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„Ischemic“ Distraction Regenerate: Interpretation, Definition, Problems and Solutions

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Abstract

The purpose of the study was to define «ischemic» distraction regeneration which happens during the compromised course of distraction osteogenesis and to show the effectiveness of the mechanical action on such regenerates in patients with bone defects and pseudarthrosis. ***Materials and Methods.*** Seventeen patients with long bone defects (forearm and lower leg) were successfully treated. They had compromised distraction osteogenesis during the transosseous osteosynthesis stages and developed ischemic regenerates. The mean size of the defects relative to the contralateral segment in the forearm bones was 22.3% and 20% in patients with defects in the lower leg bones. Mechanical stimulation of compromised bone formation was used by means of compression and compaction of problematic distraction regenerates with two techniques. In group I, an additional osteotomy of the fragment under lengthening was performed. In group II, regenerates were compacted to the height of the regenerate connective tissue layer until its bony parts contacted. We used descriptive statistics methods. ***Results.*** The process of bone tissue formation restored in all patients due to the mechanical impact on the zones of compromised distraction osteogenesis, and its complete organotypic remodeling followed. ***Conclusion.*** Based on clinical and radiological signs of a compromised course of distraction osteogenesis, the notion of „ischemic regenerate“ was defined and its manifestations were described. A retrospective analysis of the results of mechanical action on compromised distraction regenerates through compression and compaction without a change in the osteosynthesis technology shows its effectiveness.

Keywords: ischemic distraction regeneration, transosseous osteosynthesis, bone defect.

Competing interests: the authors declare that they have no competing interests.

Background

The Ilizarov non-free bone plasty is a graduated and guided transport of a vascularized graft into the problematic region within soft tissues. The Ilizarov non-free osteoplasty provides segment reconstruction and formation of new bone tissue of almost any length and shape [1–5]. However, despite the optimal conditions for autologous graft transport, this option is not perfect. Some authors associate the main problems of bone tissue regeneration with fractures that occur at the level of distraction regenerates in patients with defects, non-unions and limb lengthening [6–12].

According to our clinical experience and literature data, fractures and deformities at the level of distraction regenerates are mainly caused by premature removal of external fixation devices, inadequate loading of the segment, and hypoplastic type of distraction regenerates [8, 10, 12, 13].

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Some authors argue that the problems of distraction regenerate formation may occur in lengthening of more than 4–5 cm [14]. However, the greatest risks for formation of hypoplastic distraction regenerates arise by one-stage management of extensive bone defects measuring more than 8–10 cm [8, 13, 15]. Thereby, osteogenesis slows down and an hourglass-shaped distraction regenerate is formed in 1.6 to 13.8% of cases by repairing large long bone defect, as reported [16, 17].

As yet, there are no commonly agreed definitions of compromised formation of a distraction regenerate when a bone defect is treated using segmental lengthening with the Ilizarov technique. The most frequently used terms describing this condition are „ischemic distraction regenerate" and „hypoplastic distraction regenerate„.

The purpose of the study was to define „ischemic" distraction regeneration which happens during the compromised course of distraction osteogenesis and to show the effectiveness of the mechanical action on such regenerates in patients with bone defects and pseudarthrosis.

Materials and Methods

This work is based on the findings of the dissertation research of A.L. Shastov*.

We successfully treated 17 patients with long bone defects who developed „ischemic" distraction regenerates during transosseous osteosynthesis. In 11 patients, an impairment of distraction osteogenesis was detected in the hospital while monitoring the process of bone formation during lengthening of fragments. Six patients were admitted to the clinic with „ischemic" regenerates, already formed.

The mean age of patients was 28.9±3.1 years. Ten individuals had defects in the bones of the forearm (radial bone — 4, ulnar bone — 6) and seven patients in the tibia. The average size of interfragmentary diastasis was 6.4±0.7 cm. The average size of defects was 21.3±2.3% in relation to the length of the contralateral segment (Table 1).

Six patients (tibia — 1 case, forearm – 5 cases) had post-traumatic neuropathies. In all cases, we observed extensive soft tissue scars which were local and longitudinal, internally adherent to the adjacent fragments. The number of previous operations per patient averaged 2.6±0.5 for defects of the forearm and 3.4±0.8 for lower leg. The presence of the „ischemic" regenerate was confirmed by radiographic and ultrasound imaging, as well as CT findings.

