ISSN 0362-1197, Human Physiology, 2015, Vol. 41, No. 1, pp. 83–88. © Pleiades Publishing, Inc., 2015.
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Restoration of the Contractile Capacity of the Tibial Muscles after Closed Malleolar Fractures

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Received August 15, 2013

Abstract—According to published reports, an incomplete restoration of the muscular strength is observed after malleolar fractures. This made us evaluate the contractile capacity of the tibial muscles after treatment of 59 adult patients with malleolar fractures using Ilizarov's method. In addition, five patients underwent comprehensive follow-up examinations long after fracture treatment. We found that a practically complete restoration of the anatomical size, electrogenesis, and contractile property of the tibial muscles was possible in the interval from five to eight years after treatment. This can be explained by a precise repositioning and reliable fixation of the bone fragments during treatment and an increase in the sensitivity of the neuromotor responses to specific impacts during muscle adaptation to function under conditions of habitual motor activity.

Keywords: muscular strength, bone fracture, rehabilitation

DOI: 10.1134/S0362119714050132

According to the literature, malleolar fractures, the most common among the various bone and skeleton injuries, are observed in 22–32% of the cases [1]. After the treatment of malleolar fractures, which consist in limb immobilization, atrophy of the tibial muscles is as high as 25%, and the maximum decrease in muscle strength, 75% [2]. Even in the cases when a complete range of motion is restored in the ankle joint, patients often complain of pain when walking, a sense of fatigue in the limb, and insufficient muscle strength [3, 4]. In adolescents, muscle strength recovery reaches 85% of the conditional baseline (indicators for intact limb) 1.5 years after the end of the treatment of malleolar fracture, [5].

In patients older than 40–45 years, a special rehabilitation training program has turned out to be ineffective and fails to promote a substantial function recovery, as judged by the stabilographic test [6, 7].

Incomplete structural and functional recovery of the skeletal muscles after damage to the bones in the ankle joint,is attributed to many factors, in particular, a disruption in the trophic support of the muscle, development of posttraumatic microvascular pathologies, defects in re-innervation of muscle fibers [8], as well as damage to the capsular ligaments, offset of the foot, and long periods of ankle joint fixation.

Two stages in muscle rehabilitation can be distinguished based on electromyographic examinations of fractures: an intense recovery phase (a period from 7 days to 2 months after surgery) and a phase of moderate changes (a period from 3 months to 1 year) [9]. Another step can be identified that is attributed to reductive neuromiogenesis, when, during the period of further functional rehabilitation, patients experience a temporary decrease in contractile ability, in particular, in the weaker frontal group of tibial muscles. The mechanism of this decrease is not entirely clear. The assumption on its association with muscle injury during increase in the range of joint motion [10] is doubtful.

In contrast to adult patients, in children, treatment by Ilizarov's method (which includes an accurate repositioning and reliable fixation of bone fragments and restoration of muscle function as early as the period of medical rehabilitation) after removal of the external fixator results in acceleration of the natural longitudinal growth of the limbs and, in most cases, a complete recovery of muscle contractility in the damaged segment [11]. In the first year after injury, a rapid recovery of muscle strength reaches up to 80–90% of the conditional baseline. However, this level is not maintained. In the next 2–3 years, a decline is observed due to the effect of cupping of posttraumatic compensatory muscle hypertrophy [12]. In the long term, the maximum strength of the tibial muscles approaches the level of performance in the intact limb. The possibility of complete recovery of muscle strength in the injured extremity is not only of theoretical interest, but has an undoubted practical value, e.g., for professional athletes of all ages.

The purpose of this study was to assess the possibility of complete recovery of the contractile capacity of the tibial muscles after a closed fracture of the distal end of the malleolar bones during the treatment of mature patients with the use of Ilizarov's method.

METHODS

We examined two groups of patients. The first group comprised 59 patients (33 women and 26 men) aged 17 to 58 years (average age, 39 ± 0.9 years) with closed malleolar fractures undergoing treatment by Ilizarov's method with the apparatus of the outer trans-osseous fixation. Malleolar fractures were classified according to Muller's system as type A (24 patients), type B (16 patients) and type C (19 patients). All patients were examined at various stages of fixation of bone fragments and short and long periods after treatment. Complications and comorbidities to the major injury were absent in all patients, which allowed them to lead an active life starting from the first days of treatment at the institute clinic (self-service; walking with a gradual increase in functional load to the injured limb, which rates are determined, in particular, by the patients' age). Distribution of the functional load among the intact and damaged limbs was assessed in all patients for 5 min in a standing position by Nikolaev's method using floor scales [13].

