PHYSIOLOGY

Changes in Blood Flow during Tibial Thickening by the Ilizarov Method

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We studied circulatory changes in dog hindlimb after tibial thickening by the Ilizarov method. Distraction osteosynthesis promoted the increase in blood supply to hindlimb tissues. Changes in blood flow were most pronounced in a distraction bone regenerate after the distraction period. The increase in the volume of distraction bone regenerate determined more pronounced and long-lasting stimulation of circulation in the extremity.

Key Words: *distraction osteosynthesis; circulation; extremity*

Tibial thickening is used for the therapy of circulatory insufficiency in the extremities at the Russian Research Center "Reparative Traumatology and Orthopedics" from 1982. Clinical observations indicate that the positive effect (increase in the number of vessels and improvement of vascular relationships in distraction bone regenerate and surrounding tissues followed by acceleration of resting blood flow) is observed in patients with preserved reserves of "functional adaptation" in the vascular bed and certain volume of a distraction bone regenerate [1,2]. However, quantitative circulatory changes in muscles of the extremities remain unknown.

Here we studied the dependence of pulse blood flow in muscles of distant and near-regeneration zones in the extremities on the size of distraction bone regenerate.

MATERIALS AND METHODS

Experiments were performed on 20 adult dogs with tibial length of 12-18 cm. Mounting of the Ilizarov apparatus and longitudinal osteotomy of the tibial diaphysis were performed under narcosis. In series I (11 dogs) the size of avulsed bone fragments was 30% of the tibial length. The fragment was displaced forward. In series II (9 dogs) the size of bone fragments was 15% of the tibial length and it was displaced inward. Distraction was started on day 3 (1 mm over 4 procedures) and continued for 15 days. The period of fixation was 15 days. The animals were followed up for 6 months after removal of the Ilizarov device.

Functional state of the peripheral circulation was estimated by volume sphygmography and rheovasography. The cuff for volume sphygmography was applied on the supratalar zone. Pulse waves were recorded at a positive pressure of 30 mm Hg. For rheovasography needle electrodes were implanted dorsolaterally into the biceps muscle of the thigh (BM), semitendinosus muscle (STM), and gastrocnemius muscle (GM). Two electrodes were poisoned at a distance of 5 cm. The distance between electrodes on the leg and radial wires of the Ilizarov device was not less than 3 cm. Pulse waves were recorded using a RG 4-01 rheograph and sphygmographic apparatus in a Mingograph-82 device (tape speed 100 mm/sec). The calibration signal for rheograms was 0.05 Ω.

Basic resistance was recorded from a rheograph scale. Blood supply is the reciprocal of basic resis-

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tance. During graphical representation of changes, the value corresponding to a decrease in basic resistance was added to the control value (before surgery).

Unweighted variational series were constructed. The average value and errors were calculated. The significance of differences was estimated by Student's *t* test. The means are presented at a significance level of 95%.

RESULTS

In series I the amplitude of volume sphygmograms increased after distraction, decreased by the end of fixation and after removal of the Ilizarov device, and did not differ from the control after 6 months (Table 1). These data indicate that vascular resistance in the extremities returned to normal.

In BM, reduction of the basic resistance after distraction and fixation corresponded to a decrease in the rheographic index ($p<0.05$, Table 1). After removal of the Ilizarov device the basic resistance did not differ from the control, while the rheographic index was below the normal (insignificantly, Table 1).

In GM, reduction of the basic resistance after distraction and fixation also corresponded to the decrease in the rheographic index ($p<0.05$, Table 1). After removal of the Ilizarov device the basic resistance did not differ from the control, while the rheographic index increased (Table 1).

After distraction and fixation, the basic resistance in GM decreased more significantly than in dorsolateral muscles (by 3.1 and 2.3 times, respectively). The decrease in rheographic index during application of the Ilizarov device was the same in dorsolateral thigh muscles and GM. After removal of this device the rheographic index surpassed the control only in GM.

