Effect of Early Fasciotomy on Intramuscular Pressure and Electrical Excitability of Muscles in Experimental Compartment Syndrome

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Experiments on rabbits with compartment syndrome of the leg showed that the main pathogenetic factors of muscle injury are postischemic contracture leading to extravascular microcirculatory disorders and tissue necrosis(early postcompression period) and progressive subfascial edema (18 h-4 days). Therapeutic effect of fasciotomy in the early period consists in restoration of bloodflow due to relaxation of contracted muscles and in the late period in decompression of edematous muscles and prevention of secondary ischemia. Fasciotomy through a small section does not lead to sufficient relaxation of rigid muscles and does not essentially increase the subfascial volume. Fasciotomy decreases subfascial pressure and muscle excitability threshold, however they remain considerably elevated during day 1. An electrodiagnostic test is proposed for early (before subfascial edema) detection of postischemic contracture.

Key Words: *intramuscular pressure; compression injury of the limb; compartment syndrome; postischemic contracture; fasciotomy*

Edema of damaged tissues plays the main role in the pathogenesis of postischemic muscle necrosis. Edema impairs bloodflow, promotes the development of secondary tissue ischemia due to high pressure in the musculo-fascial spaces, and causes compartment syndrome (CS) usually treated by fasciotomy (FT) [1,4,6]. Several methods of FT on the shin are known, the most attractive is FT through a small skin section, *i. e.* closed FT [4,6] associated with low risk of wound infection and plasma loss. The role of postischemic contracture [4,5] in the pathogenesis of CS is unknown, and it is not quite clear whether FT is a pathogenetic method for treating muscle injury in CS caused by postischemic contracture and edema.

The effects of closed FT on postischemic contracture and edema of muscle tissue in experimental CS were studied to elucidate the dynamics of these two types of injuries and the role of FR in these different states, and to choose optimal methods and terms of FT in CS.

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MATERIALS AND METHODS

Mechanical injury of soft tissues of the hip with complete bloodflow arrest in the main femoral arteries was modeled in 16 Chinchilla rabbits of both sexes weighing 2.5-3 kg. The time of compression was 6 h, intensity 90 kg/18-20 cm^2. Before compression, skin on the limb was shaven. Closed FT was performed 30 min after decompression, after which small incisions were made on the anterior and posterior surfaces of the shin, through which a button probe was inserted. A small scalpel with narrow blade was inserted into this channel and the fascia were cut so that muscle tissue was exposed. Operations were performed under aseptic conditions, the wounds were powdered with penicillin. Skin was sutured with single suture. After surgery the skin was treated with Lugol solution, and the limb

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was wrapped with sterile gauze and sterile hermetic resin balloon that was fixed with a bandage.

The parameters were recorded before compression, immediately after decompression, and on days 1, 4, and 8 of the postcompression period (PCP). Circumference of the femur and shin, intramuscular pressure, and muscle excitability were evaluated. Randomized pathomorphological examination of muscle biopsy specimens was carried out.

The circumferences were measured along the middle third of the femur and upper third of the shin and expressed in percent of the initial value.

Intramuscular pressure was measured with a modified device for measurements of local pressure in the wrist channel syndrome [3]. Pressure at which the liquid overcomes tissue resistance and enters the tissue through a needle injected along muscle fibers (the compensation method) was taken for intramuscular pressure. The device recorded summary pressure created by edematous liquid and tissue resistance.

Direct muscle excitability was evaluated with a needle electrode inserted into the muscle belly. The state of the muscles was evaluated by rheobase and chronaxia and their product (arb. units). If the muscle did not react to a supramaximum stimulus (50 V, 100 msec) it was considered electrically unexcitable.

Photooptic and electron microscopy of muscle biopsy specimens from the examined compartments of the shin was used for more accurate evaluation.

Compression of the limb was performed under ether narcosis and electroanalgesia against background of intravenous relanium (0.5% solution, 0.4 mg/kg). In some cases the drug was injected repeatedly until complete suppression of motor activity.

The results were statistically processed using Student's t test and χ^2 test.

RESULTS

Observations of the animals and macroscopic examination of muscles showed that closed FT reduced the risk of infection. The majority of tissue necroses on the anterior surface of the shin looked like intramuscular sequestrae without suppuration.

Intramuscular pressure was maximum during the first hour of PCP in both operated and nonoperated animals (Fig. 1).

During the first day after FT the pressure in the anterior and dorsal surfaces of the shin was lower than in nonoperated animals. It should be noted that in both operated and nonoperated animals intramuscular pressure decreased by day 1 of PCP and increased by day 4 (this rise was most expressed in dorsal shin muscles). Parallel changes in intramuscular pressure indicate predominance of common mechanisms of injury. Their effect was more pronounced than the effect of FT.

