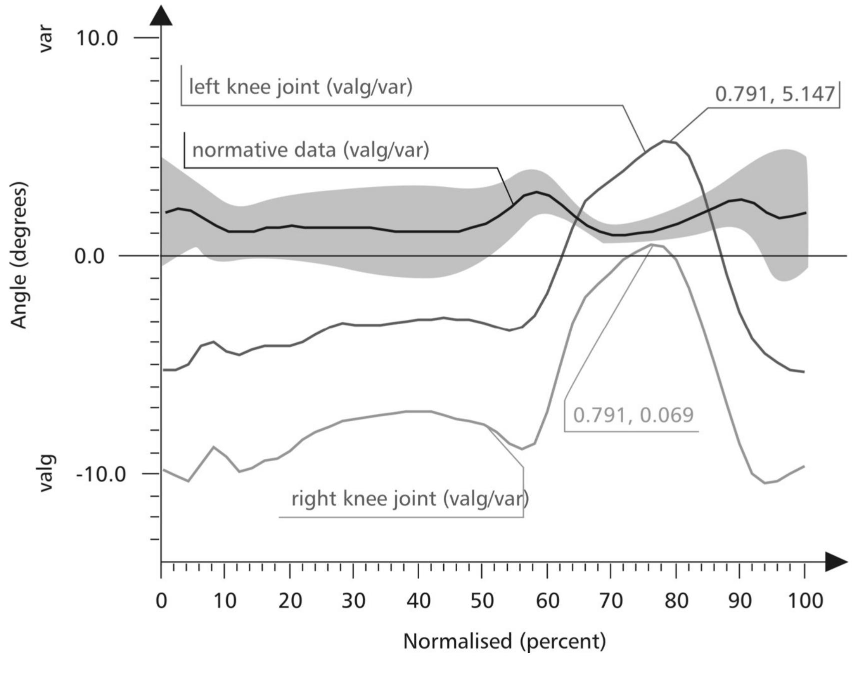

Figure 2

Angular changes in the knee joints in the frontal plane
Var – varus deformity, **Valg** – valgus deformity

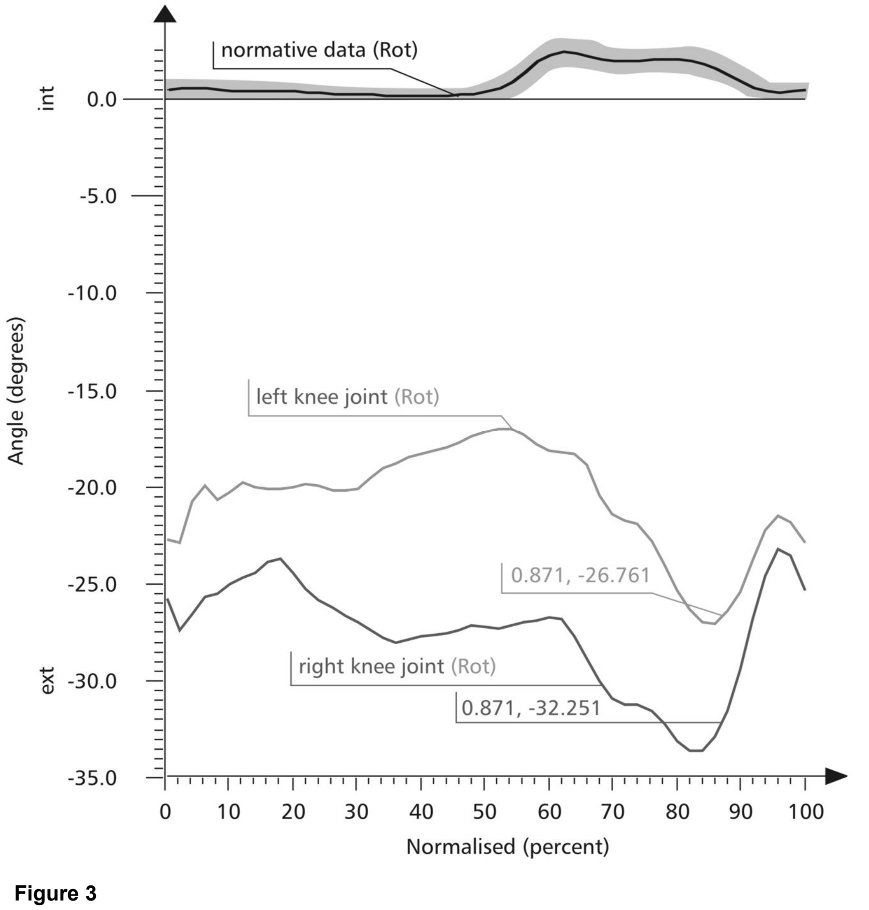

Figure 3

Angular changes in the knee joint in the transverse plane
Ext – external rotation, **Int** – internal rotation, **Rot** - rotation

dary degenerative changes. The studied persons had their ankle joint fixed in plantar flexion at an average angle of 6°. A system for three-dimensional motion analysis, Vicon 250, was used for the analysis of locomotion pattern. In the evaluated persons, no other ailments possibly affecting patients' locomotion pattern were found. The surgery was had been conducted approximately 5 years prior to this study. Characteristics of the evaluated group is presented in the Table 1.

