
Rehabilitation of Children After Operative Enlargement of Length of Limbs

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Abstract: Patients of different age with stunting one (85) or both extremities (153) discovered that in the remote terms after surgical lengthening of the limbs by Ilizarov increases stride length, but the scale of the change in length of the limbs is limited by the necessity of obtaining the effect of increasing the speed of locomotion defined by the degree of conservation than the maximum moment of muscle strength of the operated limb.

Keywords: Length of the Lower Leg, The Ilizarov Method, The Strength of the Muscles

1. Introduction

Reducing the speed of locomotion in patients with limited abilities of the musculoskeletal system is the most important indicator of the decline in the quality of their life, limiting the involvement in the educational process, labor and social activity [1, 2]. Operative lengthening of lagging limbs in the growth should lead not only to an increase in the longitudinal dimensions of the body, but also the length of the step, and also the walking speed [3].

However, as the limb lengthens, the contractile capacity of their muscles decreases, which can ultimately nullify the achievements of the orthopedist. Therefore, the search for optimal ratios of incrementing the step length and preserving the speed of locomotion is one of the most urgent problems of orthopedics.

In the literature, a large number of studies are devoted to clinical aspects of the method of operative limb elongation according to Ilizarov, while the dynamics of the state of the muscles during distraction, which determines the functional outcomes of treatment, has not been studied sufficiently [4, 5, 6, 7]. The search for permissible limb elongation scales was carried out empirically, by gradually increasing the amount of intervention and increasing, for example, the length of the legs with achondroplasia up to 18 cm [8] with apparent worsening of distant functional outcomes of treatment.

As a result, it was found that the locomotor motor activity

of patients is limited, mainly, by the reduction in the contractility of the leg extensor muscles, which should not decrease by more than 40% of the basal level [9].

2. Material and Methods of Research

For a comparative analysis of the dependence of muscle contractility on the initial longitudinal dimensions of the tibia and their variation in different groups of patients, 225 healthy children aged 6 to 18 years were examined, as well as 85 sick children and adults with a violation of the growth of one of the extremities (leading or behind by 3 -14 cm), as well as 153 patients with achondroplasia 6-30 years before the treatment and in the long term after operatively increasing limb length by Ilizarov in the orthopedic department of the Scientific Center.

Anthropometric studies and determination of the maximum moment of strength of various groups of muscles of the thigh and shin with the help of the dynamometer stands developed by us [10]. A walking distance was determined on a control section 100 m long, as well as with the help of pedometers - the number of steps and the calculation of the step length.

Statistical processing of the results was carried out using variational statistics methods with the definition of the Student's t-test, correlation and regression analyzes. Standard statistical programs used in the Microsoft Excel editor were used. The paper gives the arithmetic mean M, the error of the mean is m.

3. Results of the Study

The strength of the anterior group of hamstrings increased with the age of the examinees (Figure 1). Since the index was significantly influenced by the body weight, we used the value of the maximum moment force, referred to the mass of the body.

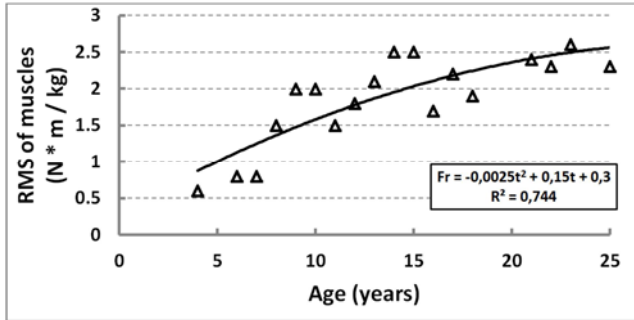


Figure 1. Dependence the moment of strength of the anterior group of hip muscles from age in healthy subjects

In children, the maximum strength of various muscle groups became larger than the extent of natural longitudinal growth and an increase in the length of segments of the limbs. At the same time, in healthy children, for every centimeter of shank length increment, the moment of strength of the muscle-plantar flexor of the foot (PFF) increased by an average of 5.6% ($R^2 = 0.947$), the moment of force of the anterior flexor of the foot by 5.1% ($R^2 = 0.900$).

The linear correlation relationship between the relative strength of muscles and the longitudinal dimensions of the limb was statistically significant only in healthy children, and in patients with a lag in the growth of one of the extremities - on the intact side (Table 1). In adults, there was no statistically significant relationship between the relative strength of muscles (RSM) and the longitudinal dimensions of the shin. Moreover, in the long-term periods after the operative lengthening of the lumbar limbs that lagged behind in the growth of the limb, the muscles proved to be large with a smaller shank length.