Maximum strength of the anterior (anterior flexors of the foot) and posterior leg muscle groups (plantar flexors of the foot) was determined using Schurov's dynamometer [14] in the isometric measurement mode with a constant length (25 cm) of the lever from the platform axis of rotation to the lock of the reverse dynamometer.

The second study group consisted of five former patients (men aged 27 to 56 years) that were administered a comprehensive re-examination after at least 5 years after completing the treatment. Muscle strength was determined in both limbs upon variation in the setting of the foot in the ankle joint at 5 degree steps, from 75 to 115 degrees. These patients were subject to electromyographic (EMG) examination of the leg muscles using a Viking-4 digital EMG system (Nicolet, United States). The amplitude of the muscle motor responses was analyzed at the supramaximal stimulus intensity, duration 1 ms.

Patients in this group were examined for the maximum diameter of the anatomic midsection area of the gastrocnemius and tibialis anterior muscles in the damaged and intact limbs and the diameter of the lumen of the popliteal artery using the Magnetom Sumphony magnetic resonance imaging instrument (Simens, Germany).

The obtained data was processed using correlation and regression analyses. Student's *t* test was used to determine the significance of differences between the groups in the cases with normal distribution of the parameters tested.

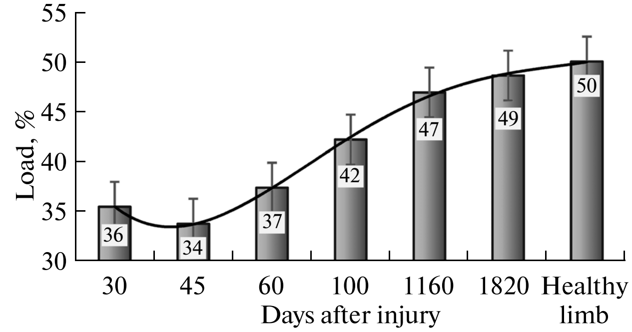

Fig. 1. Dynamics of static functional load on the injured limb (percent of body weight) during the first 2 months after injury and different intervals after completion of treatment.

RESULTS

Determination of static foot support function in a standing position was carried out in patients in the first group with malleolar injury under conditions of fixation of bone fragments using Ilizarov's apparatus. The measured indicators for static foot support function were substantially reduced. Their values were closer to normal ones (50% of body weight) only after extended time subsequent to fixation period (Fig. 1). The maximal strength of the injured tibial muscles during the treatment process ranged from 17 to 27% of the indicators for the intact limb. The greater the severity of the initial injury, the lower the relative muscle strength was (Fig. 2). The rates were particularly low in men with two damaged ankles and during injuries to the posterior edge of the malleolar bone (type C).

The indicator for muscle contractility for the injured limb was restored after the fixation period (Table 1). A long period after treatment, the strength of the anterior group of the tibial muscles reached 86% of the conditional baseline, while the strength of the posterior muscle group reached a 100% recovery.

Five years after injury, the maximum strength of the posterior group of muscles in the affected limb was higher than in the intact one, especially in men (Fig. 3).

Patients in the second group were subject to a comprehensive follow up examination long period after the end of fracture treatment. In these tests, we found that the average strength of the posterior muscle group in intact limb was 143 ± 16 N m compared to 159 ± 17 N m in the injured limb. Thus, the indicators of muscle strength in the previously injured ankle were 11% higher compared to the intact limb. Although this difference was not statistically significant in our study groups, it indicates that formal equality between the muscle performances in bilateral extremities is not determined by random individual differences. In this group of men, re-examined a long period after treatment, we observed individual differences in measurements of midsection area of the tibial muscles and

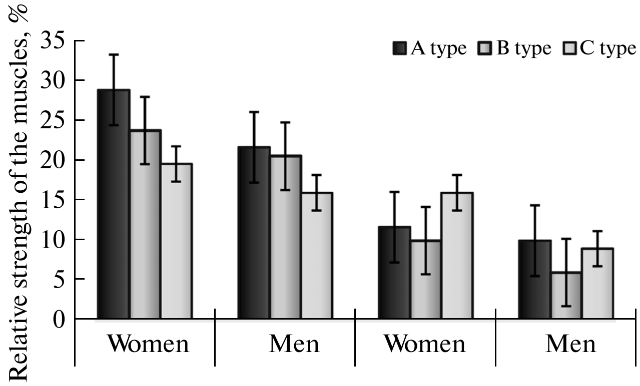

Fig. 2. Relative strength of the posterior group of tibial muscles in men and women with malleolar injuries of different severities (A, B, and C).