The study allowed to determine the ranges of dysfunctions during particular gait phases that resulted from ankle arthrodesis.

Results of the study were presented in comparison with a control group comprising 30 healthy persons (women and men) aged from 40 to 60 years (the so-called biomechanic normative data).

Assessment of locomotion was conducted in the Laboratory of Biokinetics, Chair of Anthropomotorics at the Academy of Physical Education in Krakow, Poland.

The Vicon system uses 39 markers attached at the axes of joint movements and selected anthropometric sites of the body. The markers are stuck directly on the skin of the examined person at characteristic points: on the thorax, pelvis, extremities and the head, according to a scheme corresponding to the biomechanical model "Golem". This enables spatial reconstruction of body segments. The obtained information is presented in a form of plots using the "Polygon" software.

In the analysis of locomotion, the Rancho Los Amigis Medical Center classification of gait phases[14] was used. The classification assumes that single gait cycle constitutes 100%. The system distinguishes the following gait phases: initial contact – a contact of the heel with the ground – 0%, loading response – loading of the extremity – 0-10%, midstance – middle part of the single stance phase – 10-30%, terminal stance – terminal part of the stance phase – 30-50%, preswing – take off – 50-60%, initial swing – take off of the toe –posterior swing – 60-70%, midswing – transfer of the limb – 70-85%, terminal swing – anterior swing – 85-100%.

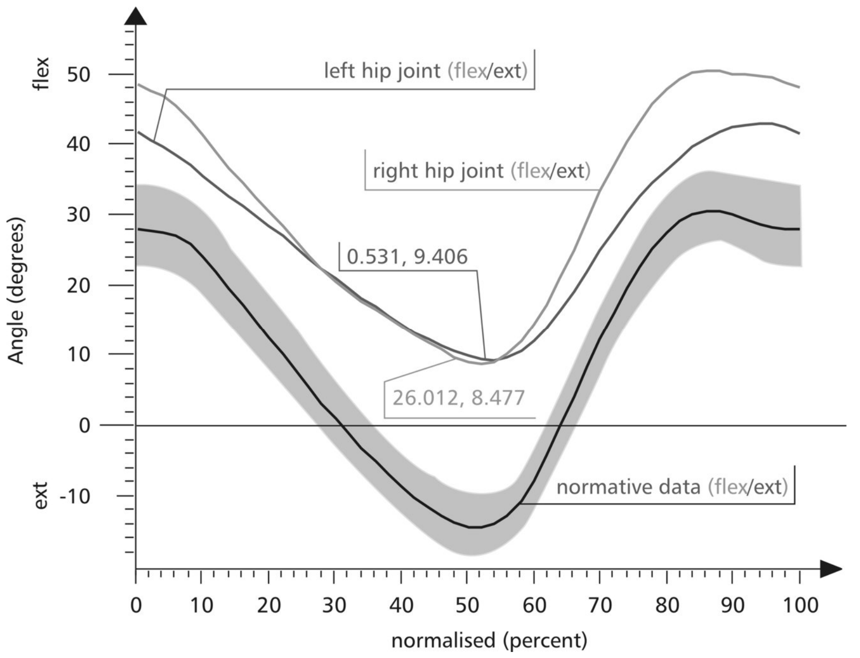

Figure 4

Angular changes in the hip joints in the saggital plane
Ext. – extension, **Flex.** – flexion

