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CIRCULATION OF AMPUTATION STUMPS

Arteriographic and Skin Temperature Studies

By

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Pain in amputated limbs is very common. But there are no reliable data on the incidence of such pain in clinical series classified according to the indication for amputation and the type of the pain. The discomfort experienced by amputees may vary in character. Sometimes its cause is obvious, as that resulting from a poorly fitted prosthesis or from infection of the skin or stump, and relief is readily afforded. There is also pain of more obscure derivation. Two types can be distinguished, which may occur singly or in combination. One is the phantom pain strictly limited to the phantom limb, usually to part of the hand or foot and invariably recurring in the same situation and with the same character in the individual patient. Persons suffering from this type of pain are usually able to describe it distinctly. The other type is the stump pain which may occasionally be very severe but which is not rigidly delimited. This is more of the character of causalgic pain (*Leriche* 1950).

The pathogenesis of the pain is largely unknown. *Leriche* (1950) believed the origin of phantom pain to be changes in the severed spinal nerves such as amputation neuroma and more general nervous lesions. Stump pain, on the other hand, he maintained to be of sympathetic derivation. It is *Leriche*'s school, in particular, which holds the cause of the pain to be pathologic changes of different types in the stump. Others regard it as of central derivation. *Leriche* demonstrated hypervascularization in stumps giving stump pain in some cases, but did not specify the number of patients examined or the arteriographic technique used. Some animal experiments have shown a similar tendency

to hypervascularization of amputation stumps, as reported by *Abeatici & Ferrero* (1953), *Hulth & Olerud* (1962) and others. On histologic examination, *Ferrero & Abeatici* (1953) found hyperplasia of nerve fibres in vascular walls and connective tissue. There is, then, much to suggest that neurovascular changes in the soft tissues of the stump give rise to pain. Apart from *Leriche*'s studies, no investigations of the vascular changes in amputation stumps in human subjects have been published. But numerous psychiatric studies of amputees are on record (*Cronholm* 1951, *Haber* 1956, *Simmel* 1958, and others). However, such investigations have been directed chiefly to phantom limb—the sensation that the amputated part of the extremity is still there—which is an extremely common phenomenon. *Loon* (1960) described oscillometric and temperature studies carried out by Ellen Brown. The oscillometric determinations showed the pulse amplitudes to be lower in the amputated than in the sound limb, and the amputation stump was also almost invariably colder than the corresponding point of the intact side. Ellen Brown found no correlation between the severity of the phantom or stump pain and the temperature recorded.

We believed it to be of interest to study in closer detail the vascular changes demonstrated in the soft tissues of amputation stumps by *Leriche*, and to correlate the findings with the clinical analysis of the patient's symptoms; we also carried out simple skin temperature determinations while raising body temperature.

MATERIAL AND METHODS

The patients in the present series underwent amputation for injury or tumour. Those amputated for vascular disorders were not included in the investigation, since the method of examination was in part founded on comparison of the amputated limb with a sound fellow in which the vessels were supposedly healthy. The patient's symptoms were closely analysed as regards the presence of pain, its incidence, and nature.

Arteriography was performed by femoral puncture and the injection of 20 ml. of 60 per cent Urografin by hand. The injection was made in the retrograde direction in order to facilitate the mixture of contrast medium and blood. A film changer was used, one exposure being made per second for approximately 25 seconds. In cases of lower leg amputation, both the thigh and the distal stump were examined roentgenographically. The examination in most cases elicited pain or a sensation

of warmth, which was in some instances fairly severe. The discomfort was short-lived and was found to correspond in time with the arterial phase of the arteriogram. It was situated in the amputated leg in its entirety, or, in a few instances, to only part of the amputation stump. Thirty-one patients were examined arteriographically in this manner.

Temperature was measured with a thermoelectric apparatus, electrodes being placed as follows: 1) a skin electrode on the medial side of the stump approximately 10 cm. above its free end, 2) a skin electrode on the stump end, 3) a skin electrode at a point corresponding to (1) on the sound leg, 4) a skin electrode on the big toe of the intact leg, and 5) and 6) muscle electrodes on the lateral side of the stump approximately 10 cm. above its free end and at a corresponding point on the other leg. The muscle electrodes served for reference. Before determining temperature, the patient lay with uncovered legs for between 20 and 30 minutes. When the temperature readings at five-minute intervals had become stabilized, the body including the arms was covered with a large electric blanket. A thick sheet was interposed between the blanket and the body for protection against burns. The patient's symptoms, if any, were recorded at each reading. In some instances, 1 ml. of dihydroergotamine was given to hasten the vasodilatation. Altogether 24 patients were examined in this manner, all except two of whom also underwent arteriography.

