

Electrically induced short-lasting tetanus of the calf muscles for prevention of deep vein thrombosis

Electrical calf muscle stimulation during surgery has been used for the prevention of deep vein thrombosis (DVT) with varied results in several studies. This effect is mainly achieved by the reduction of venous stasis in the legs. Another possible beneficial effect might be an increased fibrinolytic activity of the blood secondary to the muscle contractions. Previously, single electrical impulses have been used for stimulation, giving rise to 'single twitches' in the muscles. In the present study the effect on calf volume of muscle stimulation with groups of impulses giving a short-lasting tetanus was investigated. Changes in calf volume were recorded by strain gauge plethysmography. Optimal values for duration, number and frequency of the impulses within the groups were determined. Stimulation with groups of impulses reduced calf venous volume approximately three times more efficiently than stimulation with single impulses. Calf muscle stimulation did not enhance the increase in fibrinolytic activity of venous blood observed after oesophago- or laryngoscopies under general anaesthesia.

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In the 1960s Doran et al. claimed that calf muscle stimulation prevented decrease in venous flow velocity in the legs during operation and reduced the frequency of postoperative deep vein thrombosis (DVT) (1, 2). Since then, the effect of calf muscle stimulation on postoperative DVT has been investigated in several studies where the diagnosis of DVT has been based on the ¹²⁵I-labelled fibrinogen uptake test (3-7). In some studies a prophylactic effect was demonstrated; in others no effect was observed.

The duration and frequency of the electrical impulses used have varied considerably. Nicolaidis et al (8) measured the effect of varied impulse frequency on the increase in femoral vein blood flow velocity induced by calf muscle stimulation and found that the optimal rate of stimulation was 12-15 impulses/min. Such stimulation was shown to reduce the incidence of postoperative DVT significantly. It was suggested that the beneficial effect of stimulation was a result not only of a reduction of venous stasis but also of an increased fibrinolytic activity of the blood secondary to the muscle contractions.

In all previous studies on this topic, single impulses provoking single muscle twitches have been used. By stimulation with appropriate groups of impulses it should be possible to obtain a summation of the contractions, i.e. a short-lasting tetanus. The tension developed during a complete tetanus is about four times that of a single twitch (9).

The aim of the present study was to investigate whether calf muscle stimulation with groups of impulses producing a short-lasting tetanus is more efficient in reducing venous stasis than stimulation with single impulses. Furthermore, the effect of stimulation on the fibrinolytic activity of the venous blood has been investigated. A preliminary report of the present results has been published elsewhere (10).

Patients and methods

Study groups

Plethysmographic studies: The volume changes in the calves induced by electrical calf muscle stimulation were studied in 10 patients operated on for various abdominal diseases (7 women and 3 men, mean age 62 years, range 32-78 years).

Fibrinolytic studies: The effect of calf muscle stimulation on blood fibrinolytic activity was studied in a group of 20 patients who underwent laryngoscopies or oesophagoscopies. The patients were divided into two groups according to a randomized schedule: a control

group and a stimulation group. The mean age in the control group was 65 years and in the stimulation group 66 years (ranges 46-82 and 44-81 years respectively). Nine out of 10 patients in the control group and 6 out of 10 patients in the stimulation group were men. One patient in the control group and 4 in the stimulation group had a known neoplastic disease.

Methods

Plethysmographic studies: A Whitney strain-gauge plethysmograph was used to record volume changes in the calves induced by electrical muscle stimulation (11). Tourniquets were applied around the legs above the knees. Latex gauges filled with mercury were placed around the largest girths of the calves. The changes in circumference were registered on a two-channel writer (Servogor RE 520). Two pre-geled electrodes (MPI) were attached just below the knee joint and above the ankle on the back of the leg. These two electrodes were connected to a stimulator giving galvanic square wave impulses constructed and produced in the Department of Physiology, University of Göteborg. Stimulation could be varied in duration, amplitude and frequency of the impulses. Furthermore, the impulses could be arranged in groups with different numbers and different frequencies of impulses within each group, along with different intervals between the groups. The polarity of the impulses was regularly altered between each group of stimulation to avoid skin damage caused by electrolysis. During the recordings the patients were anaesthetized with barbiturate, N₂O+O₂ and morphine and were given muscle relaxants.

Fibrinolytic studies: In the stimulation group optimized calf muscle stimulation was performed for 10 min during endoscopy while the other group served as control. Ten millilitres of venous blood were withdrawn from a cubital vein after premedication (0.5 mg atropine, 5-10 mg diazepam) but before induction of narcosis. Another 10 ml were withdrawn after endoscopy with or without stimulation when the patients were still fully anaesthetized (halothane, N₂O+O₂ and Celocurin). The concentration of fibrinogen, plasminogen and antithrombin III in the blood was determined (12-14). The fibrinolytic activity in the blood was estimated from the area of lysis on a fibrin plate (15).

