AUTOMATIC TWENTY-FOUR-HOUR EXTREMITY LENTHENING

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According to the findings given by the experts of the World Health Organization (WHO) committee the number of congenital anomalies of skeleton growth in children doubled within the last quarter of the 20-th century and at the present moment there is a serious social problem concerning health of children's population. In Russia, for instance, the number of patients with musculoskeletal system abnormalities increased by 53%, the number of children with congenital anomalies – by 41,8% since 1966.

There is an evident tendency of increasing the number of patients in the group "Congenital anomalies" in Russia according to the recent findings. In 1993 the number of cases of congenital anomalies in children and teenagers, among which musculoskeletal system malformations made up 40-50%, was 17,4 out of 1000 people of the given age, in 1998 – 28, 2 ("The official report of health level of the Russian Federation population in 1998" the Russian Health Ministry, RAMS, 1999).

Constant increase of number of congenital anomalies of human musculoskeletal system formation and systemic disease put forward the problem of extremities lengthening, patients' stature recovery as an important medico-social task.

In spite of nearly three-centuries-old history of study the problem of congenital limb malformations treatment is still difficult to solve. The Russian Scientific Centre's "VTO" worked out approaches to treat congenital diseases in musculoskeletal system, are characterized by practical trend to eliminate anatomic symptom complex (restoration of the structure of a bone, its length and form, elimination of segment deformity, restoration of biomechanical chain of a limb), patient's functional and social rehabilitation. Instead of traumatic and occasionally even crippling methods of operative treatment there appeared physiologically well-grounded functional ways which do not disturb blood supply of a limb and use certain predetermined reserves of physiological adaptation to new growth and development conditions.

Analysis of published works devoted to the problem of extremities lengthening showed that methods of gradual and dosed distraction by devices of external fixation are spread these days. The most popular are apparatus created by Ilizarov, Wagner and Orthofix. Orthopedists reckon that the advantage of transosseous distractive osteosynthesis method by Ilizarov is in a complex of optimal conditions that provide good treatment of a patient: stable osteosynthesis,

low traumatic operative intervention, optimal tempo of distraction, functional load on a limb (Ilizarov G. A. , 1963; 1982; Fedotova R. G., 1971, 1972; Trohova V. G., 1972, Kalyakina V. I. , 1979; Popkov A. V., 1994, 1995, 1, Shevtsov V. I., 1996, Shevtsov V. I. , Popkov A. V., 1998; Rybka et al, 1989; Grill F., 1990; Fontanazza C. et al, 1991; Pouliquen J. C., 1993;1994; Wall A. et al, 1994; Catagni M. A., et al, 1994).

When defining advantages of this or that method of extremity lengthening the authors compare periods of osteosynthesis at a rate of 1 centimeter of lengthening, periods of functional rehabilitation, number of possible complications.

Average periods of osteosynthesis of a femoral bone are the shortest if Ilizarov's method is used - 30-35 days by 1 centimeter of lengthening (Kalyakina V. I., 1979; Archipov G. K., Karagodina A. D., 1987;Trohova V. G., 1988; Popkov A. V., 1992; Rybka et al, Grill F., 1990; Caton J., 1991)

The Ilizarov's method advantage is still strong both from the point of view of the least number and severity of current complications (Tchipizov A. A., 1989; Shevchenko S. D., 1990; Popkov A. V., 1991; Rigault D. et al, 1980; Wagner H., 1980; Chandler D. et al, 1988; Pouliquen J. C. et al, 1989, 1991; Caton J., 1991; Snela S. et al, 1994)

The analysis of works of the last 10 years showed that the Ilizarov Russian scientific centre "Restorative traumatology and orthopedics" is mostly experienced in extremities lengthening (over 5000 different segments). There are plenty of ways of distractive osteosynthesis developed in the Centre's clinic. The orthopedists paid special attention to the possibility of osteosynthesis automation with the help of a special device which allows to maintain twenty-four-hour distraction according to the given program and to create conditions close to the evolutionally developed process of tissue growth.

Attempts to automatize a lengthening process which used to be made by means of extraosseous and intraoseous devices and external fixation devices (Ilizarov G. A., Predein A. P., Bykov B. M., 1981; Witt A. N. et al., 1977) have not been widely adopted in clinic.