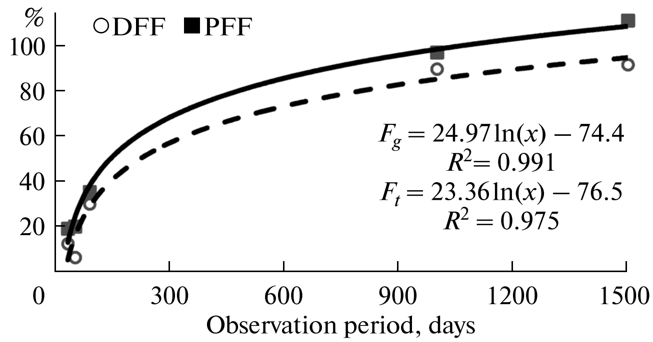

Fig. 3. Relative level (percent) of recovery of muscle strength in the dorsal foot flexor (DFF) and plantar foot flexor (PFF) in male patients.

lumen of the popliteal artery in the injured and intact limb. However, the differences in the average values were not statistically significant and did not exceed 4% (Table 2).

It is known that muscle strength is correlated with the body mass and the cross-section area at muscle midsection. In our studies, the moment of force of the leg muscles showed a logarithmic rather than linear dependence on the diameter of anatomic midsection area of the muscle (Fig. 4).

In the same second group of patients, we found a direct correlation between the values of the moment of force in the tibial muscles (F, N m) and the amplitude of the M response: $A_{\mathrm{M}} = 0.177F - 2.9$; $r = 0.806$. The maximum deviation of the individual M responses for the muscles of the injured limb ranged from 52 to 124% of the performance level in the intact limb. In general, the averaged values of indicators for the muscles in the injured limb did not differ significantly from the values for muscles in the intact limb (Table 3).

We examined the dynamics of changes in the maximum torque strength of tibial muscles upon variation in their length, determined by the differences in the angle of foot installation at the ankle joint from 115 to 75 degrees. We found that values for strength indicators for the anterior group of the injured tibial muscles reached the levels of the intact limb only in a narrow range of longitudinal dimensions of the muscle body, corresponding to the habitual installation of the foot at an angle of 100 degrees (Blix maximum, Fig. 5).

In contrast, the average values of muscle strength of the posterior group of muscles in the injured shin a long period after treatment were always higher than indicators for the respective muscles in intact limb at any initial foot setting angle (Fig. 6).

Table 1. Relative torque of tibial muscles in patients at different periods of treatment (N m)

Survey period	Number of observations	Anterior muscle group		Posterior muscle group	
		intact limb	injured limb	intact limb	injured limb
		Women			
22–44 days of fixation	13	42.2 ± 2.0	5.4 ± 1.4*	77.5 ± 6.1	19.9 ± 3.8*
45–60 days of fixation	25	44.0 ± 1.3	5.8 ± 0.9*	75.2 ± 3.3	18.2 ± 1.8*
1–60 days after treatment	23	44.7 ± 1.6	13.0 ± 2.4*	86.8 ± 3.9	37.1 ± 6.6*
1–3 years after treatment	6	47.1 ± 3.4	39.2 ± 1.8	109.8 ± 12.1	99.8 ± 12.0
4–5 years after treatment	6	44.6 ± 2.8	33.4 ± 3.4	81.9 ± 6.0	83.1 ± 5.8
		Men			
22–44 days of fixation	10	64.0 ± 2.3	7.9 ± 2.1*	125.6 ± 8.8	23.8 ± 3.8*
45–60 days of fixation	12	62.5 ± 3.4	3.9 ± 1.2*	121.7 ± 9.8	24.2 ± 5.2*
1–60 days after treatment	17	64.6 ± 2.3	19.2 ± 4.0*	117.3 ± 8.9	41.2 ± 7.8*
1–3 years after treatment	6	69.0 ± 6.0	61.6 ± 11.0	151.5 ± 13.1	146.4 ± 18.9
4–5 years after treatment	6	62.4 ± 5.9	56.9 ± 6.6	119.6 ± 10.2	132.4 ± 7.8

* Difference from the intact limb is significant ($p < 0.05$).