RESULTS

Altogether 33 patients were examined with one or both of the two methods described above. Of these, 16 were wholly asymptomatic and walked well with their prostheses. Nine suffered from constant disabling pain: stump pain in three cases, phantom pain in five, and a combination of both in one case. The symptoms in the remaining nine cases were not so severe as to be disabling, but consisted in slight or more marked—but intermittent—pain. The intermittent pain was associated with weather changes, or occurred on removing the prosthesis, at night, or "at any time". None of the patients amputated in childhood or up to the age of 20 years had any pain (seven were under 20 years).

The arteriographic appearances varied fairly widely, but a schematic classification into groups was possible. In one of the groups the arteriograms showed the arteries to be tortuous, in some cases of fine calibre and forming a dense network in part or the whole of the amputation stump. Compared with the rest of the amputated limp and with the

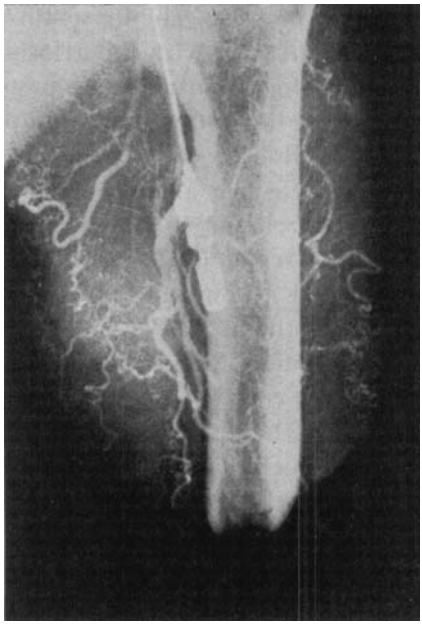

Fig. 1.
Male, 59 years, amputated in 1948. Arteriography 1960. Pain and tenderness in the amputation stump. Tortuosity of both arteries and veins serving muscles.

corresponding portion of the other leg, the appearances were those of hypervascularization. In a small number of other cases in this group the arteries were likewise tortuous, but they did not form so dense a network and were wider peripherally (Figs. 1 to 4).

The arteriographic appearances described in the preceding section were seen in the present series in patients suffering from pain of the stump or phantom type (Table 1). Three of the 31 patients examined arteriographically were excluded, since the examination was performed very soon after the amputation. Hypervascularization of the stump was, however, present in four patients without pain: two who had undergone high amputation and in whom the injury necessitated skin grafting over the greater part of the thigh; a third in whom both legs had been amputated below the knee 44 years earlier, both stumps being infected and showing navel-like gathering; and a fourth in whom the skin was in poor condition and the soft tissues excessive.

One patient who had undergone bilateral amputation had pain in one but not in the other leg. In the painful leg there was local hypervascularization and a highly ramified venous network corresponding to the hypervascularization distal to the fibular end.

In the other main group of patients, vascularization was sparse, the

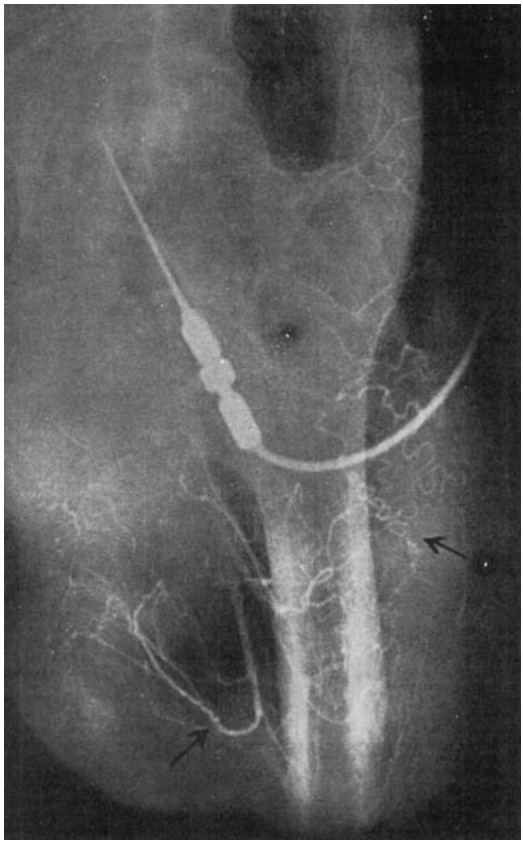

Fig. 2.
Male, 55 years, amputated 1958. Arteriography 1960. Very intense causalgic stump pain. Large number of spiralled muscle vessels.

vessels narrowed uniformly peripherally, and showed no tortuosity. In these cases the vessels appeared to be adapted to the amputation stump (Fig. 5).

