Acta orthop. Scandinav. *41*, 249–260, 1970

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CHANGES IN THE MUSCLE AND SKIN BLOOD FLOW FOLLOWING LOWER LEG FRACTURE IN MAN

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Received 2.vi.69

It is clinically well known that, after skeletal fracture in the human lower leg or foot, local oedema may persist for a considerable period of time. The question arises whether a change in local blood circulation or a change in capillary permeability and lymph damage is the reason for the oedema.

Several authors, using different techniques, have shown on animals that following an experimental fracture or immobilization of an extremity, the vascular volume and blood flow in muscles of the impaired extremity are increased at least relatively (Hulth & Olerud 1960, 1961, Imig et al. 1953, Lexer 1904, Ray et al. 1967, Rhinelander et al. 1968, Semb 1966, Stulcová & Hudlická 1967, Wray 1964, Wray & Lynch 1959). This has been made evident not only by measurements of blood flow but also anatomically, both for muscle and bone tissues.

Apart from clinical observations following direct vascular injury (Bassett & Silver 1966, Baumgartl et al. 1958, Bovill 1963, Chavez et al. 1967, Freeark et al. 1967, Hjelmstedt 1968) or studies of blood flow and vascularization of the fractured bones (Abramson 1962, *Handbook of Physiology* 1963, Lorimier et al. 1946, Sun Shik Shim 1968, Van Dyke et al. 1965), next to nothing is known about the existence and duration of circulation changes in the skin and muscles of a fractured extremity in man (Medlars 1967). The aim of the present study is to obtain some data on these points.

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* Research fellow of the exchange scientific programme of the Slovak Academy of Sciences, Bratislava, and Royal Academy of Engineering, Stockholm.

** Research fellowship of Deutsche Forschungsgemeinschaft, supported by the Swedish Medical Research Council (Project No. B68-14X-2331).

Table 1.

Patient no.	Sex	Age	Diagnosis	Time between fracture and investigation (weeks)	Type of fixation (no. of screws)	Patient walks (weeks)
1	M	36	Fract. tib. et fib. l. dx. disloc.	5/7	Metal plate (13)	0
2	M	25	Fract. tib. et fib. metaphys. l. sin. disloc.	9	2 metal plates (4 and 7)	0
2 a				15		0
3	F	30	Fract. tib. et fib. diaphys. l. sin. disloc.	11	Metal plate (7)	1
4	M	21	Fract. tib. et fib. l. sin. disloc.	12	Metal plate (13)	3
4 a				17		8
5	F	50	Fract. maleolaris l. sin. disloc.	12	Cerclage (3)	1
5 a				14		3
6	M	46	Fract. tib. et fib. l. dx.	56	Metal plate (8)	44
7	M	19	Fract. tib. et fib. l. sin. disloc.	60	Metal plate (9)	48
8	M	60	Fract. maleoli et syndosmosinis fib. l. dx. Dislocatio gravis	14	Sutura ligamenti et capsulae. (2)	2
9	M	50	Fract. tib. et fib.	15	Metal plate	0

			l. sin., dislocata complicata.		(12)	
10	F	22	Fract. cruris l. dx.	15	Metal plate (7)	4
11	M	43	Fract. tib. et fib. l. dx. dislocata, complicata.	17	Metal plate (9), skin transplant.	4
12	F	47	Fract. tib. et fib. l. dx. disloc.	22	Metal plate (10)	5
13	F	36	Fract. tibiae diaphysalis l. dx. dislocata Pseudarthrosis	30 after 1st oper. 3 after 2nd oper.	1st oper.: cerclage 2nd oper.: nail	0
13 a				32 5		2
13 b				36 9		6
13 c				39 12		9
14	M	21	Fract. tib. et fib. l. dx.	36	Metal plate	28
15	M	55	Fract. cruris l. sin.	40	Metal plate	32
16	M	18	Fract. tib. et fib. l. dx.	56	Metal plate	40
17	M	51	Fract. tib. l. sin.	56	Metal plate (12)	40
18	M	28	Fract. cruris l. sin.	48	Nail	40
19	F	46	Fract. cruris l. sin.	72	Metal plate	60

MATERIAL AND METHOD

Altogether 19 patients (13 men and 6 women) aged between 18 and 60 years (M = 36 years), without any symptoms of cardiovascular disorder, with a unilateral tibial or tibiofibular fracture (9 on the right, 10 on the left leg) were investigated. Further details concerning the investigated subjects are given in Table 1.