Our Centre has accumulated greatest experience in autodistractors designing and their clinical use. Thorough biomechanical studies of osteosynthesis stability allowed to create in the last few years a number of new and more effective devices of external fixation with the use of new materials (carboplastic ring-shaped supports and rods), new nodes of fixation and nodes of transfer. The problem of controlled osteosynthesis is solved by appearance of new distracters with autonomic control program for each transfer node.

We have accumulated experience in monosegmental (femur, shin, shoulder and forearm) lengthening in automatic mode in 139 patients and polysegmental (simultaneous) femur and shin lengthening in 32 patients. (Fig.1).

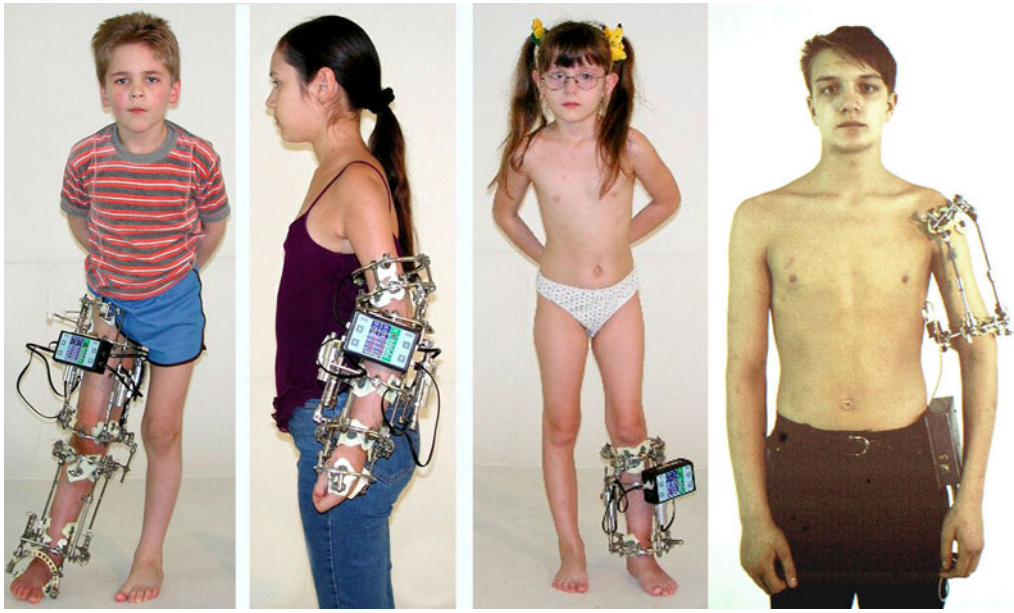


Fig. 1. Examples of lengthening of different limb segments by autodistracters.

In this case distraction was carried out uninterruptedly with the rhythm at 1 mm per day within 60 working cycles of an autodistracter. Patients were aged from 5 till 43 years old. 88 patients had congenital shortening, 83 had acquired shortening as the result of traumas, infectious bone affection, residual effects of poliomyelitis.

In monosegmental osteosynthesis a bone was lengthened by 3-16 centimeters (6,1 ± 2,0 on the average). Lower extremity is anatomically lengthened on the average by 7,2 ± 1,5 centimeters in case of polysegmental distractive osteosynthesis.

The new device of external fixation is characterized by more stable osteosynthesis (it uses new technology of pin and rod-screw construction) and provides patients with better biomechanical conditions (Fig.2).

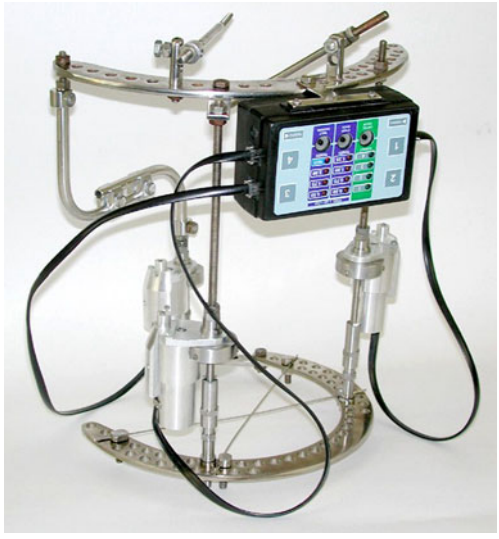


Fig. 2. Pin-rod device used for femoral bone stretching with autonomic automatic control of each transfer node.