Statistics

Conventional statistical methods were used to calculate the means and standard error of the means. The statistical significance of the differences between pairs were tested by the Wilcoxon matched pairs signed ranks test (16).

Results

The effect on calf volume of stimulation with single impulses of different durations is illustrated in Fig. 1. In the upper record

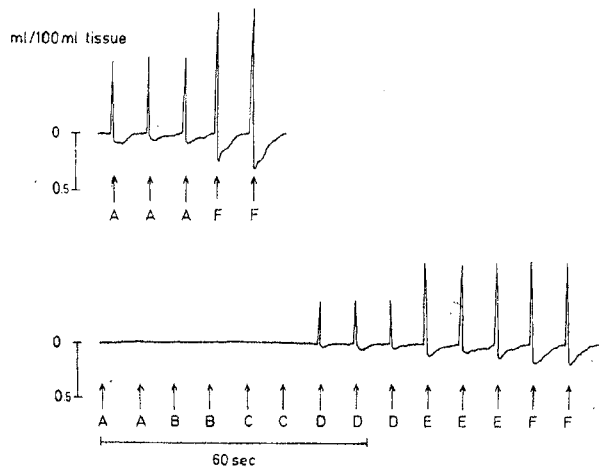


Fig. 1. Effect on calf volume of electrical stimulation with impulses of different duration before (upper record) and after (lower record) administration of muscle relaxants. (A, 1 ms; B, 2 ms; C, 4 ms; D, 8 ms; E, 25 ms; F, 48 ms.)

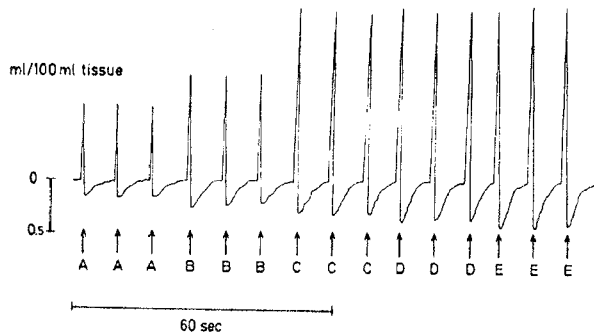


Fig. 2. Effect on calf volume of electrical stimulation with groups of impulses and different numbers of impulses within each group. Impulse frequency within the groups 8 impulses/s. Impulse duration 50 ms. (A, 1 impulse/group; B, 2 impulses/group; C, 4 impulses/group; D, 6 impulses/group; E, 8 impulses/group.)

the patient was anaesthetized with barbiturates only; in the lower record muscle relaxants were given as well. In the upper record each impulse marked by an arrow elicited a short-lasting upward-directed contraction artefact immediately followed by a transient reduction in calf volume due to diminished venous pooling. When muscle relaxants were given as well, short impulses did not evoke any muscle contraction. Impulses with a duration of 25 ms or longer still provoked forceful contractions and consequent reductions in venous volume. In the experiments described below an impulse duration of 50 ms was used.

Fig. 2 illustrates the effect on calf volume of stimulation with different numbers of impulses within each group when no tourniquet was applied. The reduction in venous volume increased with the number of impulses. The results of stimulations performed on 5 patients are summarized in Fig. 3. Six impulses per group were chosen for the following experiments.

The effects of stimulation with different frequencies of impulses within the group are shown in Fig. 4. Stimulation with 6 and 8 impulses/s appeared to be most efficient in reducing venous volume (Fig. 5). Eight impulses per second were therefore used in the following experiments.

In Fig. 6 the effect of stimulation with single impulses is compared to stimulation with groups of impulses after applying a venous stasis of 50 mmHg. Stimulation was begun when the venous pressure had increased to the same pressure as in the tourniquet and thus the volume curve had levelled off. Stimulation with groups of impulses was considerably more efficient in reducing the artificially applied venous stasis. The improvement obtained by stimulation with groups of impulses

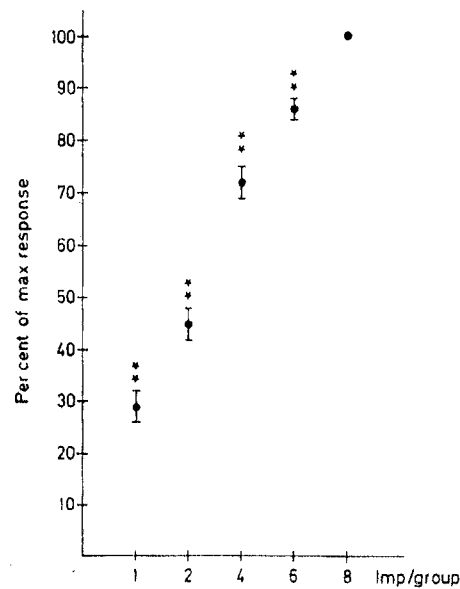


Fig. 3. Effect on calf volume of electrical stimulation with groups of impulses and different numbers of impulses within the groups expressed as percentage of maximal response. Impulse frequency 8 impulses/s. Impulse duration 50 ms. Mean values \pm s.e. from 9 series of stimulations with or without 50 mmHg of venous stasis performed on 5 patients. (Significant differences between actual type of stimulation and type of stimulation causing maximal reduction in calf volume, $**P < 0.01$).