Table 1. Correlation coefficients OMS muscle-PFF and shank length ($F=ax+b$).

The investigated limb	Number of observ	Coefficien a	Coefficiensb	Correlation coefficient
Shin in healthy children	225	0.026	-0.258	0.778
Intact limb in sick children	45	0.038	-0.595	0.457
Intact limb in adults	33	0.021	0.193	0.041
Retarded limb in the growth	45	0.011	0.168	0.046
Elongated limb	26	-0.035	2.17	-0.203

In patients with a lag in the longitudinal dimensions of one of the extremities, the dependence of muscle strength on the magnitude of its shortening was revealed. The strength of the muscles decreased with each centimeter of shortening of the affected shin by 4.6% (Figure 2). The reduction in the strength of the muscles of the intact limb depended on the degree of severity of the pathology (lag length lag), but this effect was less pronounced (2.4%).

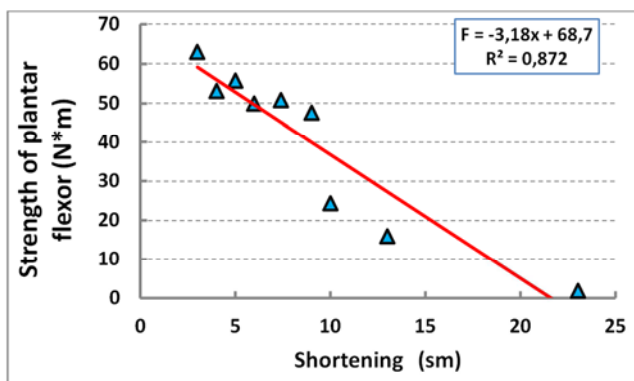


Figure 2. Dependence of the strength of the posterior group of the muscles of the shin of the affected limb on the degree of lagging of the limb segment in longitudinal dimensions.

In the long term after fractures of the shin bones (31 adolescents 13-17 years old) in cases of length loss of up to 5.5 cm or excess length up to 3 cm, the corresponding decrease or increase in muscle strength was 5.6% per 1 cm of

limb size changes.

The rate of change in the dynamometric index of muscles in healthy children depended on the rate of natural longitudinal growth. If the growth rate of the tibia exceeded 2 cm / year, the rate of increase in muscle strength began to decrease (Figure 3). Apparently, at high growth rates, a balanced ratio of growing and functioning elements began to be broken, and the muscle contractility ceased to increase.

During periods of operative elongation of the limb, the tension of the muscles increased, and the amplitude of movements in adjacent joints decreased (Figure 4). Dependence of the decrease in the amplitude of movements on the amount of lengthening of the thigh persisted even during the fixation period.

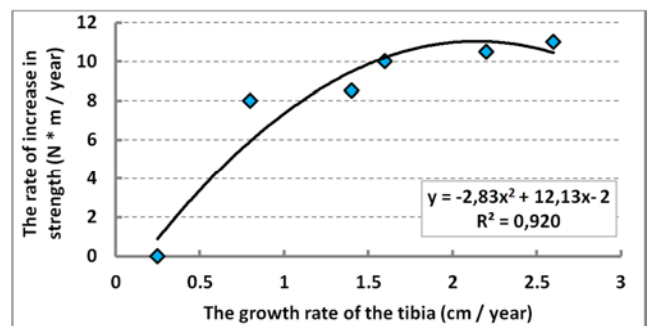


Figure 3. The relationship between the rate of increase in longitudinal dimensions and the strength of the calf muscles.

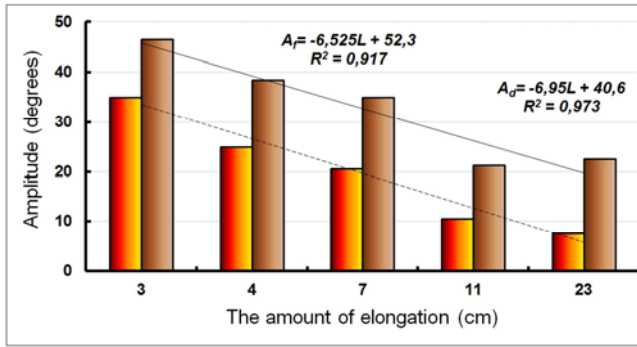


Figure 4. Dependence of the amplitude of movements in the knee joint after the end of periods of distraction and fixation from the amount of lengthening of the thigh.