In all clinical observations, mechanical stimulation of bone formation was performed

Table 1

Data of patients with „ischemic" distraction regenerates

Statistical description	Defect location	
	Forearm	Tibia
Number of patients	10	7
Mean age of patients, years	27.2±4	31.2±5
Mean interfragmentary diastasis, cm	5.5±0.8	7.6±1.0
Average size of defects in relation to the contralateral segment, %	22.3±3.6	20±2.3

* Dissertation „Optimization of recovery processes in patients with non-unions and bone defects in conditions of impaired osteogenesis (clinical experimental study)" by Shastov A.L., defended on September 15, 2016 (dissertation advisor — Borzunov D.Y., MD, PhD).

by means of compression and compaction of problematic distraction regenerates using two techniques.

The first technique involved additional osteotomy (corticotomy) of the fragment under elongation. Two or three crossed wires were inserted through the bone fragment formed. They were then fixed to an additional ring support of the Ilizarov apparatus. Distraction at a rate of 0.5–1 mm per day was initiated after 5 to 7 days postoperatively. The fragment was transported towards the „ischemic" distraction regenerate until its bony parts docked, which was determined by X-ray analysis.

The second technique involved the implementation of the idea of V.I. Shevtsov and A.V. Popkov to simultaneously compress the normotrophic distraction regenerate to the height of its connective-tissue layer („growth zone" of the regenerate) during the over- lengthening of a segment [18]. The authors of this invention proposed that, during equalization of limb lengths, they would over-lengthen the segment to the height of the „growth zone" of the bone regenerate (0.5–1.0 cm). Upon completion of distraction, they recommended to simultaneously compress with the external supports of the apparatus so that the proximal and distal regenerate bony ends docked thus compacting the connective-tissue layer.

To solve the problem of organotypic remodeling of the „ischemic" distraction regenerate in patients with bone defects and non-unions, we adapted and modified this technique. Compression was performed with either two or three steps with a break of 2–3 weeks between each step, or gradually, 2 mm per day, to dock the bony regenerate parts and to compact the regenerate peripherally, which was determined by X-ray analysis.

In the case of two-bone segment reconstruction (lower leg), oblique osteotomy to duplicate fragments or resection of the fibular bone by the length of the expected regenerate compression was performed. For reconstruction of the forearm bones, the second technique was not used because of the anatomical and functional equivalence of paired bones of the segment.

Depending on the technological approaches applied, we divided the patients into two groups.

In 15 patients of group I, additional osteotomy of the fragment under elongation was performed to compact the „ischemic" regenerate and to bridge the bone defect, and the formed fragments were transported.

In two patients of group II, the regenerate was compacted to the height of the connective-tissue layer to dock the bony parts of the regenerate according to the Shevtsov-Popkov method [18]. In most cases, preference was given to compaction of the „ischemic" regenerate following additional osteotomy and to restoration of full anatomical integrity of bone segments.

Statistical analysis

We used descriptive statistical methods. Data processing was performed using Microsoft Excel.

Results

In group I, the total duration of distraction averaged 83.5±11.9 days. The bone defect compensation was an average of 5.6±0.7 cm (95.5±3.1% of the true loss of bone length). The average compaction time was 27.9±4.7 days, the compaction amount of the ischemic regenerate was 1.7±0.3 cm, and the average fixation time in the apparatus was 130.9±20.8 days. The bone integrity of the damaged segments was restored in all cases. Complete compensation of the defect with restoration of the anatomical integrity of the bone and segment length equalization was achieved in 12 patients, which accounted for 80% of all patients. Table 2 shows results of treatment in patients of group I.

Table 2

Results of treatment in patients of group I

Statistical description	Defect location	
	Forearm	Tibia
Average duration of distraction, days	80.2±14.7	91.8±23.1
Average length of bone defect, cm	4.8±0.7	7.4±1.7
Average amount of defect compensation (% of true bone length loss)	93.8±4.3	100
Average duration of compaction, days	28.1±6.1	33.5±10.1
Average amount of compaction of „ischemic" regenerate, cm	2.0±0.5	1.7±0.8
Average consolidation time, days	107±13.2	190.5±61.8

In two patients with an initial ulnar bone defect of 8.0 cm, the shortened segment was lengthened in two stages of treatment.