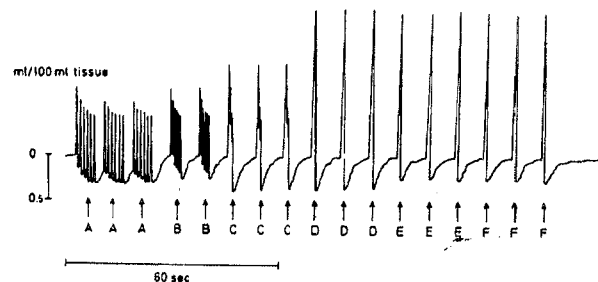


Fig. 4. Effect on calf volume of stimulation with groups of impulses and different impulse frequency within the groups. 6 impulses/group. Impulse duration 50 ms. (A, 1 impulse/s; B, 2 impulses/s; C, 4 impulses/s; D, 8 impulses/s; E, 16 impulses/s; F, 32 impulses/s.)

instead of stimulation with single otherwise identical impulses is further shown in Table 1 where data from 10 patients are given.

Values for antithrombin III, plasminogen, fibrinogen and fibrinolytic activity before and after endoscopy of the upper airways or the upper digestive tract with or without stimulation are given in Table II. The only significant change observed was an increase in the fibrinolytic activity in the control group. A numerical, though not statistically significant, increase was observed also in the stimulation group. If the two groups are combined, a significant increase after endoscopy, with or without stimulation, was observed ($P < 0.05$). The blood content of fibrinogen and plasminogen appeared to be somewhat higher and the fibrinolytic activity somewhat lower, before the endoscopies, in the stimulation group than in the control group.

Discussion

Stimulation with groups of impulses giving a short-lasting tetanus in the calf muscles reduced the venous volume with or without artificial venous stasis considerably more efficiently than stimulation with single impulses. Before muscle relaxants were given, stimulation with an impulse duration of only 1 ms evoked forceful contractions which were evidently the result of nerve stimulation since this response was totally abolished after the administration of nerve muscle blocking agents. When

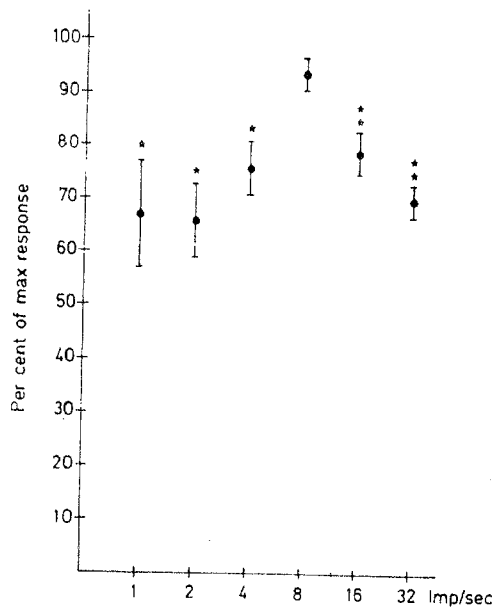


Fig. 5. Effect on calf volume of stimulation with groups of impulses and different impulse frequency within the groups expressed as percentage of maximal response. 6 impulses/group. Impulse duration 50 ms. Mean values \pm s.e. from 9 series of stimulations with or without 50 mm Hg of venous stasis performed on 5 patients. (Significant differences between actual type of stimulation and type of stimulation causing maximal reduction in calf volume. * $P < 0.05$; ** $P < 0.01$).

using electrical calf muscle stimulation on patients under full anaesthesia with muscle relaxation, it is necessary to use an impulse duration of at least 25 ms.

The values for antithrombin III, plasminogen and fibrinogen did not change after the endoscopic examinations with or without stimulation, while the fibrinolytic activity increased in the control group.

The strength of the impulses used in the present study (40–50 mA) was of the same order of magnitude as used by Becker and Schampi (4). Most other authors do not specify the strength of the impulses. From the values for voltage and estimated patient resistance given by Browse and Negus (3) and Pollock (7), it can be calculated that the strength of the impulses used in these studies was approximately 40 mA. Nicolaides et al. (8) used the same type of stimulator as Pollock (Thrombophylactor). It thus seemed justified to assume that the strength of the individual impulses used in the present study was of the same order of magnitude as in the previous ones.