Methods of surgical intervention are characterized by low traumatism. 0,3 – 0,5 cm skin incision allows to carry out partial corticotomy of a bone retaining the integrity of marrow, intraosseous vessels and periosteal blood supply of a bone. Lengthening starts 3-5 days after an operation and goes automatically and ininterruptedly. Tempo of distraction depends on methods of lengthening (monolocal and polylocal osteosynthesis) and intensity of regenerative process. Distraction tempo is kept at a rate of 0,5-2,0 mm per day according to the aim of the operation.

The patients endured automatic high-lithotripic round the clock mode of extremity lengthening much easier (with no pain) than generally excepted method of stretching with the use of Ilizarov's device (distraction tempo reaches 1.0 mm daily within 8-10 hours during 4 procedures of intaking by 0,25 mm each).

We practically did not observe any soft tissue inflammation in dorsal region, there were no any stretched extremity edemas or any impairment of sensibility. All that let patients become more physically active, increase functional load which without doubt resulted in effective reparative tissue regeneration. Lengthening as it had been planned was well fulfilled in all the patients.

Roentgenoradiological studies helped to determine that in case of osteoformation intensity automatic distraction is more preferable. Even on the 10-th day after the distraction the first signs of the osseous regenerate were observed in the form of a slight shadow; filling in the diastasis between the bone fragments. The usual distraction was followed by the same signs but with two weeks' retardation. With further lengthening a stable osseous regenerate was formed with even density and with no signs of so called "growth zone" that proves the presence of high reparative bone activity. Optic density of the bone regenerate (40-50% out of a lengthened segment shaft) is preserved within the whole period of distraction and reaches 90-100% 0,5-1,5 months after the fixation and with the usual distraction mode optic density of bone regenerate reached 70-80% only 3-4 months after the fixation.

Calculation of distractive forces fulfilled by this device showed that the forces increase smoothly and steadily with no failures, reaching maximum digits 500-600n by the end of the distraction period (fig. 3). Optimal regenerative process is determined by such dynamics of distractive forces.

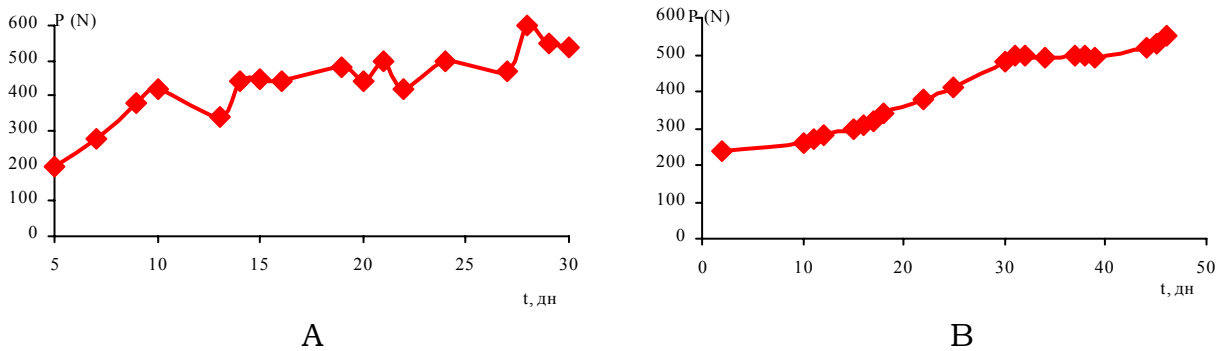


Fig. 3. Dynamics of distractive forces; a – classic mode of distraction (1mm in 4 procedures); b – automatic distraction (1mm in 60 procedures).

One of the most important tasks that a physician has to come across with is a decrease of osteosynthesis duration and functional rehabilitation. Optimal tempo and rhythm of distraction which are basic principles of distractive osteosynthesis let us solve this problem.