The recorded parameters in anterior shin muscles more than 2-fold surpassed those on the dorsal surface, and did not reach the norm even by the end of the first day of PCP. The parameters decreased most slowly in nonoperated animals. This is in line with published data on anatomical predisposition of anterior shin muscles to CS (fascial sac adjacent to the bone).

Analysis of the effect of FT on the limb circumference (femur and shin) (Fig. 2) showed different dynamics of intramuscular pressure and limb circumference: by the end of the first day the intramuscular pressure decreased, while the circumferences increa-

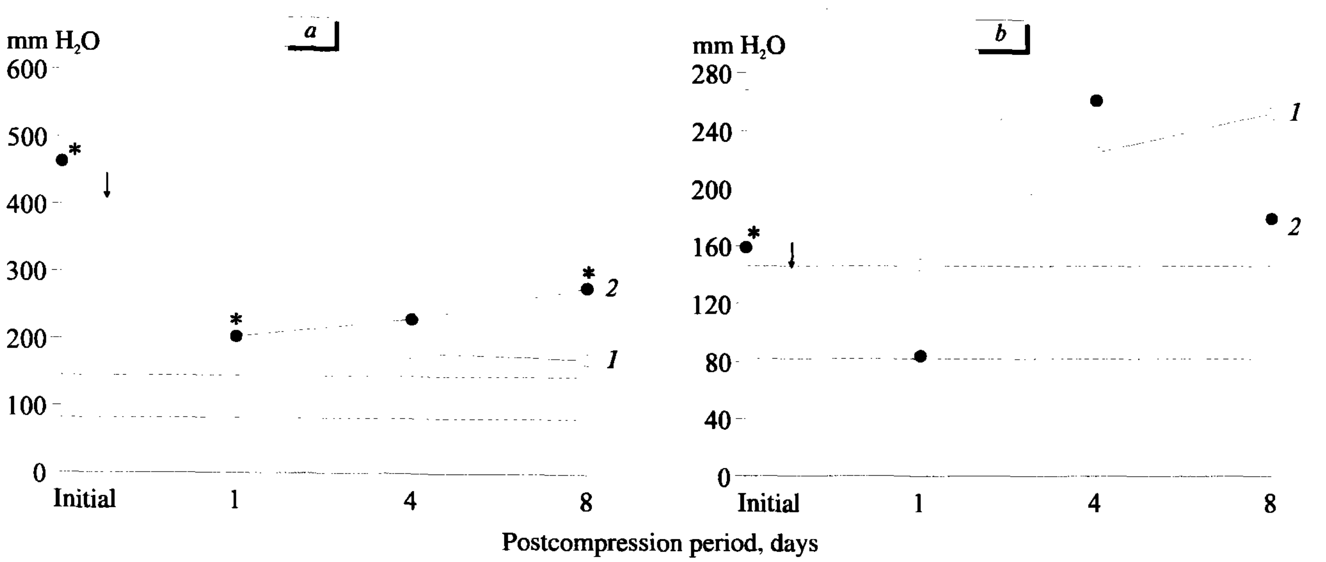

Fig. 1. Time course of intramuscular pressure after closed fasciotomy in the anterior (*a*) and surface dorsal (*b*) parts of the shin subjected to compression injury. *Differences from the control are significant. Arrow shows the time of fasciotomy. Dotted line shows confidence interval of the norm. Here and in Figs. 2 and 3: *1*) control (no fasciotomy); *2*) experiment. Initial values were recorded 30 min after decompression.

sed. Hence, subcutaneous edema did not notably affect the intrafascial pressure.

Moreover, opposite changes in pressure and subcutaneous edema after long-term ischemia indicates that the method of pressure measurement used in our study reflects mainly the decrease in postischemic rigidity, but not the changes in edematous fluid pressure.

Effects of common factors of injury on the limb circumference was more expressed than the effect of FT: there is a trend to a decrease in the circumference after surgery, but the parameters of the operated and nonoperated limbs differ only from those of intact limbs, but not between themselves.

Direct muscle excitability is an integral characteristics of muscle state reflecting muscle contractures, increased membrane permeability, and edema of muscle fibers. Edematous fluid shunts the stimulating current, thus increasing direct muscular excitability and chronaxia. Changes in the number of areactive muscles in both compartments of the shin in operated and nonoperated animals are parallel, and fluctuations in the parameters in different periods are negligible (Fig. 3, *c*, *d*).

