Clinical factors affecting lower limb torsional deformities treatment with the Ilizarov method

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ABSTRACT

Introduction: One of the many uses of the Ilizarov fixator is for torsional deformities correction. Rotational and translational bone displacement related to torsional deformities correction includes the additional tension stresses, which affect the biology of the regenerated bone. Understanding the clinical factors will assist in designing the optimal treatment strategy, thus possibly improving the outcomes.

Patients and methods: It was case series retrospective study. The study examined 56 patients. The mean follow-up time was 5 years and 6 months. The mean age at the start of treatment was 19 years and 10 months. Patients underwent derotational corticotomies of distal metaphysis of the femur or proximal metaphysis of the tibia using the Ilizarov method. In these patients, following derotational corticotomies with the Ilizarov method, numerous variables were defined and their effect evaluated: the selected treatment strategy, the rate, size, type, and level of derotation on complications, the alignment index, the correction coefficient, the elongation index, and deformation correction factor.

Results: The differences in the values of alignment index and deformation correction factor in this study subgroups were not statistically significant. We found differences in the elongation index and correction coefficient in a number of subgroups.

Discussion: In the case of correcting torsional deformation without significant elongation, acute correction and with a value of $> 30^\circ$ does not significantly affect the results. Treatment strategy, type and level of derotation had no major influence on torsional deformities treatment.

Level of evidence: Case-control study III.

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1. Introduction
Currently, the Ilizarov method is widely used in the world as the treatment of various distortions in the axis of the extremities [1–3]. One of the many uses of the Ilizarov fixator is torsional deformation correction [4–6]. With the development of imaging techniques, torsional deformations are being increasingly recognized [7,8]. Correction of torsional deformation using the Ilizarov apparatus requires using additional derotational mechanism and high-precision application of the apparatus onto the patient, which complicate the healing process and may constitute the cause of the infrequent employment of the Ilizarov apparatus for correcting torsional deformation [9].

Rotational and translational bone displacement related to torsional deformities correction [10] affect the biology of the regenerated bone. Rotational and translational displacement of bone fragments include the additional tension stresses, which may cause further damage to the nutritional blood supply to the bone [11].

Clinical factors, such as treatment strategy, type, rate, size, and level of deformation correction with the Ilizarov method may affect the results of treatment [4,11–13].

It can be concluded that understanding the clinical factors affecting the course and results of torsional deformation treatment using the Ilizarov apparatus will help in planning the optimal treatment strategy, identifying risk factors of complications; thus, resulting in shortening the duration of treatment and at the same time assisting in achieving improved treatment outcomes.

International literature contains a very small number of clinical works concerned with the treatment of torsional disorders using the Ilizarov method [6,14–16]. These works relate to a small number of patients and treat the various aspects of treatment in...
a fragmentary way. There is no comprehensive work about clinical aspects of torsional deformation treatment using the Ilizarov fixator.

The aim of our study was to evaluate the clinical aspects torsional deformation correction with the Ilizarov method. Based on the clinical data, an analysis of the effect of treatment strategy, type, rate, size, and level of derotation on the incidence of complications, alignment index, and value of the correction coefficient, elongation index, and deformation correction factor in patients after derotational corticotomies using the Ilizarov method was performed.

2. Patients and methods

In the years 1996–2010, 89 patients underwent derotational corticotomies of distal metaphysis of the femur or proximal metaphysis of the tibia using the Ilizarov method at our Orthopedics Department. The subject of the clinical trials consisted of 56 patients, who reported to the follow-up. All patients were informed about the voluntary nature of participation in the study. The research project was approved by the Bioethics Commission (decision number KB-724/2011). The subjects included 27 women and 29 men. The etiology was congenital in 28 cases, inflammatory in 16 and traumatic in 12.

In the case of femoral torsional deformation correction, the prepared femoral apparatus consisted of proximal arch, fixed to the intertrochanteric area with 2 Schanz screws, proximal ring, fixed with 2 Kirschner wires, free middle ring, and distal ring, fixed with 3 Kirschner wires. The derotational mechanisms were installed between the middle and proximal rings (Fig. 1). In the case of lower leg torsional deformation correction, the prepared lower leg apparatus consisted of proximal ring fixed with 3 Kirschner wires, free second ring, third ring fixed with 2 Kirschner wires, and distal ring fixed with 2 Kirschner wires. The derotational mechanisms were installed between the second and third ring (Fig. 2).