Table 2. Midsection area of the tibial muscles and diameter of the popliteal artery

Patient	Midsection area of the anterior tibialis muscle, cm^2		Midsection area of the gastrocnemius muscle, cm^2		Diameter of the popliteal artery, cm	
	intact	injured	intact	injured	intact	injured
K–ikh	8.34	9.77	56.39	59.86	0.69	0.80
M–in	7.58	8.88	50.20	51.82	0.72	0.71
K–ev	9.93	10.01	47.4	47.39	0.64	0.66
G–ikh	7.00	6.08	42.22	40.95	0.60	0.56
A–ov	5.44	5.18	40.64	29.93	0.80	0.66
Average	7.66 ± 0.74	7.98 ± 0.98	47.4 ± 2.83	5.99 ± 5.05	0.69 ± 0.03	0.68 ± 0.04

Table 3. Amplitude parameters of evoked bioelectrical activity of muscles

Patient	Anterior tibialis muscle, mV			Gastrocnemius muscle, mV		
	intact	injured	difference, %	intact	injured	difference, %
K–ikh	6.02	7.04	117	15.79	14.22	90
M–in	6.52	6.72	103	27.85	33.33	120
K–ev	6.73	6.38	95	29.45	36.56	124
G–ikh	6.94	7.77	112	27.02	14.05	52
A–ov	7.58	6.47	85	30.79	29.62	96
Average	6.76 ± 0.26	6.88 ± 0.25	102 ± 6	26.18 ± 2.68	25.56 ± 4.79	96 ± 13

DISCUSSION

In recent years, due to the implementation of new principles of health care intensification, in particular, an increase in "bed turnover" by reducing the period of hospital stay, the procedures of bone replacement with metal prostheses, implants, and internal fixation have been increasingly widely used. In contrast, Ilizarov's method is based on conservation and recovery of the limb's own structures, including bones and muscles. However, the use of this method requires a lengthy term of stationary treatment at a hospital or a recovery center. In this study, we provide evidence that a lengthy in-hospital stay is thoroughly justified for this treatment because it can ensure a complete recovery of the contractile ability of the muscles in adult patients, even without a special muscle training regimen.

We suggest that rapid recovery of the muscle strength in the injured ankle to the level of intact limb in the first year after treatment is not only the result of cross-impact exercises for the muscles of intact limb [15], but is also due to development of post-injury muscle hypertrophy. Hypertrophy develops under the influence of a lower muscle sensitivity threshold to the

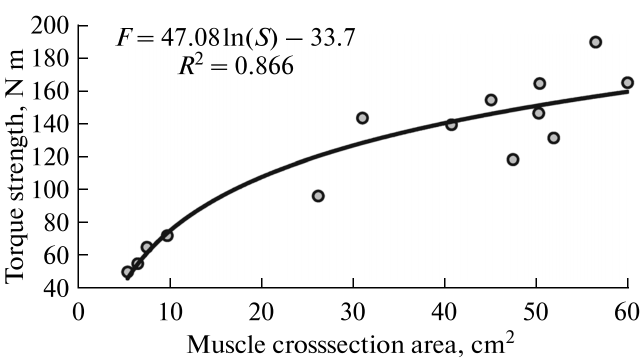

Fig. 4. Correlation between the muscle midsection area and the maximum torque strength in tibial muscles.

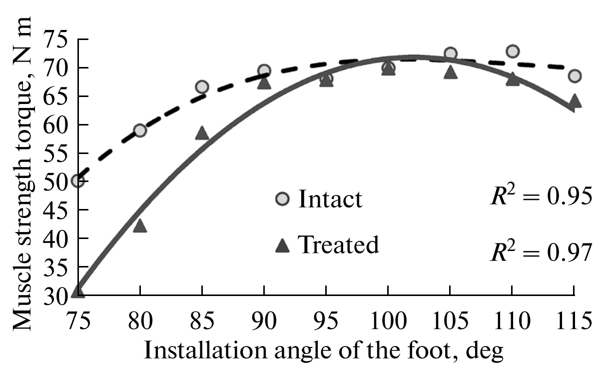

Fig. 5. Dependence of the strength of the anterior group of injured (triangles) and intact (circles) tibial muscles from the installation angle of the foot in the ankle joint.

somatic-vegetative signals during functional loading of the recovering limb [12]. The effect of changes in the sensitivity threshold towards reflex responses is well known, e.g., in sports physiology, where athletes are required to take breaks in the training process.