After the end of the elongation period in children, the initial level of muscle contractility can be achieved by realizing the remaining tissue growth reserves, for example, in patients with achondroplasia, in which the leg length in 10-15 years was 18-20 cm or about 50% of the definitive size

in healthy of people. The more the shin elongated, the less muscle strength in the long-term after the end of treatment (Figure 5). In the long term (more than a year) after the lengthening of the thigh muscles were restored to the level of 66-74% of the level of the intact limb (Table 2).

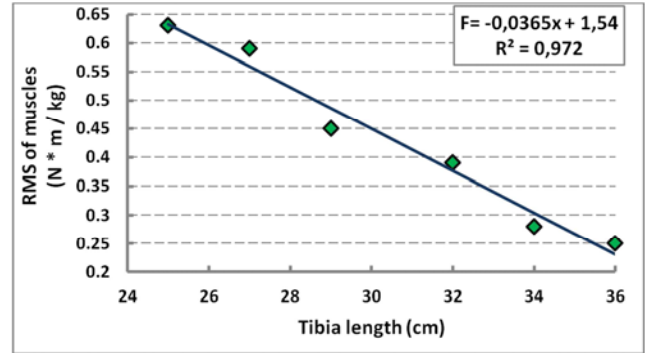


Figure 5. Dependence of the level of recovery of the relative strength of the posterior shank muscle group in patients with achondroplasia from the achieved length of this segment after treatment.

Table 2. The relative moment of strength of different groups of muscles of the thigh (N * m / kg).

A group of subjects	Number of observ.	Thoracic Extractors		Crushers of lower leg	
		Intact	Painful	Intact	Painful
Before treatment	103	1.6 ± 0.08	1.2 ± 0.07 (71%)	1.3 ± 0.06	1.0 ± 0.05 (80%)
The nearest time after treatment	27	1.5 ± 0.16	0.7 ± 0.16 (49%)	1.3 ± 0.12	0.8 ± 0.15 (65%)
Long term after treatment	27	1.6 ± 0.13	1.1 ± 0.10 (66%)	1.4 ± 0.12	1.0 ± 0.09 (74%)

It can be assumed that the reason for the lack of recovery of the muscle strength of the elongated limb is its trauma in osteotomy and distraction. However, when the children were examined after fractures of the limb bones, a complete restoration of the strength of the injured limb was revealed [11, 12].

In patients with orthopedic profile, when the lengthening of one of the limbs, the muscle strength of this limb was reduced. The relative moment of the strength of the anterior and posterior groups of muscles lagging in the growth of the tibia before treatment was 73% and 78% (p0.001),

respectively, of the healthy level, in the long term after treatment 71 and 81% (Table 3).

After the operative equalization of the length of the limbs, complete compensation for the impaired muscle strength was not observed. With an increase in the age of the patients, the level of recovery of the muscle strength of the elongated limb became smaller (Figure 7). Therefore, limb lengthening at an early age (up to 10 years), despite the difficulties associated with patient care, is justified, since natural growth processes and adaptation of tissues to new biomechanical conditions continued after treatment.

Table 3. The relative moment of the strength of the calf muscles (N * m / kg) before and after treatment.

The groups are examined.	Number of observ.	Anterior flexor of foot		Plantar flexor of the foot	
		Intact.	Painful	Intact.	Painful
Before treatment	103	0.70 ± 0.04	0.51 ± 0.04 (73%)	1.41 ± 0.05	1.10 ± 0.07 (78%)
The nearest timeframe	27	0.58 ± 0.05	0.41 ± 0.04 (71%)	1.26 ± 0.09	0.70 ± 0.10 (56%)
Long-term deadlines	27	0.68 ± 0.06	0.48 ± 0.05 (71%)	1.56 ± 0.16	1.26 ± 0.18 (81%)

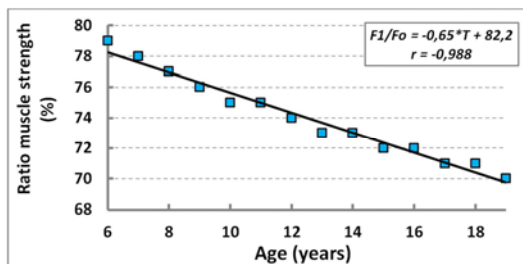


Figure 6. Age-related dynamics of the ratio of the strength of the posterior group of the calf muscles of the elongated and intact limbs at a later time after treatment.