Case report 1

Patient L., 35 years old, diagnosis: post-traumatic defect of the left tibia; chronic post-traumatic osteomyelitis of the left tibia in remission; after attempting to repair the defect by lengthening the proximal fragment of the tibia, the outcome was the formation of the ischemic distraction regenerate; a consequence of traumatic injury to the left tibia was occlusion of the anterior and posterior tibial arteries and damage to the common fibular nerve.

From the case history, it was known that the patient sustained an open multifragmentary fracture of the left tibia caused by a gunshot. Before admission to the hospital, the patient underwent multiple operations, including transosseous osteosynthesis and external fixation, and also underwent repeated sequestrectomies. One of the unsuccessful surgical interventions was an attempt to repair the tibial defect by lengthening the proximal fragment according to the Ilizarov method, as a result of which an „ischemic" distraction regenerate was formed. At admission, his left tibia was fixed with the Ilizarov apparatus. The patient walked not weight-bearing the affected leg with the help of two crutches. In the proximity to the bone defect, the soft tissues of the tibia had scarring adhered internally to adjacent tibial bone fragments. The pulsation of the posterior and anterior tibial arteries was not detected. Radiographs revealed an ischemic distraction regenerate of 5.0 cm in the upper third of the tibia. The size of interfragmentary diastasis in the middle third of the tibia was 5.0 cm; the ends of fragments were incongruent and thinned (Fig. 1a). No anatomical shortening of the segment was found.

The Ilizarov apparatus was removed from the patient and the tibia was fixed with a posterior plaster cast (Fig. 1b). Using arteriography, occlusion of the first portions of the posterior and anterior tibial arteries was detected. The region of the fibular artery was filled with contrast due to blood flow through the collateral network. Circulation to the foot was compensated.

Next, the patient underwent osteotomy of the proximal and distal fragments of the left tibia and transosseous osteosynthesis of the left tibia with the Ilizarov apparatus. The integrity of the fibula was not compromised.

Distraction in the proximal regenerate zone was initiated on the third day postoperatively. Simultaneously, the ischemic regenerate was compacted. Distraction in the distal osteotomy zone was initiated on

the fifth day at a rate of 0.5 mm per day. In the proximal osteotomy zone, the duration of distraction was 69 days, in the distal zone — 67 days. Compaction was completed when the bony parts of the „ischemic" regenerate docked. The distraction regenerate formed in the zone of the additional osteotomy was 5.0 cm long (Fig. 1c).

Open adaptation of the fragments was performed after their docking. Subsequently, supporting compression was performed at the docking site. The patient with the device on was discharged for outpatient treatment. At the follow-up appointment in the outpatient clinic, X-ray data revealed consolidation of fragments at the junction in the middle third of the tibia, remodeling of distraction regenerates, and the formation of continuous cortical plates in the periphery of the regenerates. A clinical trial for consolidation did not show mobility of the fragments and the manipulation was painless. After removal of the apparatus, no additional fixation of the segment was required and the patient was allowed to fully load the limb.

In the first patient of group II, the distraction regenerate was compacted twice by 0.5 cm with an 18 day interval. In the second patient, compaction was performed gradually for 29 days. Compaction was terminated when contact of the bony parts of the „ischemic" regenerate had been achieved. Radiographic monitoring was performed before and after the manipulation. The segments remained fixed in the Ilizarov apparatus after compaction for 95 and 190 days, respectively. In both cases, bone union of distraction regenerates was achieved.