The impulse duration used by Becker and Schampi when studying the effect of calf muscle stimulation on postoperative DVT (4) was only 10 ms. They also stated that nerve muscle blocking agents in high doses completely arrested the stimulation effect and that in their study it was necessary to use small doses of these drugs intermittently. Apparently, these problems could have been overcome by using a somewhat longer impulse duration.

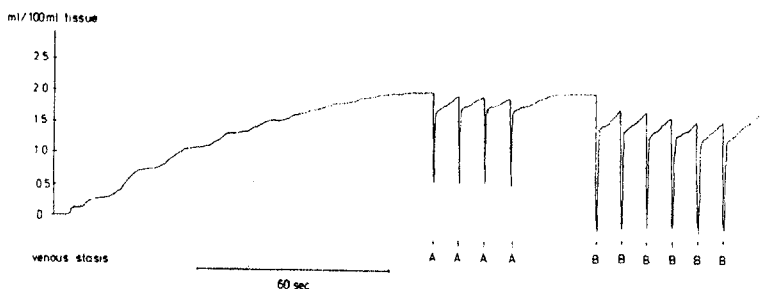


Fig. 6. Effect on calf volume of venous stasis (50 mmHg) and subsequent stimulation with single impulses and groups of impulses. Impulse duration 50 ms. (A, single impulses; B, groups of impulses, 6 impulses/group, 8 impulses/s.)

Table 1: REDUCTION OF VENOUS VOLUME (ml/100 ml) WITH AND WITHOUT VENOUS STASIS INDUCED BY CALF MUSCLE STIMULATION WITH SINGLE IMPULSES AND GROUPS OF IMPULSES

	Venous stasis 50 mmHg (n = 10) (Mean \pm s.e.)	No venous stasis (n = 9) (Mean \pm s.e.)
Stimulation with single impulses 8 impulses/min	0.22 \pm 0.05	0.29 \pm 0.11
Stimulation with groups of impulses 8 groups/min 6 impulses/group 8 impulses/s	0.65 \pm 0.13*	0.84 \pm 0.23*

* Differences between stimulation with single impulses and groups of impulses, $P < 0.01$.

The optimal impulse frequency found by Nicolaides et al. (8) was 12–15 impulses/min. Since stimulation with groups of impulses empties the veins of the lower limb more efficiently, it was considered appropriate in the present study to use a somewhat lower number of contractions per minute (8 contractions/min).

It is generally agreed that a pooling of venous blood occurs in the calves during surgery (17, 18). However, opinion differs concerning changes in volume flow during operation. Clark and Cotton (19) demonstrated a reduction in volume flow during surgery measured with thermodilution technique. Contrary to this, Lindström et al. (18) found a 100 per cent increase in volume flow during cholecystectomies measured by means of plethysmography. Since the operative procedure *per se* can increase the blood flow to the lower limb, we did not investigate whether electrical calf muscle stimulation further increased blood flow but were instead mainly concerned with the reduction in venous volume caused by such stimulation.

A significant increase in the fibrinolytic activity of peripheral venous blood was observed in the control group and a numerical, though not statistically significant, increase in the stimulation group. It is not conceivable that stimulation provoked a rapid transient increase in the fibrinolytic activity which was missed in the present study since these events are quite slow (15). The increase in fibrinolytic activity observed during the narcosis might be explained by the forceful muscle contractions caused by Celocurin (20).

Thus, stimulation of the calf muscles with groups of impulses giving short periods of tetanus reduces postoperative venous stasis considerably more than single impulses.

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Table II: BLOOD CONCENTRATIONS OF ANTITHROMBIN III, PLASMINOGEN AND FIBRINOGEN AND FIBRINOLYTIC ACTIVITY OF BLOOD BEFORE AND AFTER ENDOSCOPIES OF THE UPPER RESPIRATORY TRACT OR OESOPHAGUS WITH OR WITHOUT OPTIMIZED CALF MUSCLE STIMULATION*

	Antithrombin III (%)		Plasminogen (%)		Fibrinogen (g/l)		Fibrinolytic activity (mm ²)	
	Before	After	Before	After	Before	After	Before	After
Control group	106 ± 5	108 ± 5	110 ± 4	108 ± 6	3.2 ± 0.2	2.9 ± 0.2	176 ± 17	197 ± 14†
Stimulation group	104 ± 4	104 ± 4	123 ± 6	120 ± 4	3.6 ± 0.2	3.5 ± 0.2	159 ± 11	168 ± 14

* Mean ± s.e.; n = 10.

† Differences between values obtained before and after endoscopy, P < 0.01.

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