In the case of planned torsional deformation correction, three derotational mechanisms of a specific type were installed, evenly spaced every 120° on the circumference of the ring. To reduce translational bone displacement related to torsional deformities correction, we try to situate the bone fragments exactly in the center of Ilizarov device. In case of acute correction, we used clinical method (rotation of the hip joints; transmalleolar axis method [17,18]) to estimated value of correction per-operating. Elongation and axis correction were performed with the standard techniques, previously described in literature. The complete weight-bearing is authorized immediately in post-operative period after derotation.

In all followed patients, medical records for the entire period of treatment were analysed, and physical examination was performed during the follow-up visit. In order to determine the amount of shortening of individual segments (in centimetres) and the deformation of the axis (in degrees), X-ray images of patients’ limbs were recorded. The size of the torsional deformation in the femoral region was determined by assessing the range of internal and external rotation of the hip joints; torsion of the lower leg was assessed with the transmalleolar axis method [17,18]. Lascombes et al. complications classification was used to evaluate treatment results [19].

Elongation index was defined as the number of days necessary to maintain the fixator to achieve elongation of 1 cm. The correction coefficient was defined as the number of days needed to correct the deformation by 1 degree [20]. Alignment index was defined as the ratio of the size of the elongated limb to the size of the shortening of the limb, expressed as percentage according to the formula: elongation (cm) × 100%/shortening (cm) [20]. In order to evaluate the correction of the angular deformation, the authors introduced the deformation correction factor (DCF), defined as the ratio of the size of the angle of deformation correction (ADC) to the size of the angle of initial deformation (AID), expressed as percentage.

$$DCF = \frac{ADC}{AID} \times 100\%.$$  

The evaluation of the clinical outcome was performed according to treatment strategy (one-stage, two-stage, multi-stage), type of derotation (external torsion, internal torsion), rate of derotation (gradual, acute), size of derotation (< 30°, > 30°), and level of derotation (femur, lower leg).

The level of statistical significance of the results, depending on the level of derotation, type of derotation, rate of derotation, size of derotation, was based on the Mann-Whitney U-test. Similarly, Mann-Whitney U-test was used in the analysis of the significance of differences between mean values of variables in the study and control group. Kruskal-Wallis test was used to analyse the statistical significance of differences between mean values of variables depending on treatment strategies. All analyses were carried out

![Fig. 1. Ilizarov apparatus construction for femur derotation.](image1)

![Fig. 2. Ilizarov apparatus construction for lower leg derotation.](image2)
at an assumed level of significance $\alpha=0.05$ using Statistica 10.0 software.

3. Results

A mean follow-up time was 5 years and 6 months (2 y 1 m–15 y 6 m). A mean age at the start of treatment was 19 years and 10 months (4 y 8 m–58 y). A total of 87 surgeries were performed in 56 patients, an average of 1.55 surgeries per patient. Forty-one patients had one-step torsional deformation treatment, 10 patients underwent two-stage procedure, and 5 patients had multi-stage treatment (3–5 operations). Torsional deformation correction was performed at the level of the femur in 32 patients, and at the level of the lower leg in 24 patients. External torsion was corrected in 42 patients, while 14 patients had internal torsion correction. Thirty-two patients underwent gradual derotation and 24 patients had acute torsional deformation correction. In 37 patients, the size of the corrected deformation was below 30°, while in 19 it was above 30°.

The value of the elongation index, correction coefficient, alignment index, and correction factor depending on treatment strategy, as well as the level, type, rate, and size of derotation are shown in Table 1. The differences between the values of correction coefficient, alignment index, and correction factor depending on treatment strategy and the type and rate of derotation were not statistically significant. Elongation index in the case of two-stage treatment was 52.68 days/cm, and 47.36 days/cm for single-stage treatment: the lowest value was noted for multi-stage treatment and amounted to 29.6 days/cm. These differences were statistically significant ($P<0.05$). Rate of derotation had a statistically significant effect on elongation index. Elongation index in the case of gradual derotation was 38.65 days/cm, while in the case of acute derotation, it was higher and amounted to 57.02 days/cm; this difference was statistically significant ($P<0.05$). Size of derotation had a statistically significant effect on the correction coefficient. In the group of patients with derotation ranging below 30°, the correction coefficient was 4.0 days/degree, while in the patients with derotation >30°, the correction coefficient was lower and amounted to 2.9 days/degree; this difference was statistically significant ($P<0.05$).