Duration of extremity fixation period by the apparatus was calculated per one centimeter of stretching. (FI – fixation index). With automatic extremity lengthening FI decreased to 5-6 days in femur stretching and to 9-12 days in shin stretching.

The study of the quantitative mineral substance content with the help of dichromatic bone densitometer produced by "Norland" company (the USA) showed that distractive regenerate contained more mineral substances with automatic distraction than the usual one (Table 1).

Table 1

The content of mineral substances in distractive regenerate with femur lengthening (gr/cm^2)

Therapy period	Distraction mode	
	automatic	generally accepted
End of distraction period	0.296±0.053	0.280±0.027
End of fixation period	0.570±0.037	0.550±0.039
When device removed	1.203±0.066	1.196±0.043

It is known that bone tissue regeneration is a systemic process regulated by endocrine glands. Comparative dynamics of changes in somatotropin rate reveals peculiarities of organic matrix formation with automatic distraction.

Intensity of osseous metabolism with lengthening, which is revealed through resorption and matrix neoplasm, clearly effects blood enzymes activity of alkine phosphatase (Al P) and acid phosphatase (Ac P).

Table 2

Alkaline and acid phosphatase activity in serum with shin lengthening in automatic mode.

Periods of study	Al P mmol/l	Ac P mmol/l
Control	1.56±0.12	0.15±0.01
Preoperative	1.67±0.11	0.19±0.02
Postoperative	2.67±0.42*	0.22±0.01
10 day distraction	6.68±0.40*	1.20±0.09*
30 day distraction	7.05±0.45*	1.20±0.12*

60 day distraction	6.60±0.57*	1.80±0.12*
90 day distraction	6.60±0.57*	1.50±0.12*
30 day fixation	5.62±0.41v	1.40±0.11*
60 day fixation	5.80±0.56*	1.40±0.10*
90 day fixation	4.40±0.34	1.40-0.10*
No apparatus	4.12±0.24	1.20±0.11*

* - data different from the control are trustworthy

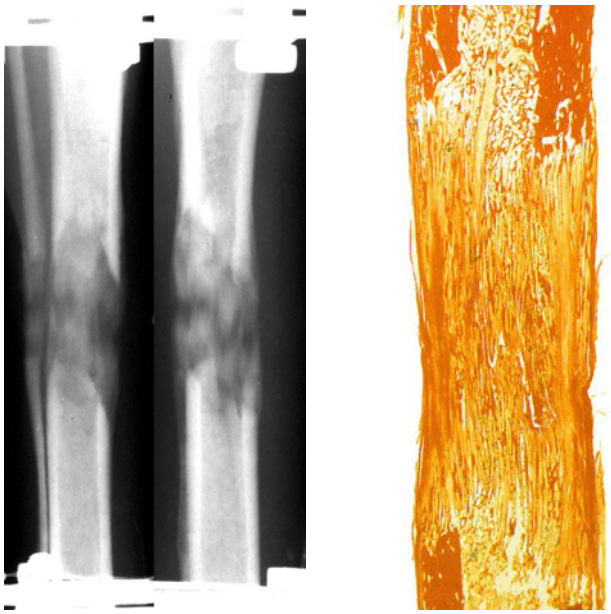
As it is seen in Table 2 Al P as a generally accepted marker of osteoblasts is especially active during the first month of distraction. In later periods its level is stabilized (6.6±0.5mmol/l) and it gradually decreases since the beginning of the fixation period. The process of the bone tissue resorption depends on the functional condition of osteoclasts. The latters contain lyzosomal enzymes , acid phosphatase in particular (Ac P). The utmost Ac P activity is observed on the 60th day of distraction (1,80 mmol/l) when osteocerebral channel starts being formed in peripheral areas of the regenerate.

For morphological study of the regenerative process peculiarities the automatic shin lengthening was carried out in 20 mongrel dogs after close flexible osteoclasia. Daily tempo of distraction mode made up 1mm (sixty-fold fractivity with simultaneous transfer of fragments by 0,017 mm as in clinic). The distraction period lasted for 4 weeks with the subsequent fixation of a shin with the help of Ilizarov's apparatus up to the continuous cortical plate forming. 14 days after the distraction the regenerate "growth zone" consisted of immature connective tissue richly capillarized with great number of low differentiated cellular elements. Certain chains of free red cells were found among thin bundles of collagenic fibers. On both sides of the connective tissue inlayer an intensive process of osteogenesis took place.