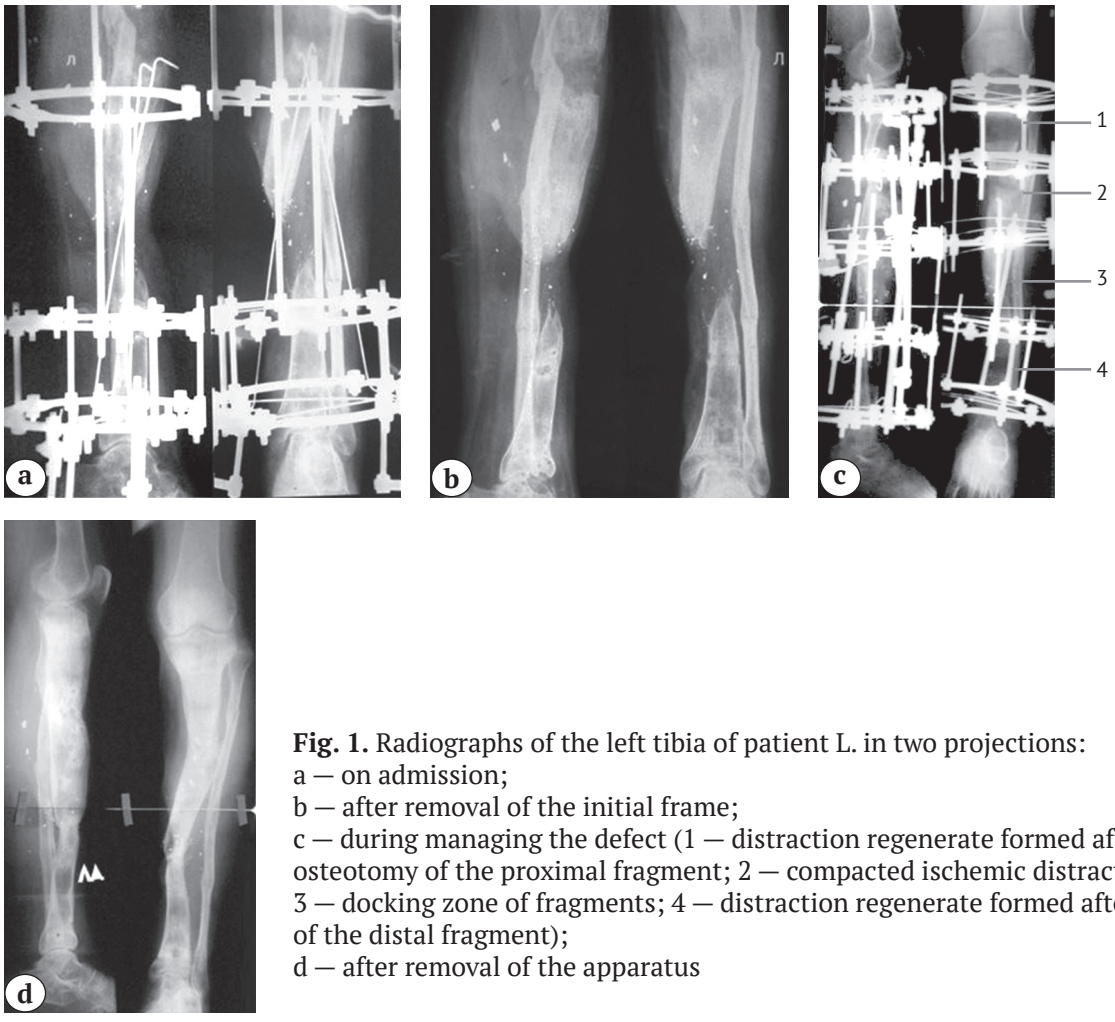

Fig. 1. Radiographs of the left tibia of patient L. in two projections:
a — on admission;
b — after removal of the initial frame;
c — during managing the defect (1 — distraction regenerate formed after additional osteotomy of the proximal fragment; 2 — compacted ischemic distraction regenerate; 3 — docking zone of fragments; 4 — distraction regenerate formed after osteotomy of the distal fragment);
d — after removal of the apparatus

Case report 2

Patient S., 32 years old, was admitted to the Center's clinic one year after sustaining an open fracture of the bones of the right tibia in an accident. A total tibial bone defect of 10 cm developed after repeated sequestrectomies, performed to treat the osteomyelitic process, and multiple attempts to manage the bone defect according to Ilizarov. On admission, the patient had fistula with purulent discharge, combined contractures of adjacent joints, soft tissue scarring, shortening and lack of supportability of the right lower limb. Fibular fragments in the upper third were duplicated, there was no union.

