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THE IMPACT OF LOWER LIMB-LENGTH EQUALISATION ON POSTURAL STABILITY IN PATIENTS TREATED WITH THE ILIZAROV METHOD

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ABSTRACT

Background and Objective
The aim of this study was to assess postural stability in patients with varying degrees of equalisation of limb shortness in the lower leg after treatment with the Ilizarov method (IM) compared to a control group, which consisted of people with lower extremities of equal lengths.

Material and Methods
The study included 58 men treated with the IM due to lower limb-length (LL) inequality in the lower leg and 61 healthy men who served as the control group. Patients with LL inequality were divided into two groups with varying degrees of limb equalisation. The measurement was made using the Biodex Balance System, which enables examination of the patient's ability to control balance and to assess the patient's lower limb support function by determining their ability to control bilateral, dynamic postural stability on an unstable surface.

Results
The study showed that not all patients treated with the IM obtained results matching those in the control group. The largest limb-loading asymmetries were recorded in patients with limb shortness of >1 cm. People with LL asymmetry up to 1 cm obtained better results in terms of all measured parameters compared to patients whose LL discrepancy after treatment was more than 1 cm. The results of the

balance parameter on an unstable surface differed between the patients subjected to treatment with the IM and the group of healthy individuals.

Conclusions
People with lower limb-length asymmetry up to 1 cm obtained better results on all measured parameters compared to those with a limb-length discrepancy exceeding 1 cm. The results of the balance control parameter obtained on an unstable surface differed between groups of patients following treatment with the IM and healthy individuals. People with limb-length asymmetry up to 1 cm following the treatment placed their weight in the lower extremities in a similar way as healthy individuals did.

Key Words: *leg length inequality, Ilizarov technique, postural balance, asymmetry, dynamic test*

INTRODUCTION

Limb-length inequality poses a significant challenge for contemporary orthopaedics and biomechanics and is a source of functional problems, impaired limb functioning and, consequently, the statics and dynamics of the musculoskeletal system.[1–7]

In the case of a lower limb-length (LL) inequality of ≥2.5 cm, the preferred choice for limb equalisation is lengthening the shorter limb using the Ilizarov method (IM) and Taylor spatial frame (TSF) method.[8,9] Because it offers the possibility of lengthening the limbs and the option to correct coexisting axial deformations (apart from the TSF or the stimulation of epiphyseal plate activity), this method of treatment has become one of the ways of correcting moderate to severe length discrepancies and axis corrections in the extremities.[1,2,9–12]

Surgical treatment improves limb functioning and eliminates the consequences of this pathology on the musculoskeletal system. Balance and symmetrical load distributions between both lower extremities influence the biomechanics of the musculoskeletal system.[13–17] Having correct balance and load distributions allows for proper functioning and motor activity.[14–16,18,19] IM does not always lead to the full equalisation of the shortness. In such cases, the projected equalisation and the subsequent limb functioning and improved balance may not meet expectations. Thus, the analysis of balance and load distribution behaviour is an important outcome.

Little is known about the effects of lower limb equalisation on postural stability and on the ability to control balance on an unstable surface. [20–22] Few studies on balance and limb-load distribution after Ilizarov equalisation compared these parameters in healthy people.[15,23] Performing such an analysis seems justified, as clinical experience shows that, despite the satisfactory outcome of treatment in terms of length correction, the function of the lower extremities after removing the Ilizarov apparatus and completing comprehensive treatment still appears to be abnormal in some patients.[1,15]

The aim of this study was to assess postural stability in patients with varying degrees of equalisation of limb shortness in the shin after treatment with the IM and to compare their results with a control group consisting of people with equal LL.

MATERIALS AND METHODS

The study included 119 subjects: 58 men (aged 22.3±12.1) treated with IM due to LL discrepancy in the lower leg and 61 healthy individuals. The groups did not differ significantly in terms of height (169 vs. 167 cm), BMI index (23.98 vs. 23.31 kg/m^2) and aetiology. The inclusion criteria were as follows: informed consent to participate in the study, the presence of full medical and radiology records, completed treatment with IM in the lower leg, limb shortness after the treatment of <4 cm, lack of limb axis disorders requiring further correction and observation period of at least 24 months.