In some regions ends of growing trabecules joined and formed a bone bridge 1,5-3 mm broad. Owing to the evident periosteal osteogenesis the width of the regenerate was either equal to or exceeded the width of the adjacent ends of fragments.

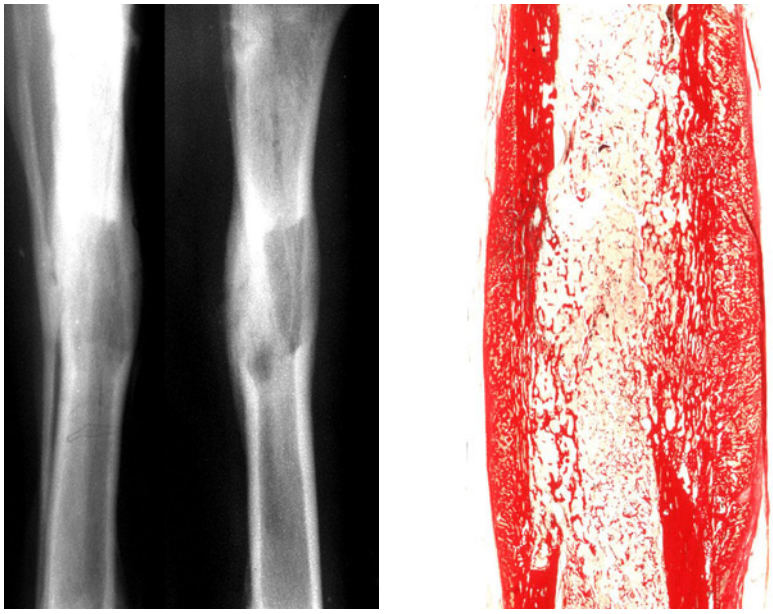
On the 28th day of the distraction, osseous sections of the regenerate became wider up to 10-15 mm and maintained longitudinal lined structure. The middle zone of the clear space was not well distinguished as it was covered with a thick network of trabecular shadows of considerable length; all that indicated adhesion of new tissular epical sections. The cross section of the regenerate as a rule was bigger than that of fragments by 1-3 mm. The histologic study showed that diastasis is filled with spongy osseous tissue (fig. 4). Inconsiderable zones of the connective tissue (0.6×6.5 mm; 10×13 mm) were preserved in intermediary space. Trabecules had a prolonged form in the zone of the regenerate sections closure; active osteoblasts were found on the surface of trabecules. The process of osteogenesis resorption of bone trabecules took place in the roots of the regenerate which coincided with clear spaces on roentgenograms.

The distraction being completed, 15 days later, the regenerate lost its zonal structure. There appeared a continuous cortical plate along the regenerate periphery on two or three sides. This device was taken off of one of the dogs and that did not affect any further bone remodeling. Adhesion took place in 4 dogs right in the period of distraction (on 14-21st day).



a b

Fig.4. Roentgenogram (a) and histopogram (b) of the regenerate after 28 days' of the automatic shin lengthening in the experiment