There were 8 cases of translational bone displacement in the series (4 mm–8 mm, mean value 6.9 mm). The correction of translational bone displacement were made by modification of the Ilizarov fixator. The derotational mechanisms were transformed into translational mechanisms. The translational/derotational mechanisms were placed parallel to each other, all oriented in one direction.

The values of the average number of complications per surgery depending on treatment strategy, as well as the level, type, rate, and size of derotation were not observed to possess statistically significant differences (Table 2).

In the study group, we observed 41 complications. According to Lascombes classification, there were grade I complications in 31 cases, grade Ila in 4 cases, grade IIb in 4 cases, grade IIIa in 1 case and grade IVa in 1 case (Table 3).

Table 1
Value of alignment index, correction coefficient, elongation index, and deformation correction factor in subgroups.

<table>
<thead>
<tr>
<th>Treatment strategy</th>
<th>Alignment index [%]</th>
<th>Deformation correction factor [%]</th>
<th>Elongation index [days/1 cm]</th>
<th>Correction coefficient [days/1 grade]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Two-stage</td>
<td>98</td>
<td>6.92</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>One-stage</td>
<td>97</td>
<td>20.22</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>Multi-stage</td>
<td>100</td>
<td>0</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>Level of derotation</td>
<td>Lower leg</td>
<td>98</td>
<td>7.28</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Femur</td>
<td>96</td>
<td>22.53</td>
<td>100</td>
</tr>
<tr>
<td>Type of derotation</td>
<td>Internal torsion</td>
<td>96</td>
<td>9.95</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>External torsion</td>
<td>97</td>
<td>19.65</td>
<td>100</td>
</tr>
<tr>
<td>Rate of derotation</td>
<td>Acute</td>
<td>103</td>
<td>18.21</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Gradual</td>
<td>97</td>
<td>12.81</td>
<td>100</td>
</tr>
<tr>
<td>Size of derotation</td>
<td>&lt; 30°</td>
<td>100</td>
<td>14.59</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>&gt; 30°</td>
<td>89</td>
<td>26.54</td>
<td>100</td>
</tr>
</tbody>
</table>

$P<0.05$.

Table 2
Value of complications per surgery in subgroups.

<table>
<thead>
<tr>
<th>Complications per surgery</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment strategy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two-stage</td>
<td>0.524</td>
<td>0.2</td>
</tr>
<tr>
<td>One-stage</td>
<td>0.375</td>
<td>0.17</td>
</tr>
<tr>
<td>Multi-stage</td>
<td>0.666</td>
<td>0.11</td>
</tr>
<tr>
<td>Level of derotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower leg</td>
<td>0.303</td>
<td>0.13</td>
</tr>
<tr>
<td>Femur</td>
<td>0.583</td>
<td>0.05</td>
</tr>
<tr>
<td>Type of derotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal torsion</td>
<td>0.41</td>
<td>0.5</td>
</tr>
<tr>
<td>External torsion</td>
<td>0.364</td>
<td>0.35</td>
</tr>
<tr>
<td>Rate of derotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute</td>
<td>0.353</td>
<td>0.33</td>
</tr>
<tr>
<td>Gradual</td>
<td>0.391</td>
<td>0.76</td>
</tr>
<tr>
<td>Size of derotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 30°</td>
<td>0.391</td>
<td>0.54</td>
</tr>
<tr>
<td>&gt; 30°</td>
<td>0.444</td>
<td>0.78</td>
</tr>
</tbody>
</table>
Table 3

<table>
<thead>
<tr>
<th>Category of complication</th>
<th>Number of complication</th>
<th>% of complication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint stiffness</td>
<td>13</td>
<td>31.7</td>
</tr>
<tr>
<td>Pin-site infection</td>
<td>12</td>
<td>29.2</td>
</tr>
<tr>
<td>Deformation of new bone formation area</td>
<td>4</td>
<td>9.76</td>
</tr>
<tr>
<td>Nerve injury</td>
<td>2</td>
<td>4.9</td>
</tr>
<tr>
<td>Premature consolidation</td>
<td>2</td>
<td>4.9</td>
</tr>
<tr>
<td>Deep vein inflammation</td>
<td>2</td>
<td>4.9</td>
</tr>
<tr>
<td>Soft tissue necrosis</td>
<td>1</td>
<td>2.44</td>
</tr>
<tr>
<td>Incomplete osteotomy</td>
<td>1</td>
<td>2.44</td>
</tr>
<tr>
<td>Delayed consolidation</td>
<td>1</td>
<td>2.44</td>
</tr>
<tr>
<td>Joint subluxation</td>
<td>1</td>
<td>2.44</td>
</tr>
<tr>
<td>Vascular injury</td>
<td>1</td>
<td>2.44</td>
</tr>
<tr>
<td>Fracture of new bone formation area</td>
<td>1</td>
<td>2.44</td>
</tr>
</tbody>
</table>