Changes in muscles with intact excitability are more demonstrative. First, there is a trend to an increase in the threshold values of stimulating current up to day 4, after which this parameter tended to decrease. Second, the threshold excitability of muscles in the operated limbs is lower than in nonoperated limbs. Differences in muscle excitability of muscles in operated and nonoperated animals became more pronounced by day 4, indicating different severity of muscle damage. In addition, the excitability of fasciotomied and nonfasciotomied injured muscles often remains high (more than one order of magnitude supresses the normal), which indicates significant effect of nonspecific damaging factors, little affected by closed FT.

Only postischemic contracture of muscles can be such a damaging factor, whose intensity decreases during the first 24 h of PCP; muscle rigidity is little influenced by FT, particularly by closed FT, and during this period it is the main factor of intramuscular extravascular microcirculatory disorders in the damaged limb. Postcompression muscle contracture prolongs ischemia by many hours and inevitably leads to muscle necrosis [4,5]; while its early removal can save viable muscles.

Subfascial edema develops only after transformation of contracture into necrosis with subsequent recovery of bloodflow. Therefore the increase of threshold values of stimulating current in the examined muscles after resolution of the contracture primarily reflects their damage by progressive intrafascial edema.

The dynamics of electrical excitability of the muscles did not correlate with the limb circumference, which reflected mainly edema of the subcutaneous fat, while the volume of muscles surrounded by unstretchable fascia remained unchanged. By contrast, intramuscular pressure on day 1 of PCP correlated with electrical excitability of muscles in the later period, which indicated a relationship between ischemic contracture and severity of muscle injury and edema.

Hence, the effect of early FT consists in relaxation of rigid muscles and restoration of bloodflow, and is retained during further edema; the therapeutic effect of late FT consists in decompression of edematous muscles and prevention of secondary ischemic necrosis. Published reports confirm that extensive sections of the skin and fascia more effectively restore the

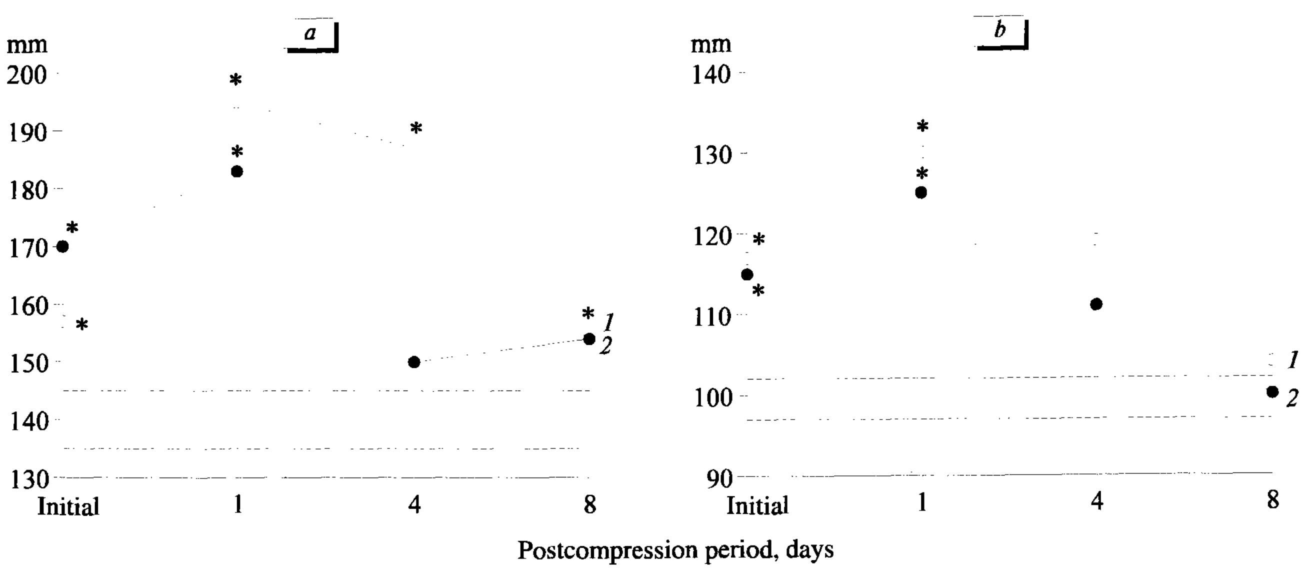

Fig. 2. Time course of femoral (*a*) and crural (*b*) circumference of the limb subjected to compression after closed fasciotomy. *Difference from the norm is significant. Dotted line shows confidence interval for limb circumference before injury.