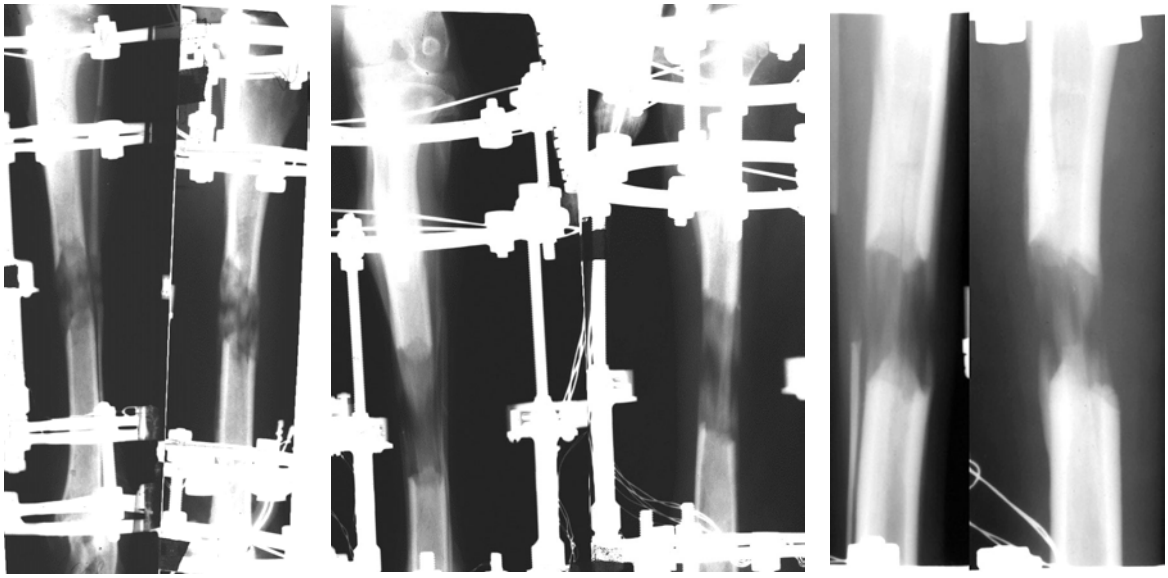
a b

Fig.5. Roentgenogram (a) and histopogram (b) of the regenerate after 30 days' fixation

For 30-35 days since fixation took place (Fig. 5) new formed shaft section acquired homogenic structure and cross section was observed only in its centre. Osteocerebral cavity was observed in the new formed sections adhesive to fragments. The device was removed off all the animals as soon as the whole cortical plate getting spread in several directions had been formed

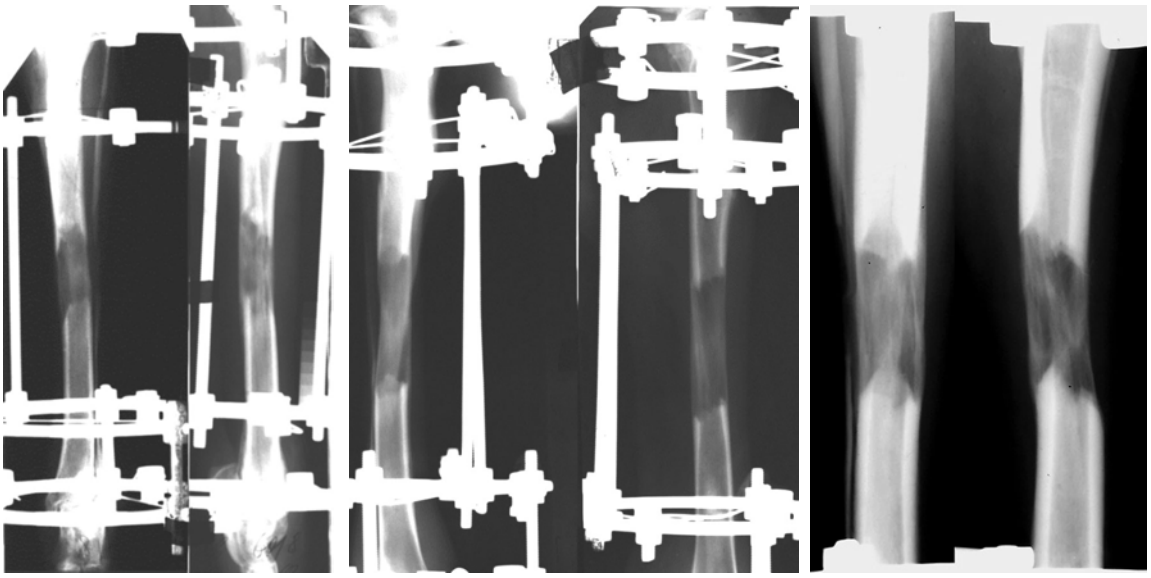
along the regenerate periphery. The histopograms along the regenerate periphery indicated that the remodeling of spongy bone into a compact one with osteons formation took place. Osteocerebral cavity contained hemopoietico-adipose cerebrum.