4. Discussion

4.1. Type and rate of derotation

Ilizarov apparatus allows for gradual, mixed, or acute deformities corrections. Lobst recommends acute deformation correction [13], Kucukkaya et al., in some cases, performed acute correction of deformations by Taylor Spatial Frame and then removed Taylor Spatial Frame and made plate fixation of bone fragments [5]. According to Carbone [21] and Catagni et al. [22], acute correction can be made in case of external torsion < 20°. Solomin believes that acute correction can be made in case of deformities < 35°. Bigger correction increased risk of nerves and blood vessels injury. In case of large deformities, multi-stage or multi-level treatment is recommended [23]. However, most researchers recommend gradual correction of deformation [11,12,16,24]. Gradual deformation correction is indicated especially in the case of large and complex deformation, and minimizes the risk of damage to the soft tissues, especially the nerves and blood vessels [4]. Hosny and Fadel recommend gradual correction of multiplane deformation for better soft tissues adaptation and minimizes the risk of complications [12]. They observed 3 peroneal nerve injury in group of 5 patients with angular or torsional deformities correction. He revitalizes acute correction [16]. Also Paley and Nakase believe that gradual correction is safe [11,25]. There are no works about process of regenerated bone consolidation after acute and gradual derotation. Rotational and translational displacement of bone fragments may cause further damage to the nutritional blood supply to the bone [11]. Pluripotent cells, in case of low oxygen concentration transformed into chondral and fibrous tissues, not into bone tissues [26]. There is no a clear definition of value of acute correction which didn’t cause nerve injury. This value is depending on anatomy and soft tissues and bone configuration [25]. Experimental research on soft tissue indicates favourable long-term effect of low energy stretching as compared to the strong short-term stretching [4]. The complete weight-bearing could increase bone healing because Ilizarov fixator has good stability in frontal and sagittal plane, and allows for micromovement in long axis. This mechanical properties of Ilizarov fixator can increase new bone formation after acute or gradual correction. In our work, we observed no effect of treatment strategy, and the type and rate of derotation on clinical parameters such as the value of correction coefficient, alignment index, and correction factor, as well as the average number of complications. Only elongation index was found to be significantly higher in the group with acute derotation. These results lead to a number of conclusions. Performing acute torsional deformation correction does not cause, with the exclusion of higher elongation index, inferior clinical outcome and is not burdened by an increased risk of complications as compared to gradual derotation. This may be due to the fact that in the first few weeks after osteotomy, the regenerated bone shows the best blood supply [27]. Regenerated bone, in the first two months after osteotomy, shows the highest susceptibility to stretching, in next months appears intensive bone mineralisation [28]. Correctly performed corticotomy allows for achieving a valuable regenerated bone, even with potentially traumatic acute derotation. Aside from higher elongation index, the evaluated parameters did not differ depending on the rate of derotation. This demonstrates considerable regenerative and adaptive abilities of the regenerated bone and soft tissue surrounding it. Acute correction reduces the duration of treatment, which potentially minimizes the risk of complications associated with long-term retention of fixator and reduces the cost of treatment. Performing single-stage simultaneous large elongation and acute derotation adversely affect the regenerated bone, which increases the elongation index.

4.2. Internal torsion versus external torsion

Taylor and Tetsworth indicate that internal torsion creates more problems as compared to external torsion [29,30]. However, Jaarsma et al. found that patients with external torsion have more functional problems than those with internal torsion [8]. Taylor states that the risk of damage to the peroneal nerve is greater for external torsion correction of the lower limb due to stretching of this nerve [31]. In our study, we did not observe statistically significant differences in outcomes for patients with internal and external torsion corrections. Properly planned treatment strategy, rate, and size of the correction, as well as precise assembly of the Ilizarov apparatus allow for reducing complications and normal tissue adaptation, both in the group with external and internal torsion.