The previously installed apparatus was removed (Fig. 2 a), debridement was performed and limb fixation with the Ilizarov apparatus followed. Osteotomy of the proximal tibial fragment was performed after the infection process had been arrested.

Bone transport continued 40 days until the contact of the fragments was achieved, with 1 mm per day. In radiographs, an „ischemic" distraction regenerate 4.0 cm long was detected (Fig. 2 b). Compression in the „ischemic" regenerate zone was performed for 29 days until its bony parts reached full contact, 1.5–2 mm per day (Fig. 2 c). At the junction of fragments, an open adaptation was performed. Fragment consolidation took 190 days. The tibia consolidated with a residual shortening of 10 cm (Fig. 2 g, d).

The second stage of treatment was performed to lengthen the segment by 7.5 cm and to correct valgus deformity when weight-bearing and a complete remodeling of the bone tissue had been achieved. Regular formation of distraction regenerate was observed during this stage.

Discussion

Non-free osteoplasty according to Ilizarov is widely used clinically for managing bone defects, limb lengthening, deformity correction and eliminating pseudarthrosis [2, 4–6, 8, 10–13, 15]. However, the repair of extensive defects and lengthening of the limbs may results in fractures or non-unions at the level of distraction regenerate [8, 10–13, 19].

It is known that the distraction regenerate is represented by two vascularized bony parts, separated by a connective-tissue layer, which has a leaner network of newly formed vessels [20–23]. If the connective-tissue layer prevails over the bony parts, then the car-

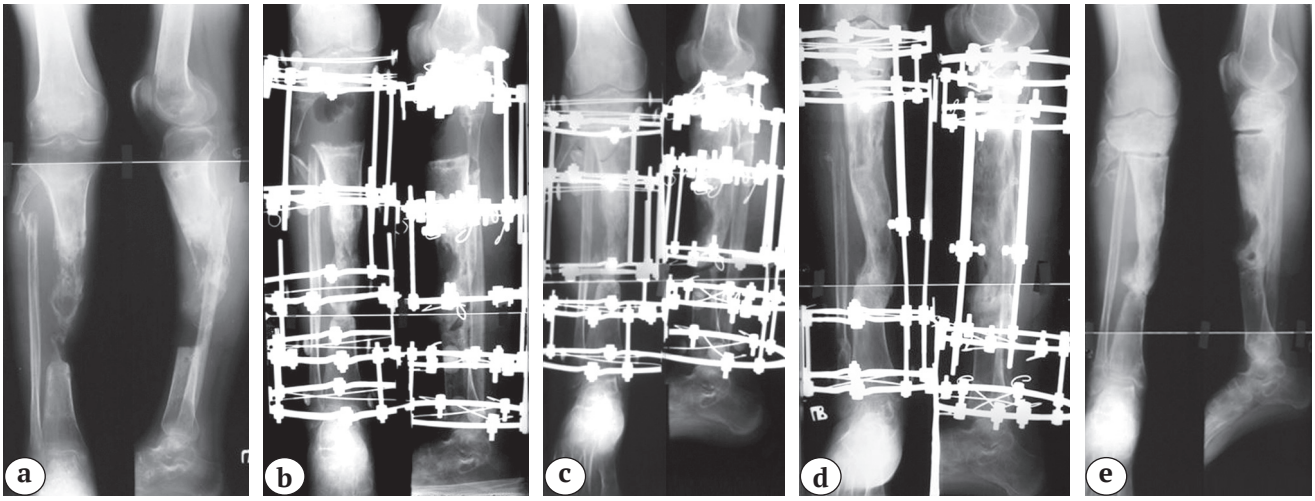

Fig. 2. Radiographs of the right tibia in two projections with adjacent joints of the patient S.:
a — on admission;
b — after transport of the fragment and formation of the „ischemic" distraction regenerate;
c — after compaction of the „ischemic" distraction regenerate;
d — before removal of the apparatus;
e — the result at this stage of treatment

tilaginous fibrous tissue, devoid of blood vessels, is formed, resulting in the development of pseudoarthrosis at the level of distraction regenerate. In the literature, there are data on the heights of the connective-tissue layer (more than 8–10 mm) in the distraction regenerate that are critical and risky for non-union development [23].