This group of patients, in whom vascularization was sparse and the vessels showed no tortuosity, included none with any form of discomfort whatever.

Occlusion of the popliteal artery was demonstrable in three cases. Two of these patients had phantom pain and, in addition to the occlusion, hypervascularization with narrow and tortuous arteries distally in the stump. The third patient had neither pain nor hypervascularization of the stump.

The patient with slight or intermittent pain all exhibited vascular changes of varying degree which were, however, not definitely related to the severity of the pain.

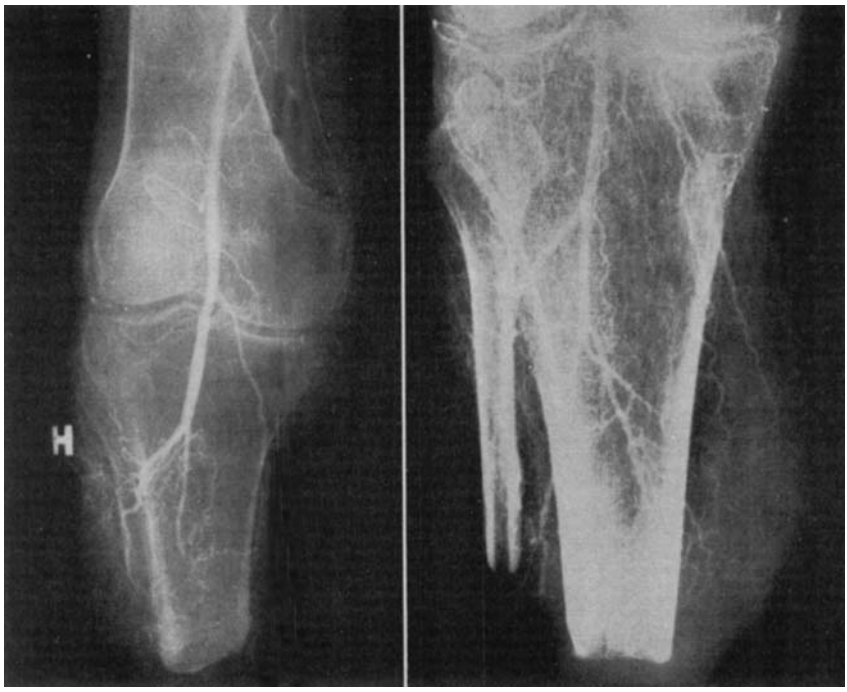

Fig. 3. *Fig. 4.*

Fig. 3. Male, 47 years, amputated in 1955 and reamputated for pain in 1958. Arteriography 1960. Intense pain persists in the phantom limb. Numerous tortuous arteries, especially on the fibular side.

Fig. 4. Male, 65 years, amputated in 1959. Arteriography 1960. Very intense phantom pain. Numerous spiralled arteries.

TABLE 1
Arteriographic Findings in 31 Amputated Limbs.

	Hypervascularization + tortuosity of wide wessels	Arteriosclerotic occlusion	Normal
No pain, skin good		1	12
No pain, but infection or skin grafting	4		
Moderate pain	5	1	
Disabling pain	6	1	1(?)

(The table includes 28 patients, three of whom underwent bilateral amputation. One of the bilateral amputees had pain in only one limb, where there was local hypervascularization).