In series II the amplitude of volume sphygmograms increased after distraction, but did not differ from the control by the end of fixation and 3 months after removal of the Ilizarov device (Fig. 1, *a*). It should be emphasized that after distraction the amplitude of volume sphygmograms was 1.7 times lower than that observed in series I. Moreover, the amplitude of volume sphygmograms increased more rapidly than in series I (by 6 times).

Changes in the basic resistance and rheographic index in BM and STM were similar to those observed in series I. Basic resistance in GM significantly decreased after distraction ($p<0.05$), returned to normal after removal of the Ilizarov device, and did not differ from the value observed in series I (Fig. 1, *b*).

The reduction of basic resistance after distraction corresponded to a decrease in the rheographic index (similarly to series I). Thus, changes in the vascular bed were unidirectional and promoted a similar increase in the resistance to pulse waves in various segments of the extremities. The rheographic index increased after fixation, but then did not differ from the control (Fig. 1, *c*). In series II the rheographic index after fixation was 1.6 times higher, while in the follow-up period this parameter was 1.4-fold lower than in series I (Fig. 1, *c*).

In our experiments the duration of distraction was 15 days. Therefore, newly formed vessels of a distraction bone regenerate were involved in functional activity, but did not undergo reduction and transformation. In series I the volume of a distraction bone regenerate 2-fold surpassed that in series II. The cuff for volume sphygmography was applied on the lower third of the leg (minimum soft tissues). This procedure allowed us to measure pulse pressure in magisterial vessels. Blood flow parameters in BM and STM reflected changes in blood flow in the region not associated with a distraction bone regenerate. Recording of these parameters in GM reflected changes in the zone of posttraumatic hyperemia.

Volume sphygmography showed that distraction synthesis stimulated pulsation in magisterial vessels of the leg. The increase in pulse pressure was most pronounced after 15-day distraction, which corresponded

TABLE 1. Blood Flow in Dogs in Series I (30% Avulsion of the Tibia, Forward Displacement, $M\pm m$)

Period	Amplitude of sphygmograms, mm	Basic resistance, W		Rheographic index, W	
		BM and STM	GM	BM and STM	GM
Before surgery (*n*=11)	0.65±0.13	200±9	262±12	0.070±0.009	0.050±0.006
End of distraction (*n*=10)	1.47±0.12*	184±11	196±17	0.040±0.007*	0.030±0.008*
End of fixation (*n*=8)	1.05±0.21*	182±12	207±19	0.050±0.007*	0.040±0.007*
Without device					
3 months (*n*=6)	0.84±0.15*	199±14	270±21	0.060±0.012	0.070±0.011*
6 months (*n*=5)	0.68±0.13	199±13	263±23	0.060±0.017	0.070±0.012*

Note. *$p<0.05$ compared to parameters before surgery.