The time lapse between the fracture and the investigation varied from 1 week to 18 months. In 4 patients the investigation was repeated at 2 to 6 week intervals.

On the day of the accident the fragments were replaced surgically and fixed by means of A.O.-metal plates and screws (nailing was used in two cases). The operation was carried out under Fluothane narcosis (in one case under lumbar anaesthesia), in a bloodless operative field, and lasted 55–130 minutes. In no case was the extremity immobilized with a plaster bandage. Within 11 weeks (on an average), the patients were allowed to place full weight on the injured extremity. Up to that time they could move on crutches and practise gymnastics.

The arterial blood flow through the vascular bed of the lower leg muscles and the cutaneous bed of the foot was measured by venous-occlusion plethysmography. Flexible, air-filled rubber cuffs with a double wall (segmental or terminal plethysmographs) according to Dohn (1956) were used. The cuffs adhered with moderate pressure to the investigated segment (40–50 mm H_2O) and enabled measurement of the blood flow without any discomfort even in the fractured extremity. Pressure changes in the plethysmographic cuffs were recorded by means of pressure receptors (0–30 mm Hg, Elema – Sch.) on a Mingograph 81 (Elema – Sch., Stockholm). For a more detailed description of the method, see Graf & Westersten (1959) and Graf (1964). The same arrangement was also used to measure the venous capacity (compliance). The volume change in the investigated segment induced by a change in the occlusive pressure in the range of 0–60 mm Hg was taken as a relative measure of the distensibility of the capacitive vessels.

All the investigations of blood flow rate and venous capacity were carried out simultaneously on comparable segments of the healthy and the fractured extremity, respectively. The arterial blood flow was measured repeatedly during rest and in the course of the first two minutes of reactive hyperaemia, induced by a 4-minute long arterial occlusion (for the skin blood flow) or an arterial occlusion lasting likewise 4 minutes and including one minute of ischemic muscular work (for muscle blood flow). All the blood flow values represent the means from 5–8 measurements.

RESULTS

In the majority of cases significantly higher blood flow values, both in the calf muscles and in the acral skin bed of the foot, were found in the fractured than in the healthy leg (Figures 1A, 2A). The calf blood flow (muscle) in the fractured extremity averaged, for the whole group, 7.4 ml/100 ml per min and in the foot (skin), 4.2 ml/100 ml per min. These values correspond to 185 and 212 per cent, respectively,

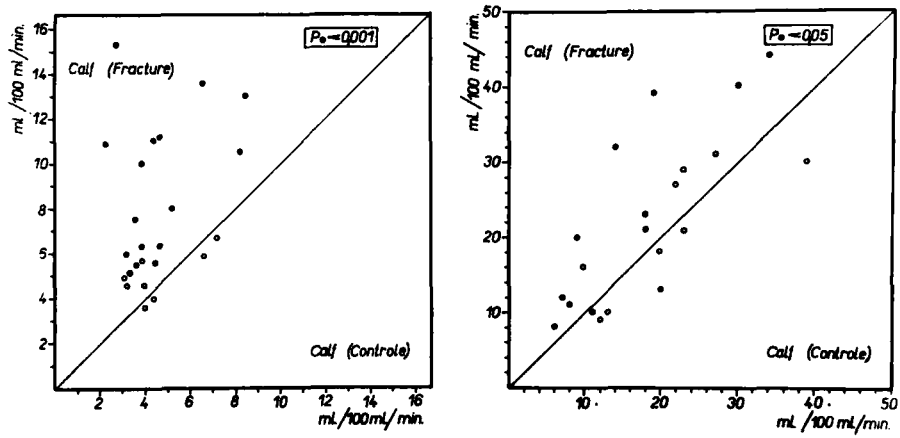

Figure 1 A and 1 B. Muscle blood flow in the calf of a fractured extremity (ordinate) related to the calf blood flow of the intact control leg (abscissa). Unfilled circles—blood flow values in subjects investigated 9–18 months following the fracture. Figure 1 A. The average blood flow values measured at rest. Figure 1 B. The average blood flow values measured during 2 minutes of reactive postischemic hyperaemia.

of the blood flow through the corresponding segments of the healthy extremity. At the same time no unequivocal relationship was found between the degree of blood supply in the lower leg and that in the foot.