Patients were qualified based on the analysis of medical records, physical examination and radiological analysis. All patients had full mobility in the joints, and there was no contracture in the joints.

Limb-length was measured with an X-ray performed with digital technology using K-PACS program version 1.6 (IMAGE Information System, London, UK). All X-rays were taken in a standing position. The program worked with X-ray images in DICOM format and permitted measurement of the length of the lower extremities, setting the line from the highest point of the femoral head to the point located mid-width of the articular surface of the distal epiphysis of the tibia.

Patients with a lower LL discrepancy were divided into two groups based on the degree of limb equalisation. There were no torsional deformation in all of the patients. Group 1 consisted of 37 men (aged 19.8 ± 7.3) whose limb shortness after the completed treatment was <1 cm (within physiological asymmetry). This group was not subjected to further correction. Group 2 consisted of 21 men (aged 26.1±8.3) whose limb shortness after the completed treatment was ≥1 cm, but did not exceed 4 cm. In the doctor's opinion, the shortness did not require further correction, as the inequality was well within the confines of compensation. Group 3 consisted of 61 controls (61 men; aged 21.9±1.9) with no dysfunction, pain or lower LL inequality. The LL in men from the control group was the same or asymmetry (below 1 mm). Such values, in the authors' opinion, did not impact the study results.

The minimum period between the end of the treatment and the beginning of the study was 24 months (mean 40.11±12.19 in Group 1 and 42.05±11.23 in Group 2).

Due to the lack of conclusive tests for determining the dominant limb, dominance was determined in all groups on the basis of personal preference (the respondent alone indicated the dominant limb) and using three tests: kicking a ball, stepping onto a 20-cm block and testing balance recovery, which involved throwing the respondent off-balance by gently knocking the interscapular area and observing which foot the person uses to regain balance.[24] We believe that does not have a bearing on the balance after onset and correction of LL discrepancy.

The postural stability test allowed for an analysis of the patient's ability to control balance. The measurements were made using the Biodex Balance System SD, which allowed the researcher to assess the patient's neuromuscular control and lower limb support functions by determining the patient's ability to control bilateral, dynamic postural stability on an unstable surface. The stability of the platform could be changed using the resistance force. Springs in the lower part of the platform and a gear unit regulated the platform's instability by acting directly on the matrix, which has a diagonal line of 55 cm, allowing for deviations of around 20 degrees from the chosen level in all directions (Figure 1). Analysis of the results was conducted using the operating system Windows CE 6.0 R3.

In the dynamic test, researchers analysed the subject's ability to control the angle of the platform's support plane compared to the locked position. The assessment was made based on the "percentage ratio of remaining in a particular zone," which required a shift of the platform from the horizontal plane, expressed in degrees. These values were expressed as the percentage of the entire test duration that the patient spent in a particular zone. A comparison of both lower limbs showed the differences in possible limb loads between the limbs that were operated on and those that were not.[25,26]

Target zones A, B, C and D are equal to the angle of platform deviation. They are marked by concentric circles in the middle at the centre of the platform (Figure 2).

FIG. 1 Image of a person examined during the dynamic test performed using the Biodex Balance System SD.
Source: Own documentation.