The rate of restoration of joint function (the amplitude of muscle contraction) after elongation of the limb depended on the magnitude of this elongation (Figure 7). The increased rate of recovery is characteristic for patients with limb bone elongation within 10%, the rate of restoration of joint function is calculated mathematically in the absence of lengthening. The obtained curve corresponds to that in patients with the end of bone fracture treatment.

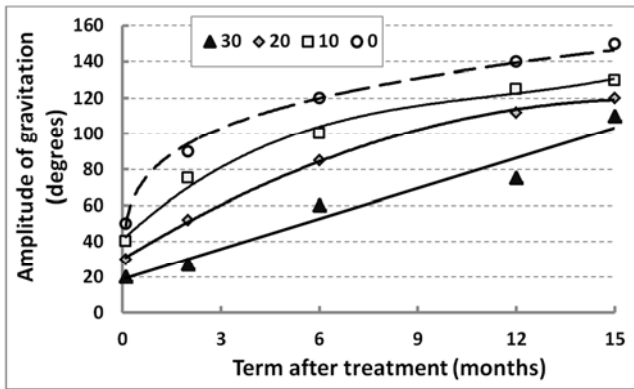


Figure 7. Dynamics of recovery of the amplitude of movements in the knee joint after elongation of the limb by a different amount.

To accelerate the functional rehabilitation of muscles, methods of therapeutic physical training were applied. The effectiveness of kinesiotherapy depended on the magnitude of elongation of the limb and the age of the patient. It is known that sports training is ineffective for building muscle strength in children during a period of rapid longitudinal growth of the body. The reason for the described phenomenon is explained by the fact that cell division is carried out only after suppression of cell-specific functional manifestations and destruction of the corresponding intracellular structures. Growth is based on the translation processes, as a result of which protein synthesis is realized, and differentiation - on the processes of transcription, activation of certain parts of the genome by inductors, as a result of which the cell receives new molecules entering the cytoplasm.

In patients (experimental group), where the procedures of kinesiotherapy were regularly performed, after the limb was extended by 20% of the original longitudinal dimensions, the recovery schedule was much higher than the corresponding curve in the control group (Figure 8). Already 2 months after the end of treatment, the amplitude was approaching 100°. Nevertheless, later, 15 months after the treatment, the difference in joint mobility in the patients of the experimental and control groups was leveled.

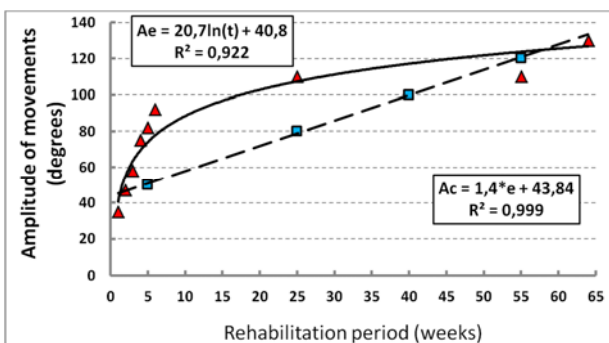


Figure 8. Dynamics of restoration of amplitude of movements in the knee joint in patients of the experimental (Ae) and control (Ac) groups.

Consequently, the use of methods of kinesiotherapy during the treatment of patients in the complex affected mainly the rate of functional rehabilitation of the muscles and joints of

the elongate limb, which is especially important for athletes.

An increase in the reduced contractility of the muscles of the elongated limb is important for restoring locomotion speed. Earlier it was established that for transferring inpatients to an outpatient treatment regimen, the day-to-day path should be at least 2 km [13]. To overcome such a path, the speed of locomotion should increase to 2.5 km / h, and the strength of the anterior muscle group of the thigh will reach 20 N * m (Figure 9). When the muscle strength reaches 30 N * m, the distance traveled exceeds 3 km. The relationship between the speed of locomotion and the strength of the posterior group of the calf muscles was 27% less pronounced.