The morphological study clearly showed that the reparative osteogenesis had had considerable potential which helped to speed up the distraction. It is true that a higher tempo of automatic distraction up to 2 and even 3 mm per day did not cause any fundamental changes in the intensity of osseous regeneration (Fig. 6 and 7).



a b c

Fig.6. Roentgenogram of the shin by the moment when lengthening with different speed of automatic distraction is completed: a – 1mm daily, b – 2mm daily, c- 3mm daily.



a b c

Fig.7. Roentgenogram of the shin of the same experiment one month after the fixation: a – tempo of lengthening 1mm a day; b- 2mm a day; c – 3mm a day.

Osteogenesis can be put under active control both at the period of distraction and when it stops – at the period of fixation. A number of patients (42 people) went through biomechanical stimulation of reparative osteogenesis according to V. I. Shevtsov and A. V. Popkov's method (license № 2071740 RF) which purpose was to avoid passive expectation of consolidation during the period of fixation but try to act properly turning distractive osteosynthesis into a compressive one round the first days after that lengthening discontinued. This process is accompanied by the metabolic changes as the result of micro-traumatized distractive regenerate and these changes accelerate reparative osteogenesis by activation of a system of osteotropic hormones, when parathyrine-depended phase is initial and then rapid ALP and TL AlP activation in blood, when doing it content increase and electrolytes systemic index take place; distractive regenerate is remodeled with the increased energy supply. (Fig.8)

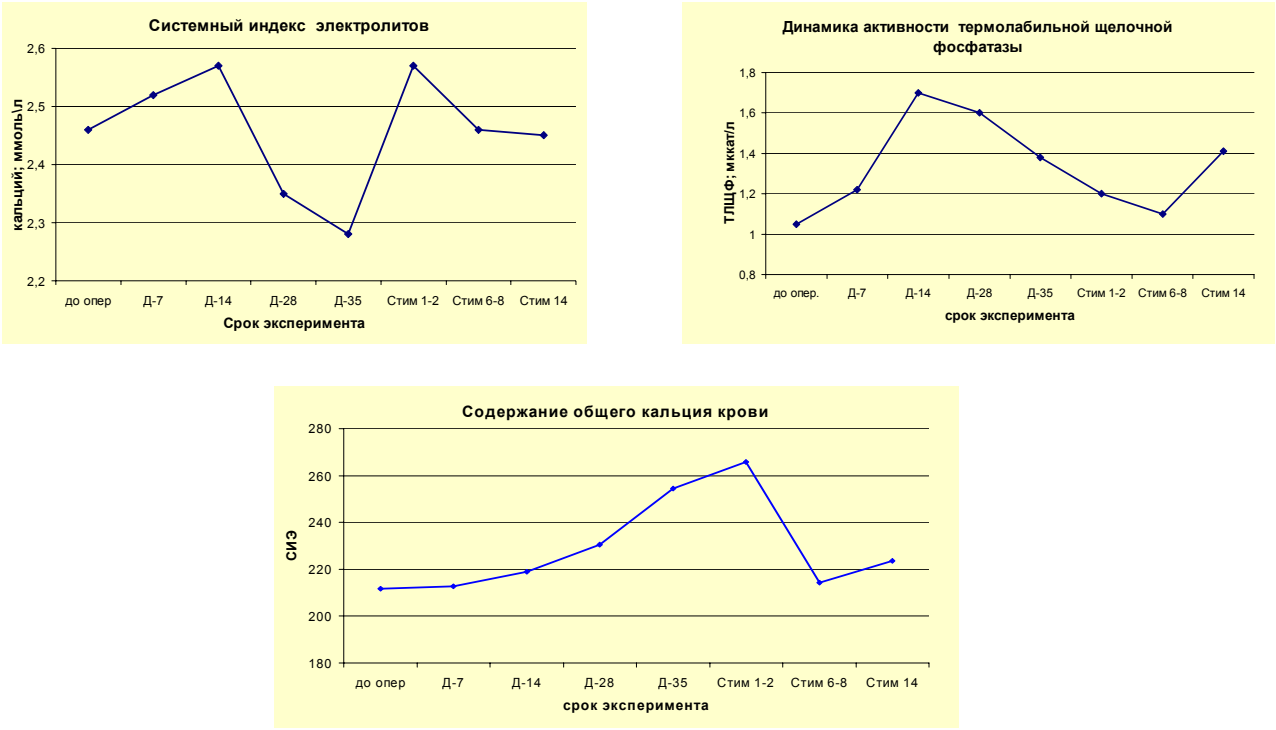


Fig. 8 Biochemical dynamics of reparative osteogenesis activation with sequential distractive-compressive osteosynthesis by Shevtsov –Popkov.