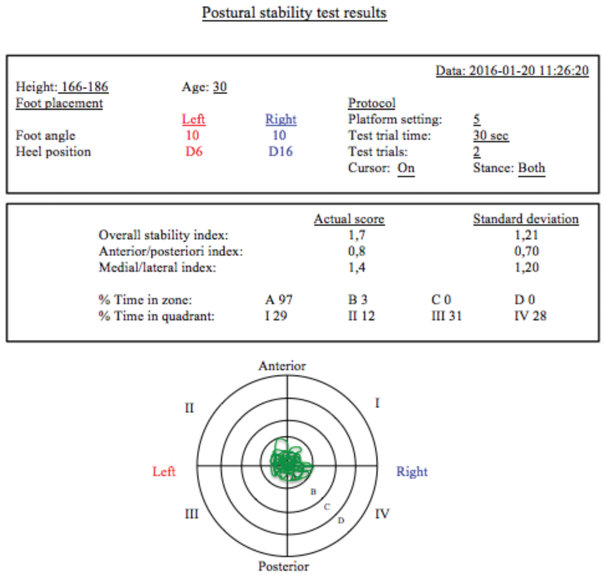

FIG. 2 A sample of a dynamic test performed using the Biodex Balance System SD indicating the zones, quadrants, and the left and right side.
Source: Own documentation.

The longer the time remained in Zone A by patients, the greater their ability to control the angle of the platform, that is, their balance. This indicated good neuromuscular control and proper support given by both legs.

After doing further analysis and comparing results, the differences were determined between the operated-on and non-operated-on limbs using a percentage ratio showing the patient's time spent in different quadrants during the test. The quadrants represent four quarters of the test graph shown in the study report (Figure 2).

To check limb-loading symmetry in both extremities, quadrants I (%) and IV (%) and quadrants II (%) and III (%) were compared. Values that were equal or close to one another indicated limb-loading symmetry between limbs.

All patients were informed about how the Balance System works. Each participant stood on the platform barefoot, allowing for the accurate determination of the position of feet.[25,26]

Everyone taking part in the study performed one preliminary test to become acquainted with the principle of working of the platform. That test and the two analytic tests lasted 30 s at level 5 (a medium level of difficulty).

The Shapiro–Wilk test was used to analyse the distribution of the data. A student's *t*-test or Mann–Whitney *U*-test was used to examine the difference between limbs. The ANOVA by ranks and the Kruskal–Wallis test with a post hoc comparison using the least significant differences test were used to compare balance test results. $p<0.05$ was considered statistically significant.

RESULTS

Lower limb discrepancy prior to the surgery differentiated the studied groups at a significant level (Table 1). In Group 1 patients (LL shortness of <1 cm), the difference was 20.95 mm, while in Group 2 patients (LL shortness of <1 cm), it was 36.81 mm. Mean values also differed significantly for lower limb shortness that remained after treatment (Table 1). In Group 1, limb discrepancy was 1.11 mm; in Group 2, it was 13.86 mm.

The control group exhibited the best ability to control balance, which also indicated proper neuromuscular control and proper lower limb support functioning (Table 2). The mean value of the percentage ratio of remaining in Zone A was 96.34±6.37. Slightly lower results were achieved by Group 1 (86.57±5.59). By far, the weakest results, which indicated postural stability disorders and problems with balance, were observed in Group 2 (67.33±5.61). Those patients additionally had the highest percentage ratio of remaining in Zone B (6–10° platform deviation relative to the horizontal plane) and Zone C (11–15° deviation relative to the horizontal plane)—19.52% and 9.38% of the time, respectively. In Group 2, the majority of patients had considerable postural stability disorders producing values from Zone D, in which the deviation of the research platform from the horizontal plane was as much as 16–20°. This further emphasised the prevalence of considerable balance disorders during the dynamic test.

TABLE 1 Statistical Characteristics of Lower Limb Parameters of the Examined Groups and the Mean Value Variations

Variable	LL shortness <1 cm (N=37)		LL shortness ≥1 cm (N=21)		Student's *t*-test
	$\bar{x}$	*s*	$\bar{x}$	*s*	*p*
Time after surgery (months)	40.11	12.19	42.05	11.23	0.5517
Lower limb shortness prior to surgery (mm)	20.95	10.61	36.81	7.46	**0.0000**
Lower limb shortness after surgery (mm)	1.11	1.03	13.86	2.33	**0.0000**

Probability values of p < 0.05 are marked in bold.
LL, lower-limb length.