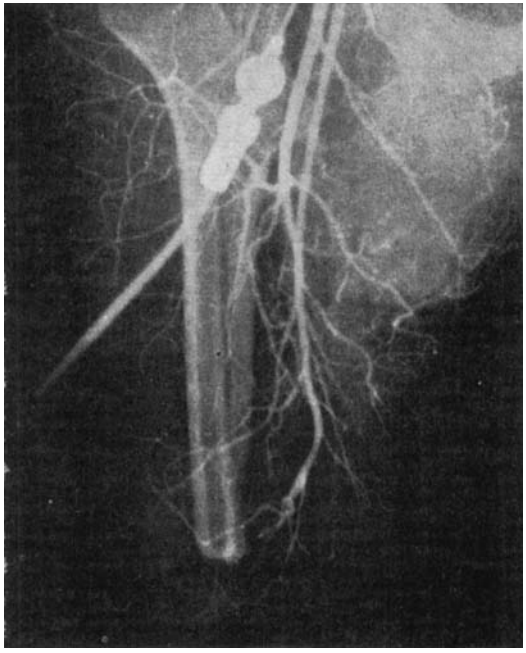

Fig. 5.
Female, 17 years, amputated in 1951 for a fibrosarcoma on the lower leg. Arteriography 1960. No symptoms. Normal vascular ramifications.

Measurement of skin temperature gave the following results: as a rule the temperature of the skin on the stump was lower than at the corresponding level on the sound leg. In 9 of 24 cases the skin temperature on the stump was higher than on the other side. This difference was not related to the presence of absence of pain. On raising body temperature a difference was, however, found between patients experiencing phantom pain during the experiment and those who did not do so. Phantom pain was present or developed when body temperature was raised in nine patients; in eight of them the skin temperature on the stump rose distinctly (more than 2° C), while at the corresponding level on the intact leg it rose only in one instance. In the remaining case, a steep fall in skin temperature on the stump was associated with the onset of severe phantom pain. The popliteal artery was occluded in this case. In only four of 15 patients in whom no phantom pain developed during the warming process did the skin temperature on the amputation stump rise. Figs. 6 to 9 illustrate these temperature curves. Muscle temperature was in the great majority of cases lower on the amputated than on the sound side, and did not alter when body temperature was raised.

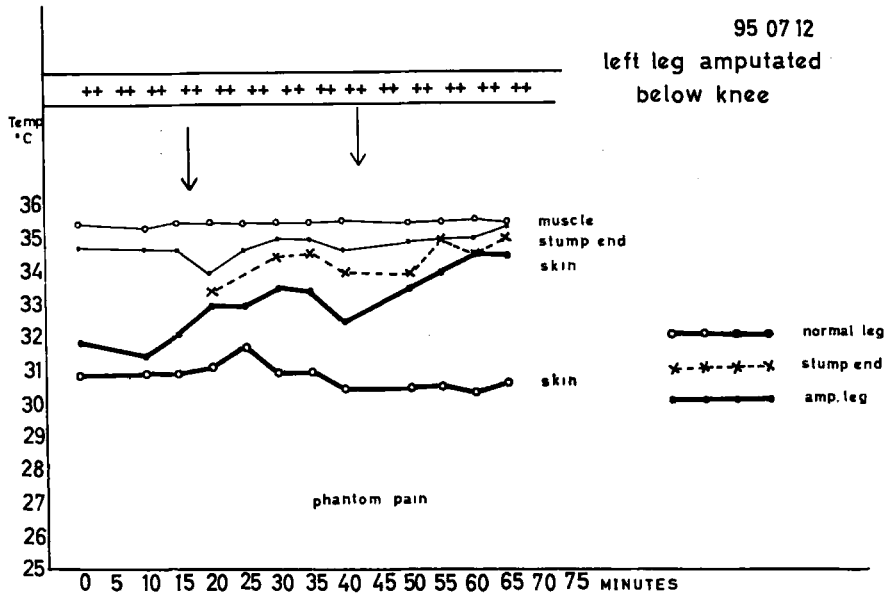

Fig. 6.

Skin temperature curve in a 65-year-old man with severe phantom pain (same patient as the arteriogram in Fig. 4). On raising body temperature, the skin temperature on the amputated limb rises steeply but remains stationary on the intact side.