4.3. Size of derotation

Nakase et al. observed a larger elongation index in patients with derotation above 10°, and proposed that the tension stress created in regenerated bone during derotation may adversely affect the newly formed bone tissue. He suggests that torsion stress delays the process of bone remodelling. He believes that for greater derotations, a longer period of maintaining the fixator should be planned [11]. Derotation > 30° requires more time for correction, but is not more technical difficult. In our work, we noted a significantly lower correction coefficient in patients with derotation above 30° as compared to the group with derotation up to 30°, which may due to the fact that the period of consolidation of the regenerated bone is similar in both groups, but in the group corrected > 30° spreads out over a larger number of degrees. In the group with derotation > 30°, we observed significantly higher elongation index. This may be due to the fact that performing elongation and large derotation in a single stage of treatment cause damage to nutritive circulation of the regenerated bone in excess of its compensatory and regenerative abilities, resulting in a slower formation of the regenerated bone. The size of the correction did not significantly affect the alignment factor, correction factor, and the number of complications. We believe that atraumatic corticotomy, preceded by drilling of the bone, as well as the correct and precise installation of the apparatus, allows for derotation, without simultaneous elongation, in a single step with a high value of the angle thanks to reducing torsional stresses during derotation, and ensuring appropriate conditions for the formation of regenerated bone. Lack of differences in the clinical parameters, excluding the elongation index, in the groups with derotation up to 30° and > 30°, and a lower correction coefficient in the group with derotation > 30°, encourages performing acute treatment of large derotations in the case of planned small distraction. In the case of a planned concurrent large elongation and derotation, derotation of up to 30° is indicated. This is due to the fact that derotation > 30° increases the elongation index, which
extends the time required to maintain the Ilizarov apparatus. In the case of derotation with a large elongation, for a derotation with a large angular range, gradual correction of torsional deformation is recommended. This treatment strategy can reduce the number of stages of treatment, which will reduce the risk of complications associated with any surgery, and should result in a better final result and patient comfort.

4.4. Strategy

Elongation index was the lowest in multi-stage treated patients, it was intermediate in patients treated in a single step, and the highest in the group treated in two stages. This could be due to the fact that in multi-stage treated patients, as a result of large reduction, major distractions were frequently performed. For large elongations, only the period of distraction was increased, while the period of consolidation was similar to the cases with small elongations, which reduced the elongation index.

4.5. Level of derotation

Higher correction coefficient in the case of derotation in the femoral area as compared to patients with lower leg derotation may result from a different distribution of forces acting on the femoral segment. Larger soft tissue forces operate within the femur, which when combined with frequent contracture of the knee joint give a bigger moment of force [32].

4.6. Complications

Velazquez et al. noted an increase in complications in the case of using the apparatus for a longer period of time and comprehensive treatment. He observed no correlation between the emergence of complications and etiology, number of previous surgeries, and elongated segment [33]. Increased incidence of complications is associated with the complexity of the defects [6]. According to Sims and Saleh, risk factors for infections in the area of the implants are age, low tension of the wires, long term maintenance of the apparatus, correction of deformation, and location of the fixator on the femoral segment [34]. In our work, we observed no effect of treatment strategies, as well as of level, type, rate, and size of derotation on the average number of complications.

4.7. Comparison to other techniques

There are the other techniques for derotation: plates, nails, and monolateral and hexapodal external fixators [5–7,35,36]. Derotation with plates is a good method tolerable for patients, not complicated and not expensive [35]. Intramedullary nails derotation is mini-invasive and allows to early rehabilitation [36]. Monolateral external fixators give good stability of bone fragments and are good tolerable for patients [7]. Plates, nails and monolateral external fixators give no chance for very precise and gradual correction. This method does not allow for a derotation with a large angular range. Hexapodal external fixator gave very good precision of derotation, but is expensive and needs computer software [5,6]. Derotation with Ilizarov fixator gives very good precision, allows for a derotation with a large angular range, is not expensive and can be done without computer software.

5. Conclusion

In the case of torsional deformation correction with the Ilizarov method, treatment strategy, type and level of derotation had no remarkable influence on torsional deformities treatment with the Ilizarov method. During treatment of angular deformities of the extremities, including torsional deformation, it is not always possible to obtain full correction. Deformation correction factor, introduced by the authors, facilitates the evaluation and comparison of the results of treatment.

Disclosure of interest

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