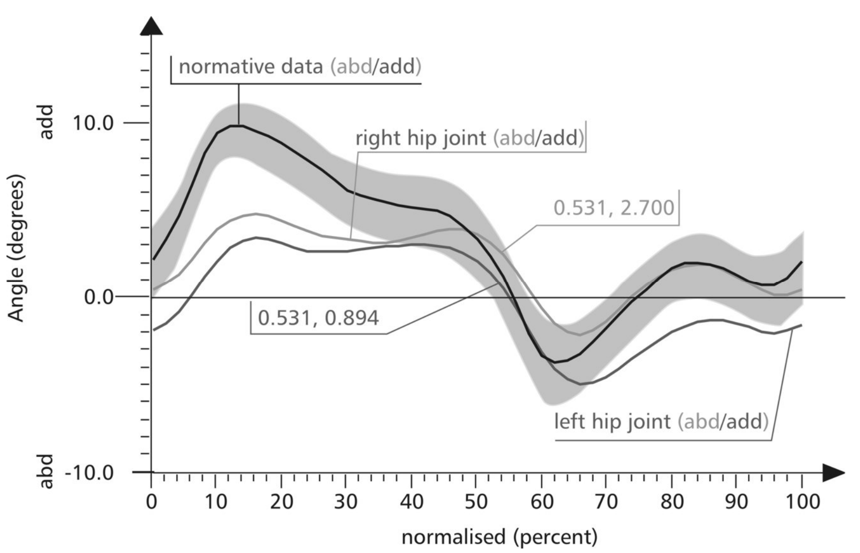

Figure 5

Angular changes in the hip joints in the frontal plane
Abd – abduction, **Add** – adduction

Results

On Figures 1-6, mean values (for 14 persons) of angular changes in the knee and hip joints were presented in three planes of motion, in a normalised gait cycle at natural velocity. Grey band on each plot represents variability of results in healthy population (the so-called biomechanical normative data).

Analysis of angular changes in the knee joints

Shape of curves of angular changes in the knee joints in sagittal plane is markedly similar to the biomechanical normative data plot.

Only is there a slight restriction of flexion in the non-operated limb noticeable, during the midswing phase – by approximately 10° as compared to the biomechanical norm (Figure 1).

However, gait pattern is changed in frontal plane. The articulations work symmetrically, yet, they are positioned in a marked valgity when the whole gait cycle is considered. Maximum value of angular changes in the knee joint of the operated limb is approximately 10º during the loading response phase, whereas the minimum value, occurring during midswing, is similar to the lower limit of the biomechanical norm. The curve of knee joint changes on the non-operated side was maintained at a 4-5º level of valgity for 0 to 60% of the cycle, while in the swing phase, it shifted towards varus deformity of the joint – maximum value was 5º during midswing (Figure 2).

External rotation of the joints that exceeds normative data is evident during the whole gait cycle. Maximum external rotation of the knee joint in the operated limb is approximately 34º by the end of midswing, while in the non-operated limb, maximum external rotation of the joint is 25º at the beginning of the terminal swing phase. This indicates that the difference between the biomechanical normal values and the obtained results is over 20º during the whole gait cycle (Figure 3).

Analysis of angular changes in the hip joints

Work of the hip joints in sagittal plane is characterised by a marked limitation of extension. During the preswing phase, hip flexion is 9º in the non-operated limb and 8º on the operated side, as appropriate. Maximum normal value for movement during this phase of gait is approximately 14º of hyperextension (Figure 4).

In frontal plane, amplitude of movement in the hip joints is similar to that of the biomechanical norm. During stance, adduction of the limb is slightly limited – by approximately 6º in the right joint and approximately 3º in the left joint. During swing, only is the left hip articulation working in excessive abduction – approximately 4º below normative data (Figure 5).

In patients with ankle arthrodesis, excessive external rotation of the hip joints was observed during walking; the rotation was 18º for both joints