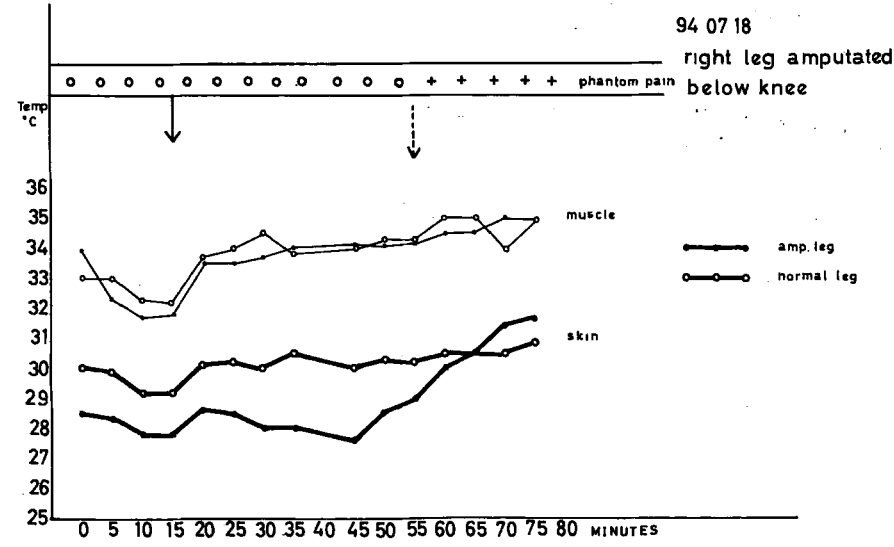

Fig. 7.

Skin temperature curve in a 66-year-old man with severe phantom pain. Marked elevation of skin temperature on the amputated side coincides with the onset of phantom pain.

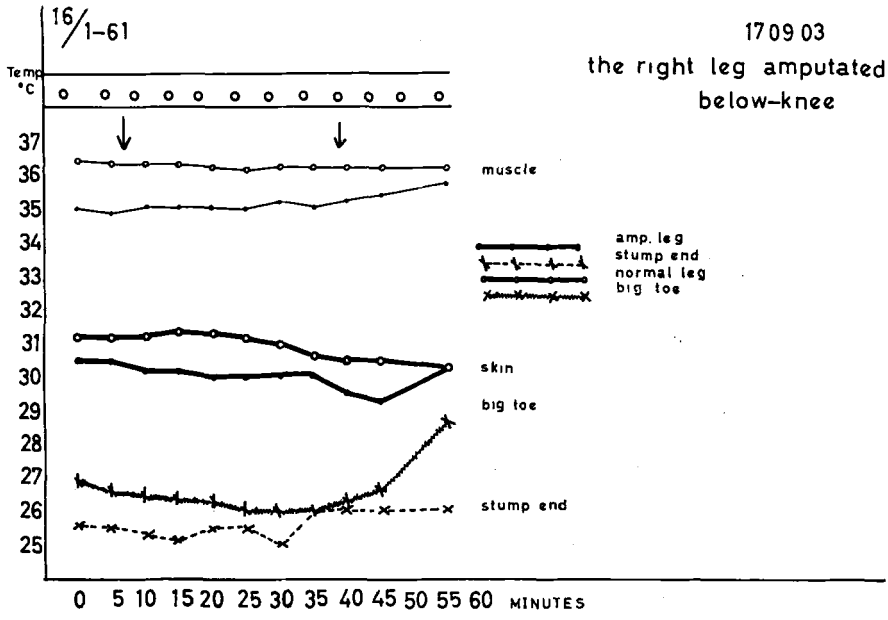

Fig. 8.

Skin temperature curve in a 16-year-old youth free from symptoms. Slight rise on the stump end but not elsewhere on the stump.

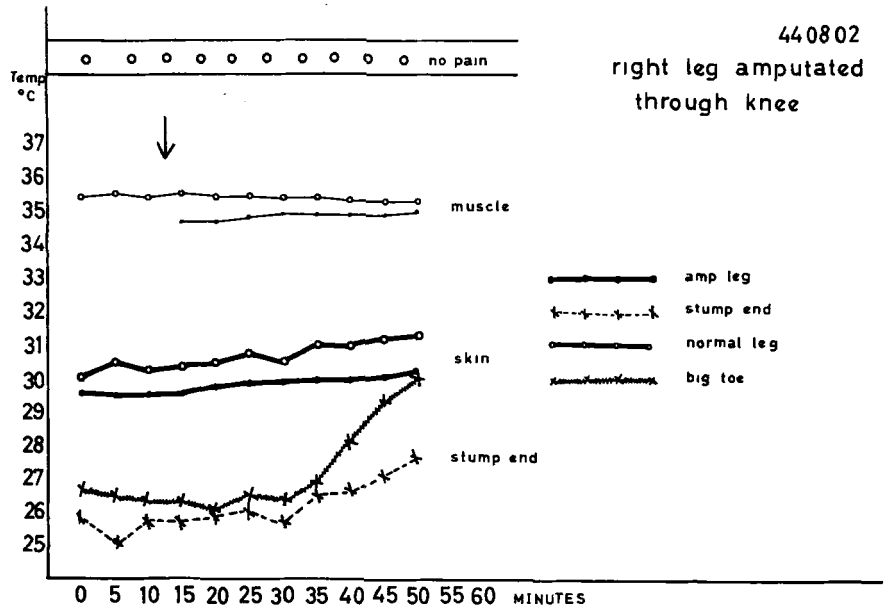

Fig. 9.