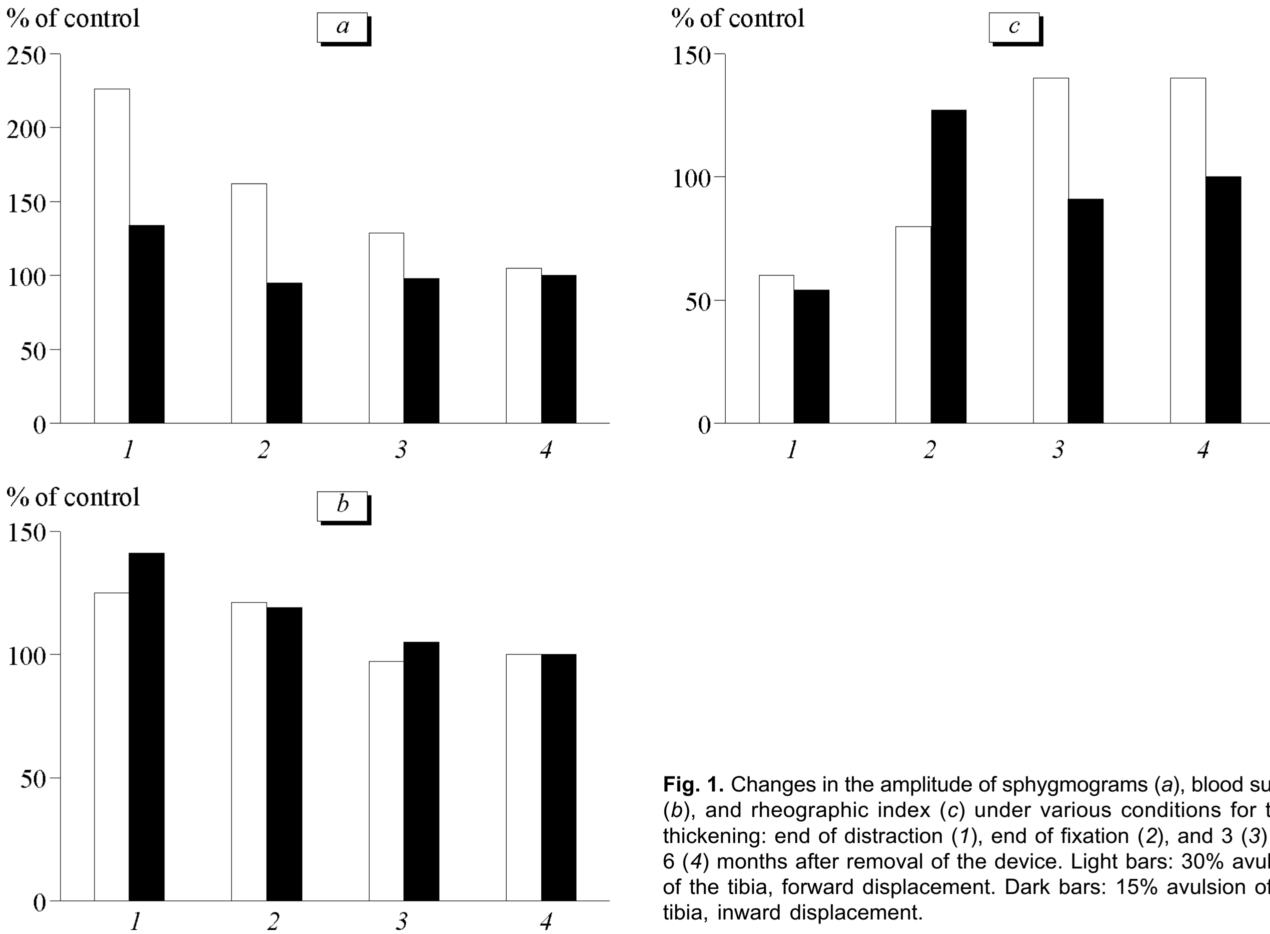

Fig. 1. Changes in the amplitude of sphygmograms (*a*), blood supply (*b*), and rheographic index (*c*) under various conditions for tibial thickening: end of distraction (*1*), end of fixation (*2*), and 3 (*3*) and 6 (*4*) months after removal of the device. Light bars: 30% avulsion of the tibia, forward displacement. Dark bars: 15% avulsion of the tibia, inward displacement.

to maximum involvement of newly formed vessels of a distraction bone regenerate in the circulation. During fixation and after removal of the Ilizarov device pulse pressure in magisterial vessels of the leg progressively decreased to the control level. These periods correspond to partial reduction and transformation of newly formed vessels into the organotypic bed of bone segments.

The amplitude of pulse waves in GM increased after fixation. These data indicate that pulse blood flow in tissues functionally involved in the vascular bed of newly formed bone segments increased.

Increasing the size of avulsed tibial fragments was accompanied by a proportional increase in pulse pressure in magisterial vessels of the leg and lengthening of the effect.

Our findings indicate that distraction osteosynthesis promotes the increase in the circulation in extremities, which is particularly pronounced in the corresponding segment. When the size of avulsed bone fragments after longitudinal osteotomy was 15% of the tibial length, the duration of stimulatory action did not surpass 4 months. The increase in the amount of newly formed bone tissues was followed by pronounced and long-lasting stimulation of circulation.

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