In the subgroup investigated 9–18 months following the fracture, no difference was found in the muscle and the skin blood flow between the intact and the fractured extremity (Figures 1A, 2A—unfilled cir-

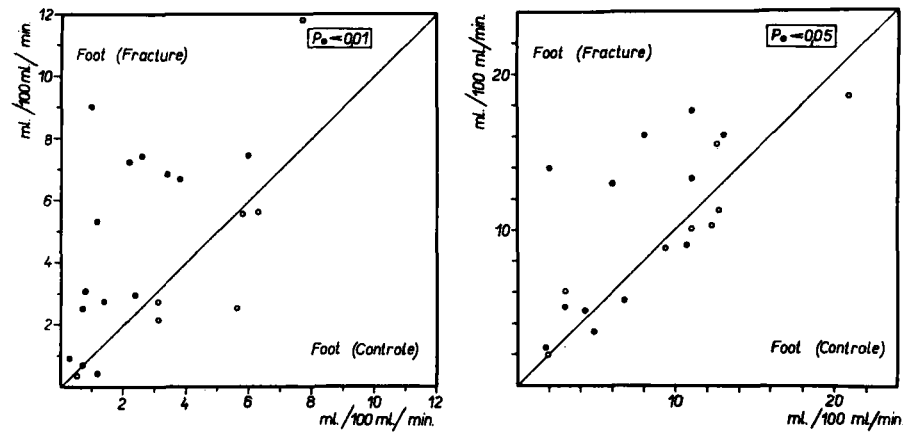

Figure 2 A and 2 B. Skin blood flow in the foot. For description see Figure 1.

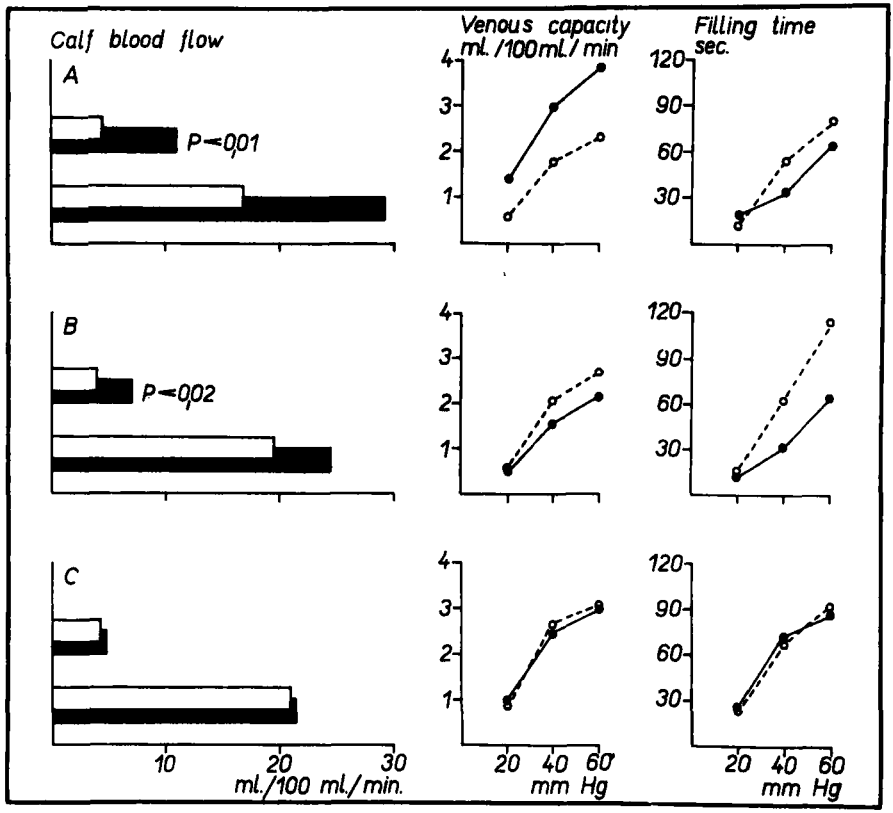

Figure 3. Values of blood flow (left columns), venous capacity (middle), and filling time (right) in three subgroups A, B, and C (for specification see text). Black columns and heavy lines represent the values obtained from measuring in the fractured extremity, white columns and dashed lines—values from intact control extremity. The upper double-columns in all subgroups represent blood flow values at rest, the lower double-columns values of blood flow in reactive hyperaemia.

cles, Figure 3C) when evaluated as a group. An intra-individual comparison had, however, shown the respective values for muscle and skin blood flow to attain in some cases as much as 158 and 154 per cent of those in the intact extremity.