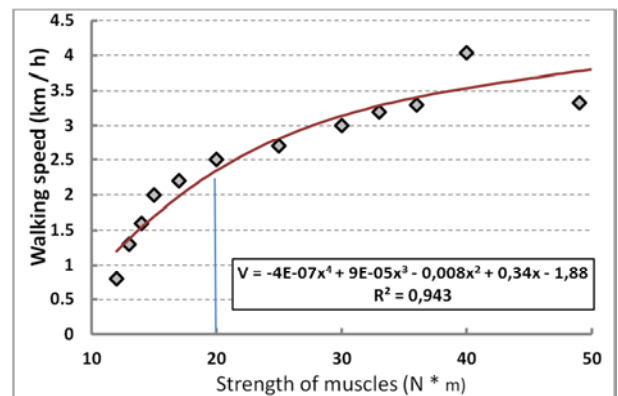


Figure 9. Dependence of the walking speed on a section of 100 m from the maximum strength of the anterior group of hamstrings.

The length of the step in patients with achondroplasia before treatment was on average 47.5 cm. Two years after elongation of the shins, an average of 45%, the step length in patients increased by 24% and reached 59 cm (Figure 10). The characteristic relationship between the length of the step and the length of the lower limbs is normal in the norm: $L = 62.3 * L_n(x) - 203$; $R^2 = 0.880$. In the long term after treatment, the improvement of a number of locomotion parameters was noted in patients: locomotion rate increased by 15%, the average daily locomotor motor activity reached 7.1-1.89 km (51% more than before treatment). This is due to the increase in the length of the limbs and, accordingly, with the increase in the length of the step.

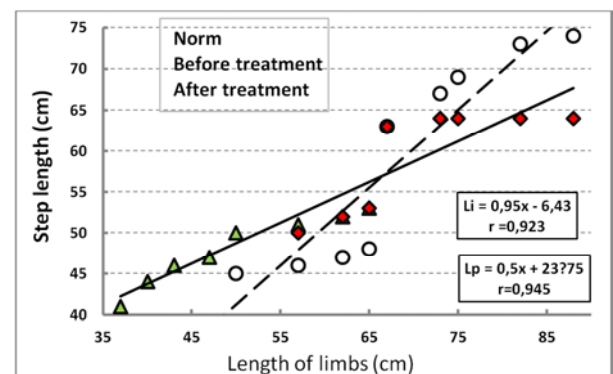


Figure 10. Dependence of the length of the step on the length of the lower extremities in healthy subjects (rings) and in patients with achondroplasia before treatment and after treatment.

Despite the decrease in the strength of the hip muscles within 30%, the dependence of the rate of locomotion on muscle strength in patients was described by the same linear regression equation as in healthy children and in patients before treatment: $V = 3.837 * F^{0.1168}$; $R^2 = 0.556$.

Nevertheless, patients were unable to reach the level of the speed of locomotion of healthy peers after treatment. Moreover, healthy people use walking laws to facilitate vibratory movements of limbs and save energy, the laws of inertia (pendulum), which can not be fully realized by patients [3]. Therefore, after lengthening the extremities, the parameters of locomotor motor activity were almost completely dependent on the level of functional rehabilitation of the hip muscles.

Thus, the main factor limiting the walking speed in patients with reduced limb length is a significant lag in the length of the step. The elimination of this lag does not allow to fully compensate for the deficiency of motor activity, since the lengthening of segments of extremities, unlike natural growth, does not lead to an adequate increase in muscle contractility.

If the orthopedist is compelled to equalize the length when one of the extremities lags behind in growth, then with the shortening of both extremities the physician should plan the optimum elongation. The elongation of segments of limbs found empirically on the basis of many years of clinical experience, for example, in achondroplasia (10 cm hip and 12 cm of tibia), are apparently close to optimal. When elongating to large values, especially the hip, as a rule, the rate of restoring the contractile ability of muscles slows down.

4. Conclusions

1. In healthy children the maximum moment of muscle strength attained depends on the length of the leg. Patients with a gap in size of the limb is accompanied by a decrease in contractile ability of muscles.
2. Increasing the length of the limb in patients after rapid elongation, in contrast to the increase in size through natural growth, does not lead to an increase and to a decrease in muscle strength, the level of which is not recovered in the remote terms after treatment.
3. In healthy children the maximum moment of muscle strength attained depends on the length of the leg. Patients with a gap in size of the limb is accompanied by a decrease in contractile ability of muscles.
4. Increasing the length of the limb in patients after rapid elongation, in contrast to the increase in size through natural growth, does not lead to an increase and to a decrease in muscle strength, the level of which is not recovered in the remote terms after treatment.

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