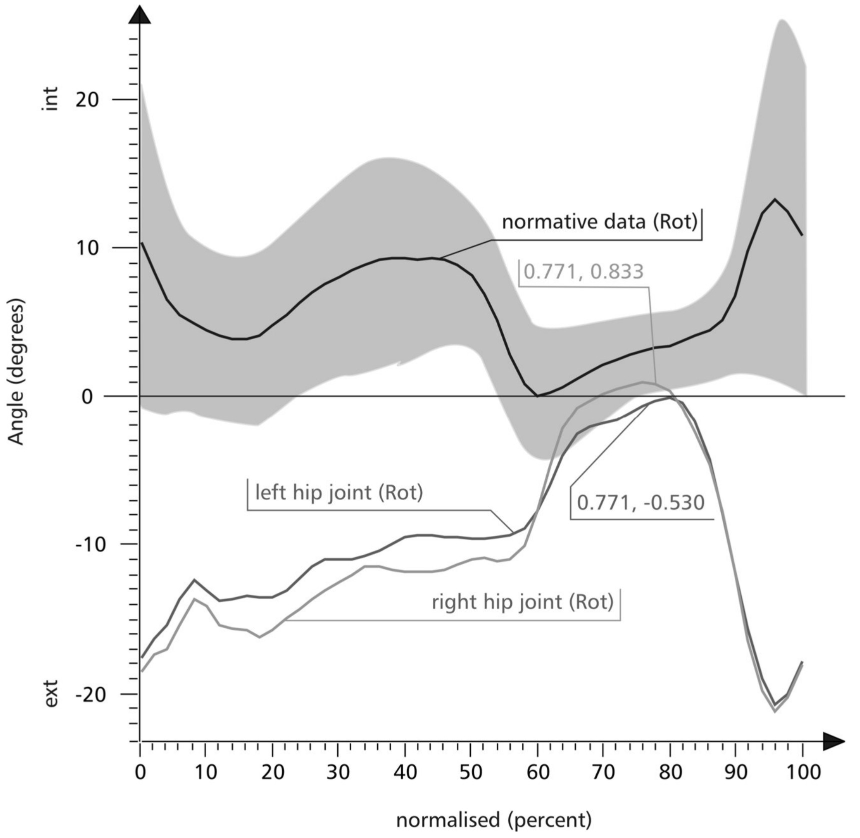

Figure 6

Angular changes in the hip joints in the frontal plane
Ext – external rotation, **Int** – internal rotation, **Rot** - rotation

during the initial contact phase. Solely in the midswing phase, joint rotation values are similar to the lower limit of the biomechanical norm (Figure 6).

Discussion

Surgical arthrodesis of the ankle joint results in occurrence of abnormal movements in the knee and hip joints. Changes in the ranges of motion in those articulations may result from formation of compensatory mechanisms in the joints or secondary pathological changes. Greatest changes in the knee joints were observed in frontal and transverse planes. Valgus deformity of the knee joint on the operated side was present during the whole gait cycle. Range of motion in the left knee articulation during stance was also shifted towards valgity, however, during the midswing phase, it was shifted towards varus deformity. Significant external rotation was found both in the left and right knee joint.

In the hip joints, a change in motor pattern was also observed that resulted from ankle arthrodesis. There is no natural hyperextension in the hip articulations at the moment of toe take off (the initial swing phase); slightly reduced joint adduction also occurs during stance, as well as excessive abduction in the left hip during swing is observed. Similarly to the knee joints, the hip articulations underwent excessive external rotation ranging above normal values.

In the analysis of particular gait cycle phases and spatial positioning of the lower limbs joints during locomotion, it is noticeable that greatest deviations from the biomechanical normative data were found in frontal and transverse planes both in the knee and hip joints.

During stance, the knee joints work normally in the sagittal plane but are positioned in valgity and external rotation, while the hip joints are positioned in excessive flexion, restricted adduction and excessive external rotation. During the swing phase, normal flexion in the knee joints is maintained, however, external rotation increases and valgity of the knees is reduced. Flexion in the hip joints is also maintained and movement in frontal plane is similar to the biomechanical norm. Further, external rotation is also reduced – during midswing, it is at borderline of the lower limit; subsequently, marked external rotation in the joints recurs.

For correct gait, dorsal flexion of the foot of 5-10º is essential. As there were more women in the evaluated group, in whom the ankle joint is stiffened at slight plantar flexion (appoximately 5º) so that they could wear high-heel shoes, excessive external rotation was observed in our assessments of locomotion. During walking without shoes, female patients cannot walk on toes but place the whole foot onto the ground, while hyperextension of the knee and hip joints occurs. This results in external rotation of the knee and hip joint. It seems possible that if patients had walked on a treadmill in heightened-heel shoes, the changes would not have been manifested to such an extent.

External rotation of the knee and hip is a compensation of the lack of mobility of the ankle joint. Persistence of this mechanism for a longer time may affect functioning of these joints that work at abnormal conditions. To minimise this compensation, patients use shoes with heightened heel.

Studies conducted by Thomas et al.[12] also demonstrated restriction of extension in the hip joint, however, no significant changes were observed in the remaining planes of the hip joints or in the stereotype of the knee joint movement. They also conclude that after arthrodesis, range of motion does not significantly change in the remaining articulations of the lower extremity.

Thus, there are only anecdotal reports describing the effects of arthrodesis of the ankle joint on functioning of the knee and hip joints, while there are no unequivocal conclusions, based on solid empirical studies, that would allow determining the pattern of movements in the joints of the lower limbs following arthrodesis.

Conclusions

1. Surgical procedure of arthrodesis affects functioning of the knee and hip joints in three planes of motion.
2. Greatest deviations from the biomechanical normative data were observed in frontal and transverse planes for both the knee and hip joints.
3. Excessive flexion of the hip joints and external rotation of the knee and hip joints is present during the whole gait cycle.

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Translated from Polish into English: Marcin Tutaj, MD, PhD