If this subgroup (investigated 9–18 months following the accident) is omitted from the evaluation, the mean blood flow through the muscle of the injured extremity in the rest of the patients is 9.3 ml/100 ml per min, i.e. 216 per cent of the value in the healthy extremity, 4.3 ml/100 ml per min ($P < 0.01$). The corresponding skin blood flow

through the foot was 4.6 ml/100 ml per min, i.e. 242 per cent of 1.9 ml/100 ml per min in the control extremity ($P < 0.01$).

The mean blood flow values during the first two minutes following the end of ischaemia, in the reactive hyperaemia, showed a tendency for the differences between the fractured and the intact extremities to diminish both in the calf muscles (23.0 ml/100 ml per min in the fractured against 16.7 ml/100 ml per min in the intact, i.e. 138 per cent) and in the skin vascular bed (10.0 ml/100 ml per min against 6.9 ml/100 ml per min, i.e. 145 per cent). Nevertheless, the differences were still statistically significant ($P < 0.05$) (Figures 1B, 2B).

We designated the ratio of the blood flow in reactive hyperaemia to that at rest as "tonal reserve". This reserve was very low in cases with markedly enhanced blood flow due to bone fracture—in Group A (Figure 3) it was down to 2.65 and in Group B to 3.51, compared to the control values of 4.35 in the intact extremity. This ratio expresses also a considerable decline of the resting vasomotor tone in the fractured extremity.

As could be expected, no difference in reactive hyperaemia of muscle and skin between the healthy and the fractured extremity was found in the subgroup investigated 9–18 months following the fracture. In this subgroup there was no obvious local oedema in the injured leg. In fact, the mean blood flow values and the peak-flow in some of the patients of this group were even lower during the course of reactive hyperaemia in calf muscle of the fractured extremity. A control investigation of the muscle blood flow by the ^{133}Xe clearance method corroborated this finding (Delius & Kellerová, unpublished observation).

Changes in the vascular capacity of the calf segment of the fractured extremity were not unequivocal in comparison with the constant finding of the markedly increased blood flow in this region: (A) The venous capacity in the calf segment of the injured extremity was significantly higher than in the opposite uninjured segment in 6 subjects ($P < 0.01$ at congesting cuff pressures of 40 and 60 mm Hg) Figure 3, Group A). (B) Rather lower values were found in 5 patients (Figure 3, Group B). (C) Practically no differences in the vascular capacity of the calf segment were found in the group investigated 9–18 months following the injury (Figure 3, Group C, $N = 8$).

An examination of the blood flow in these subgroups showed that in Group A (with increased vascular capacity of the calf segment on the fractured side), the muscle blood flow at rest is significantly higher (11.03 ± 3.3 ml/100 ml per min) than in Group B with a smaller

vascular capacity (6.96 ± 1.8 ml/100 ml per min) ($P < 0.05$). As regards clinical symptoms, patients of Group A showed a greater proneness to oedema formation in the fractured extremity.

The time needed to attain peak-volume of the investigated calf segment from the start of the occlusion was designated as filling time, which depends on congesting cuff pressure, vascular tone, state of vein filling, and, above all, size of arterial influx. The curve for the relationship between the height of the occlusive pressure and the filling time of the investigated segment, plotted from values measured on the fractured extremity with a high blood flow, shows a shortened filling time during congestion in comparison with the intact or healed limb (Figure 3).

DISCUSSION

Acute and chronic experiments with artificial fractures in animals (Lexer 1904, Ray et al. 1967, Rhinelander et al. 1968, Sun Shik Shim 1968, Wray 1964, Wray & Lynch 1959), which show increased blood flow and increased volume of the resistance and capacity section of the vascular bed in the fractured limb, justified the assumption that a fracture in man might likewise induce changes in the blood flow of individual compartments of the vascular bed of the limb. Apart from Giebel (1964) who found increased temperature of the skin in the area of the fracture as late as three weeks after the accident and Baumgartl et al. (1958) who found by angiography a denser vascular pattern, enlarged blood vessels, and a faster flow of a contrasting substance in extremities with tibial fracture, we have not come across reports that deal specifically with haemodynamic changes in the muscle and skin vascular bed of limbs accompanying non-complicated fractures of the long bones in man.

A uniform finding in our group of subjects was a significant increase of blood flow through the calf and foot vascular bed of the injured lower limb.

Neither an evaluation of the entire material nor repeated individual evaluations of the data over a period of 1–22 weeks following the fracture showed any correlation between blood flow and the time lapse after the accident. Since our patients were investigated at various intervals after the injury and at different stages of the healing process of the fracture, we could not follow more closely the evolution of changes in the blood flow. But the overall trend permits the assump-

tion that in the majority of cases there is no further increase of the blood flow after the thirteenth week after the fracture.