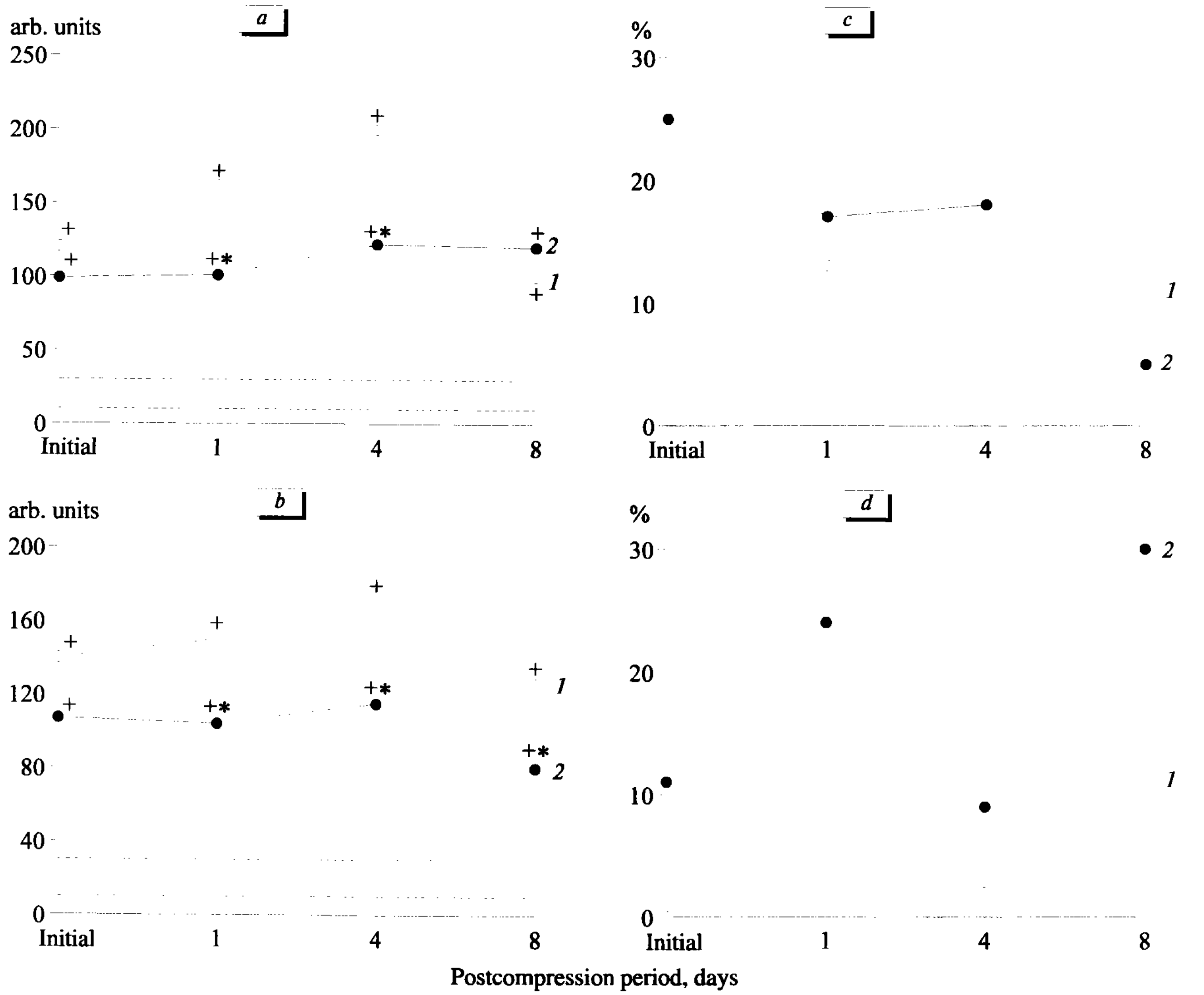

Fig 3. Effect of closed fasciotomy on direct muscle excitability (*a*, *b*) and electrical excitability of muscles (*c*, *d*) in the anterior (*a*, *c*) and surface dorsal (*b*, *d*) parts of the shin. Differences are significant in comparison with: *control; +intact limb. Dotted line shows confidence interval for normal excitability.

bloodflow by relaxing the muscles by blunt separation and removal of tight sacs (fascia and skin); sometimes, in grave cases, minor tibial bone can be removed for this purpose [4,6]. These manipulations are directed against both damaging factors.

Our experiments showed that closed FT improved tissue pressure and electrical excitability of shin muscles, which however remained increased during the first day of PCP.

Randomized morphological studies on day 1 of PCP and 2 weeks after injury confirmed better state of muscle structures and more pronounced restoration processes in the studied limb segments in fasciotomied animals.

Our findings suggest that CS can be predicted by electrodiagnosis before intrafascial edema from changes in electrical parameters of induced muscle contractions using an accurate method of stimulation impedance myography [2].

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