TABLE 2 Mean Value Variations of the Percentage Ratio of Remaining in Different Zones in All Examined Groups, Post Hoc Comparison and LSD Test

Variable	Group		$\bar{x}$			Probabilities for post hoc tests, LSD test and *p*-value		
	F	*p*	LL shortness <1 cm	LL shortness 1≥ cm	Control group	LL shortness <1 cm—LL shortness 1≥ cm	LL shortness <1 cm—control group	LL shortness ≥1 cm — control group
Zone A [%]	184.05	**0.0000**	86.57	67.33	96.34	**0.0000**	**0.0000**	**0.0000**
Zone B [%]	188.00	**0.0000**	8.70	19.52	2.66	**0.0000**	**0.0000**	**0.0000**
Zone C [%]	81.95	**0.0000**	4.03	9.38	0.75	**0.0000**	**0.0000**	**0.0000**
Zone D [%]	25.31	**0.0000**	0.70	3.86	0.25	**0.0000**	0.2832	**0.0000**

Probabilities of p < 0.05 are marked in bold.
LL, lower limb length; LSD, least significant differences.

All IM patients achieved results comparably different to controls. They differed significantly in all groups (p<0.0001), except for the difference between the control group and Group 1 (p=0.2832) observed in Zone D. Such findings confirm that balance and postural stability disorders persisted in patients after surgery. In Group 2, limb-length inequality had an even greater negative impact on balance control and postural stability.

During the study, the largest limb-loading asymmetries were recorded in Group 2 (Figure 3). The subjects predominately shifted their body weight onto the non-operated-on limb (59.67%), thus relieving the limb that was subjected to treatment (40.37%). This shift indicated disorder in the limb's support function following equalisation and its attempt to "relieve itself" when attempting to control balance on an unstable surface.

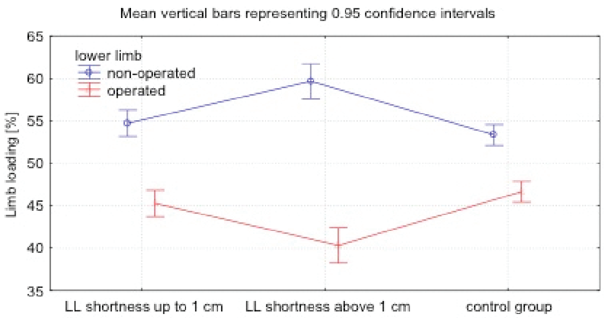

FIG. 3 Mean values of limb loading for the operated-on and non-operated-on extremities in all studied groups.

We observed a tendency to place a greater load on the non-operated-on limb and on the dominant limb in the controls, although no statistically significant differences appeared between the Group 1 and the control group (Table 3). This demonstrated similar correct neuromuscular control and support functions in both lower limbs in these patients. One can thus conclude that when limb shortness of ≥1 cm remains after surgery, it can have a significant impact on lower-extremity load bearing.

DISCUSSION

Treatment of lower limb length inequality in the lower leg using the Ilizarov apparatus is associated with a few complications during equalisation.[1,9,11,19] Despite the ongoing modernisation of the external fixator and improvements to surgical techniques, many patients experience orthopaedic problems such as reduced joint mobility, persistent pain and impaired function of the operated-on limb during locomotion or while standing up, after both the treatment and rehabilitation.[27–29] Balance disorders increase the risk of falls and injuries.

Operating under the assumption that one of the characteristics of correct biomechanics of the musculoskeletal system is the symmetry of limb loading, one study compared these parameters under static and dynamic conditions for operated-on and non-operated-on limbs.[15] The current postural stability study, conducted using a

TABLE 3 Mean Value Variations of the Lower Limb Loading in Non-Operated and Operated on Extremities in All Studied Groups, Post Hoc Comparison and LSD Test.