Data obtained from the subgroup investigated 9–18 months after the fracture lead us to conclude that, in the absence of complications during the healing process, the originally increased blood flow values in the calf (muscle) and foot (skin) become normal once again which may be ascribed more or less to the completion of the healing process and gradual normal loading of the extremity.

The tendency for the difference in blood flow values between the injured and the intact limbs during reactive hyperaemia to level out may be explained by the fact that the relative ratio of the increased blood flow due to the fracture loses its significance at peak hyperaemia. Nonetheless, even during this situation of reactive hyperaemia, the differences between the intact and the fractured limb persist at the limit of statistical significance: this again implies the presence of further factors affecting the vascular bed.

An intra-individual comparison of the degree of increased blood flow failed to give any correlation between the measured values in the muscle and the skin regions, a fact which is probably associated with the relatively high reactivity of the skin—mainly the acral vascular bed to outside stimuli, thermal changes, etc.

An analysis of the causes and the mechanisms that induce an increased blood flow through the calf and the foot vascular bed of the fractured extremity must take into account several factors. Changes in blood supply of these tissues were noted already in the first and second week following the fracture. At this early stage, predominantly local and reflex effects associated to the trauma itself may be presumed to be causally involved: enhanced local metabolism, changes in pH, pain, lesion of nerve tissue, or ischaemia during operation. An increase of vascular volume and blood flow in the muscle and the bone vascular bed is induced in a relatively short time not only by the healing process itself (Abramson 1962, Baumgartl et al. 1958, *Handbook of Physiology* 1963, Ray et al. 1967, Rhinelander et al. 1968, Sun Shik Shim 1968, Van Dyke et al. 1965, Wray 1964, Wray & Lynch 1959) but also by the immobilization of the limb (Hulth & Olerud 1960, 1961, Imig et al. 1953, Semb 1966, Stulcová & Hudlická 1967) as has been shown in animal experiments. The action of these mechanisms we presume to be cumulated and as such responsible for the observed increase in blood flow. Nevertheless, we incline to the view that the increased blood flow in the muscle is, to a major extent, part of the pathophysiological picture

of the fracture itself, and that the haemodynamic changes accompanying muscular atrophy due to inactivity during immobilization of the limb are an additive factor. This assumption is supported by our failure to find any correlation between the calf blood flow values and the degree of the muscle atrophy—if it was present—qualitatively assessed on the basis of clinical investigation. The extremity was not completely immobilized during the healing period: the patients had restricted freedom of limb movement and began to walk and put pressure on it relatively early. In addition, an increase in the calf blood flow was found to be accompanied by a significant increase of blood flow in the acral skin region of the foot. It would then seem that a rather important vasodilatory reaction takes place in the fractured limb, which affects not only various tissues (muscle, skin), but also limb segments remote from the fracture area and various sectors of the consecutive vascular bed, as implied in the parallel changes observed in the capacitance vessels.

An experimental correlate of this described decline in vasomotor tone in the fractured limb might be seen in the work by Wray (1964) and Wray & Lynch (1959) who found increased values of blood flow in the femoral artery following a tibial fracture in the dog and by Ray et al. (1967) who found by means of labelled albumin in rabbits that an increased blood volume persists in the tissues of the limb as late as eight weeks after the fracture.

SUMMARY

In a group of 13 men and 6 women, aged 18–60 years, with unilateral tibial or tibio-fibular fractures (9 right, 10 left), the calf (muscle) and foot (skin) blood flow was investigated by means of venous-occlusion plethysmography simultaneously in the fractured and intact legs.

In subjects examined 1 to 22 weeks following the fracture, we found a significantly higher muscle blood flow in the calf segment of the fractured extremity, on an average 9.3 ml/100 ml per min (216 per cent), in comparison with the intact limb, 4.3 ml/100 ml per min ($P < 0.001$), and a higher skin blood flow of the foot, 4.6 ml/100 ml per min (242 per cent) against 1.9 ml/100 ml per min ($P < 0.01$).

In the course of reactive hyperaemia, induced by 4 minutes of ischaemia, there was a tendency for the difference in blood flow values between the injured and the intact limbs to level out, but they still remained on the border of significance ($P < 0.05$).

After 9–18 months following the fracture, the enhanced muscle and skin blood flow in the fractured leg mostly had returned to normal. Nevertheless, in some subjects we found higher values even after this time.

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