The formation of bone tissue depends on the angiogenesis capacity in the distraction regenerate [19, 24–27]. It is proven that blood flow increases in the limbs during elongation using the Ilizarov method. However, in post-traumatic or post-resection chronic bone defects, the initially impaired blood circulation is not always compensated for [13, 19]. Pronounced scarring, angiotrophic disorders, endosteal damage and impaired intraosseous blood circulation, resulting from multiple surgical interventions, traumatic and radical resections, and aggressive high-energy trauma, also have a negative effect on the limb trophism and, thus, adversely affect the osteogenesis process [24–27].

Osteotomy quality, stability of the apparatus and the rate of distraction also influence osteogenesis capacity [23, 24, 28]. Some authors recommend reducing the rate of distraction when the connective-tissue layer height reaches more than 8–10 mm, and increase the rate when the height is less than 2 mm which is associated with the risk of premature union [23].

There are no commonly accepted classifications of differences in outcomes of distraction osteogenesis. According to the literature, the reference classification of the distraction callus is the Ru Li's classification, in which the author identifies ten types and five shapes of distraction callus [22, 29] which are:

Shape 1. Fusiform (the regenerate is wider than the interfragmentary diastasis).

Shape 2. Cylindrical (the regenerate is the same width as the interfragmentary diastasis).

Shape 3. Concave (the regenerate tends to produce an hourglass appearance)

Shape 4. Lateral (the regenerate has an edge defect).

Shape 5. Central (the regenerate is a thin pillar in the central portion of interfragmentary diastasis).

In our opinion, shapes 3 and 5 may be referred to as an „ischemic" distraction regenerate formed according to the hypoplastic type. Shape 4 (with the formation of the marginal defect and the hypoplastic type of bone formation) is inappropriate to define as „ischemic" regenerate. It is usually associated with traumatic osteotomy, and elongation of fragments which may result in the formation of angular deformity. A typical example is a new bone defect along the anterior surface in the upper third of the tibia during tibial lengthening with antecurvatum of transported fragments.

The terms „hypoplastic" and „ischemic regenerate" are not synonymous. They define different clinical situations [4, 30, 31].

Clinical and radiological signs of „ischemic" regenerate:

a) connective-tissue layer area is greater than that of the bony parts of the regenerate;

b) interfragmentary diastasis is greater than the regenerate;

c) length and surface of the bone sections do not tend to increase (according to the findings of dynamic X-ray examination);

d) development of endplates of bone sections of the regenerate showing signs of non-union formation (atrophic non-union);

e) inconsistency of the organotypic remodeling of the regenerate by the end of consolidation, along with persistent pathological mobility during a clinical consolidation test;

f) formation of a soft tissue defect in the projection of the „ischemic" regenerate.

One feature is specific for hypoplastic regeneration: the diastasis area is greater than the regenerate area. The regenerate that is formed according to the hypoplastic type is capable of organotypic remodeling without additional interventions. Its connective-tissue layer is then replaced by bone tissue, the

bony parts bridge, and a compact bone layer is formed along the periphery. Upon completion of organotypic remodeling, the regenerate does not fully fills in the defect gap along the periphery of its central part, as a rule, and acquires the shape of an hourglass.

This study retrospectively analyzed the results of mechanical effects on compromised distraction regenerates using compression and compaction. The analysis indicates its effectiveness, so there is no need to change the technology of osteosynthesis. The techniques consist in mechanical effects produced on the „ischemic" regenerate with 1) an additional osteotomy for lengthening a fragment and further graduated retrograde transport of the fragment by creating a new distraction regenerate; 2) by either a gradual or simultaneous approaching of the ends of fragments to compress the height of the connective-tissue layer, thus shortening the segment. The stimulation effect on bone formation and on the recovery of organotypic remodeling of the „ischemic" distraction regenerate was achieved by its gradual compaction.

Competing interests: the authors declare that they have no competing interests.

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Ethical approval: all procedures performed in studies involving patients were conducted in accordance with the requirements of the 2013 Helsinki Declaration of Revision. Informed consent for this type of research is not required.

Consent for publication: the patient provided voluntary consent for publication of case data.

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