Earlier, Kolcheva et al. [11, 12] examined the long-term dynamics of strength recovery in tibial muscles in 153 persons 13–17 years after treatment of closed malleolar fractures. It turned out that, as early as the first year after treatment, the levels of muscle strength in the injured limb approached the values in the intact limb, but subsequently decreased by 20% and increased again only 5–8 years after treatment. A long period after treatment, muscle strength of the injured ankle was higher than baseline in female patients with relatively minor injuries (fracture of one large malleolar bone) when the duration of fixation of the shin bones did not exceed 30–45 days [16]. The authors also reported a phenomenon of compensatory increase in the muscle strength of the muscles of the intact tibia, when strength of the injured limb remained lower than 50% of the conditional baseline.

We found that the strength of the anterior group of tibial muscles reached standard levels when installation of the foot corresponded to the length of the resting muscle. This is important for coordination of movement due to the provision for existence of an interval of optimal power loads, when a voluntary regulation of muscle contraction is carried out with maximum accuracy and minimum consumption of specific energy [17]. Consequently, after injury at alternate foot positions, subsequent coordination of motion can be diminished.

This study was carried out as a survey in adult patients. We presume that malleolar fractures cannot be more traumatic to the tibial muscles than malleolar injury at the level of muscle midsection. The reasons for the poorer treatment results observed by other authors can be explained by biomechanical factors, in particular, the fact that muscles can absorb most of the energy during bone fracture. In fact, during injuries at the distal end of the tibia, it is the relatively smaller length of the distal bone fragment that leads to a greater displacement force in the fracture seam during dorsal and plantar flexions of the foot. Our study revealed that even despite the precise repositioning of the bone fragments with the aid of Ilizarov's apparatus, during the period of boundary resorption of the bone, the rigidity of fixation is slightly decreases. During this period, the indicator of the functional load on the limb was reduced (see Fig. 1).

A long period after injury, the strength of the posterior tibial muscles of the injured ankle reached the levels of muscle strength the intact limb or surpassed it. However, this prevalence in the strength indicator was not observed in all cases, and it was not statistically significant. What is of critical importance is that it was shown previously that, in healthy children, during the process of natural growth, an increase of 1 cm in the length of the tibia leads to a 2.4% increase muscle strength, whereas post-traumatic compensatory acceleration of the longitudinal tibia growth by the same value results in a 5.5% increase in muscle strength [18]. In adult patients, this mechanism for increasing muscle size due to a natural growth of contractile elements is not observed. Nevertheless, magnetic resonance imaging of the tibia confirmed a possibility for a post-traumatic muscle hypertrophy and an increase in their cross-section area at the site of injury.

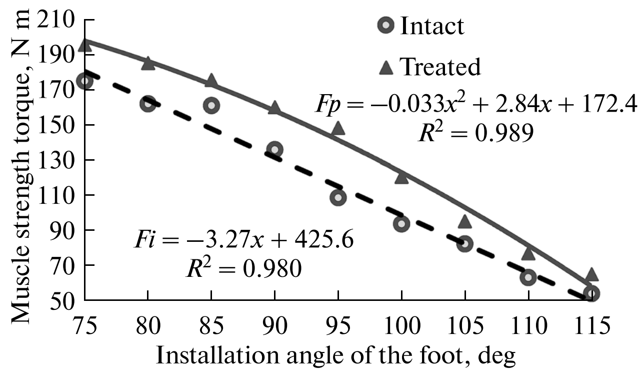

Fig. 6. Dynamics of average strength indicators of the posterior group of tibial muscles at different installations of the foot at the ankle joint.

Thus, precise repositioning and reliable fixation of tibia bone fragments during the treatment of patients by Ilizarov's method is of great importance for ensuring the level of functional rehabilitation of the tibial muscles. With this method, it is possible to obtain a complete recovery of contractile ability of the tibial muscles, in the long-term, after treatment of malleolar fracture in mature patients. The final mass of the recovered muscle and its bioelectrical activity and strength may approach or exceed the baseline. During equal participation of both limbs in the locomotor act, the compensatory increase in the functional parameters of the muscles of the injured limb is attributed to the greater sensitivity of executive structures in the recovering limb to the somato-autonomic reflex responses.

CONCLUSIONS

(1) Treatment of patients with malleolar fractures by Ilizarov's method, which includes a precise repositioning and reliable fixation of bone fragments, makes it possible to maintain the contractile capacities of the muscles and exercise a functional load on the injured limb in the process of medical rehabilitation.

(2) Assessment of long-term effects in the posterior group of tibial muscles after treatment of adult patients did not reveal any atrophy of tibial muscles or reduced muscle contractility or electrogenesis indicators.

(3) Assessment of long-term effects in the anterior group of tibial muscles in adult patients showed that the maximum torque is fully recovered only in a limited range of angles of the original installation of the foot.

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Translated by I. Grishina