For those patients who went through monolocal automatic distractive shin osteosynthesis without stimulation FI made up 11,9±9,9 days/cm, in case of the stimulation - 5,5±2,2 days/cm. On the whole, with polylocal osteosynthesis in a group where stimulation is carried out on both segments, FI made up 5,4±2,1 days/cm, and with no stimulation on the average FI was 10,1±4,3 days/cm. In case of shoulder lengthening FI was shortened to 2 days per each centimeter of the regenerate length.

Condition and soft tissue regeneration play a decisive role in the patient's rehabilitation. The study of the functions of the limb soft tissues during the process of lengthening helped us to find out that in optimal conditions for distractive osteosynthesis in automatic mode stromal-parenchymatous relations in muscular fibers close in toward parenchyma: larger muscular fibers with small amount of connective tissue inlayers and a large number of microvessels prevail. Numerical density of microvessels is considerably higher than that according to the Ilizarov's classical lengthening (Fig.9).

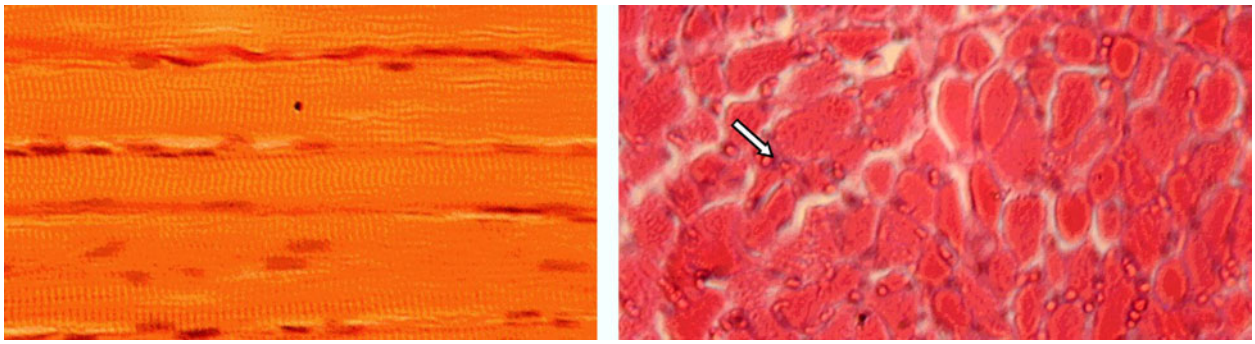


Fig.9. Histotopogram of the front tibial muscle of a dog after shin lengthening by 20% (30 day distractive regenerate compression): normal histostructure of a mustle (A), plenty of capillaries in endomysia (B) -×300.

The amplitude of movements in the joints adhesive to a stretched segment reached 80-100 % out of the initial findings in all the patients in clinical conditions by the sixth month since Ilizarov's device had been removed.

As a clinical example you may have a look at the case report of patient M., 16 years old. Diagnosis: consequences of hematogenic osteomyelitis femur shortening by 7 cm. The femur has been lengthened in the automatic mode with daily tempo at 1mm per day, FI – 5days/cm (Fig. 10).

Fig.10. Patient M., 16 years old, at treatment stages (A); roentgenograms of a femur at the stages of lengthening (B): a – before treatment; b – on operation day; c – end of distraction period; g – day of apparatus removal.

Thus, new technologies of extremity lengthening are highly effective and help to increase intensity of reparative osteogenesis and to create favourable conditions for muscular tissue regeneration and all that results in cutting the time spent on osteosynthesis and accelerating functional rehabilitation.

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