Variable	LL	Probabilities for post-hoc tests, LSD test, *p*-value		
		LL shortness <1 cm—LL shortness ≥1 cm	LL shortness <1 cm—control group	LL shortness ≥1 cm—control group
Lower limb loading	Non-Oper.	**0.000258**	0.167949	**0.000001**
	Operated.	**0.000258**	0.167949	**0.000001**

Probabilities of p < 0.05 are marked in bold.
LL, lower limb length; LSD, least significant differences.

dynamic test in a standing position, showed differences between the examined limbs during load-bearing activities. The study revealed a tendency to place a greater load on the non-operated-on limb or, for the control group, the dominant limb. The biggest variations between the registered parameters were found in subjects with a limb-length asymmetry of ≥1 cm. The mean value of percentage loading obtained in this group for the non-operated-on limb was 59.67%; for the operated-on limb, it was 40.37%. Such limb-loading asymmetry may be related to lateralisation and the tendency to relieve the surgically treated limb. On the other hand, healthy subjects and patients with a limb shortness of <1 cm placed the load almost equally on both extremities.

Literature reports have attempted to assess postural stability and balance in patients treated with the Ilizarov apparatus.[14,15,19,20] However, no reports evaluating postural stability and balance using a test on an unstable surface have been published. Our results are in line with the results obtained by Bhave et al. in a test using a pedobarographic platform.[20] The authors found that the equalisation of the length of lower limbs in IM patients resulted in the normalisation of the percentage distribution of limb loading both during locomotion and in static conditions. Morasiewicz and Dragan observed symmetrical distribution of body weight in post-corticotomy surgery patients during a test on a platform, performed with the aim of limb derotation using an external fixator.[14] The mean value of percentage loading of the operated-on limb was 47.81%, while the limb not subjected to treatment was 52.19% (insignificant difference). Morasiewicz et al. compared the percentage distribution of lower-limb loading and balance in IM patients and healthy volunteers. They observed similar values for the percentage distribution in both groups; however, a worse balance was observed in the controls. They argued that the influence of abnormal muscular balance, unequal distribution of muscle strength and fixed compensation mechanisms of limb inequality, even after limb-length equalisation, resulted in inferior balance.[15] Dolgnov et al. were among the first to present results on limb loading percentage in 75 patients treated with the IM.[19] They found that, even if there were significant differences in limb loading before treatment, that is, up to 70%, normalisation of the measured parameter and the symmetrical limb loading distribution occurred after limb equalisation. Equally interesting conclusions were reached by Koczewski et al., who analysed limb-loading distribution during walking and standing, but under laboratory conditions.[29] The static test performed before and after treatment confirmed that partial normalisation of the parameters occurs in cases of complete limb equalisation. Nevertheless, they judged limb loading to be still asymmetric.

Our findings indicated that, in patients with limb-length inequality of <1 cm following surgery, normalisation of the operated-on extremity's support function followed. This may have been associated with improved joint mobility and increased muscle strength, which are undoubtedly the body's reaction to treatment and rehabilitation. Unfortunately, if a limb shortness of ≥1 cm remains, there will continue to be disproportionate limb loading on an unstable surface. Adequate balance control requires proper functioning of the musculoskeletal system: in this situation, the degree of asymmetry of LL after the therapy had an influence on that functioning.[30]

In our research, which aimed to examine the ability to control balance on an unstable surface, the results from both groups of IM patients differed significantly from those found in the healthy controls. By far, the most substantial problem with controlling balance was found in patients with limb-length inequality ≥1 cm. The mean value of the ratio of remaining in Zone A (0–5° deviation of the platform relative to the horizontal plane) was only 67.33%. Very often, the deviations were substantial, amounting to as much as 16–20° (Zone D). This clearly demonstrated that the equalisation of the locomotive limbs had a significant impact on the ability to control balance. In patients with unequal limb length exceeding 1 cm, proper balance was extremely difficult to achieve.

CONCLUSIONS

People with lower limb-length asymmetry up to 1 cm obtained better results on all measured parameters compared to those with a limb-length discrepancy exceeding 1 cm. The results of the balance control parameter obtained on an unstable surface differed between groups of patients following treatment with IM and healthy individuals. People with limb-length asymmetry up to 1 cm following the treatment placed their weight in the lower extremities in a similar way as healthy individuals did.

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