Skin temperature curve in a 43-year-old man without pain. No rise on the amputated side.

DISCUSSION

The arteriographic and skin temperature studies were carried out in a series of patients in whom amputation was indicated by injury or tumour. The vascularization of the stumps was found to be profuse, sparse, or of an intermediate form. In some instances, the arteriographic appearances were probably pathologic, consisting in sinuous vessels and persisting venous networks. Pathologic vessels of this type were seen only in patients with pain. In those without any form of discomfort, the vascularization was as a rule sparse—unless skin infection was present or the stump had been treated with skin grafting. Skin temperature measurement showed the skin of the stump to rise in temperature when body temperature was raised in patients with phantom pain, while in those without current phantom pain the skin temperature usually did not rise.

In a clinical series of this type, classification into groups must be regarded with some reserve since it is founded on the discomfort reported by the patients. But two distinct main groups could be distinguished: one in which no pain whatever was reported, and one in which pain was so severe (of phantom or stump type) that the patients were unfit for work for long periods or permanently. Some of the patients in this latter group were even unable to wear their prostheses. There was also an intermediate group in which the pain was slighter or only intermittent but not so severe as to prevent work. On relating the arteriographic findings with this clinical classification, a definite predominance of hypervascularization with vessels of pathologic appearance is found in the group with disabling pain. The wholly asymptomatic group, on the other hand, was found to have what might be called normal vascular ramification—that is, the number of vessels appeared to be adapted to the tissues to be supplied and their calibre narrowed uniformly. However, there were exceptions in both groups, and a larger series would be required to confirm the observations in the present study. Skin temperature determination gave results which could be correlated with the incidence of phantom pain during the body warming process.

Many factors have to be taken into consideration when attempting to interpret the vascular phenomena demonstrated in the present study. It seems unlikely that the abnormal vascularization and skin temperature reactions are anything more than manifestations of altered metabolism in the tissues of the amputation stump. The hypervascularization does not necessarily imply that the circulation is adequate, but

should rather be interpreted as an incorrectly adapted cirkulation. There might be changes in vascular tone due to substances acting upon the vessels, both those of normal occurrence and pathologic metabolites such as, for instance, polypeptides. Finally, but not least important, consideration must be given to changes in innervation due to amputation neuroma, hyperplasia of the autonomic nervous system, and the like.

SUMMARY

Thirty-three persons amputated for injury or tumour were examined with arteriography and skin temperature measurement after warming the body. Amputees with symptoms such as phantom pain or stump pain differed from those suffering no pain: in the former group the stumps were found to show hypervascularization, the vessels frequently being tortuous. Patients experiencing pain during the body-warming process also exhibited a rise in the skin temperature on the stump.

RESUME

Trente-trois personnes amputées par suite de lésions ou de tumeurs ont été examinées par artériographie et contrôle de la température de la peau, le corps ayant été réchauffé. Les amputés avec des symptômes tels que douleurs-fantômes ou douleurs dans le moignon diffèrent de ceux qui ne souffrent d'aucun symptôme: dans le premier groupe on a trouvé une hypervascularisation des moignons, les vaisseaux étant fréquemment tortueux. Chez les malades éprouvant des douleurs durant le processus de réchauffement du corps il y avait aussi une élévation de la température de la peau du moignon.

ZUSAMMENFASSUNG

Drei und dreissig Personen, die wegen Verletzungen oder Tumoren amputiert worden waren, wurden mittels Arteriographie und Hauttemperaturmessungen nach Erwärmung des Körpers untersucht. Amputierte, die and Phatomschmerzen oder Stumpfschmerzen litten unterschieden sich von denen, die keine Schmerzen hatten. In der ersten Gruppe zeigten die Stümpfe Hypervaskularisation und die Gefässe waren oft gewunden. Patienten die Schmerzen während der Erwärmung des Körpers angaben, zeigten auch eine Erhöhung der Hauttemperatur am Stumpf.

REFERENCES

Abeatici, S. & Ferrero, R.: Studio arteriografico dei monconi d'amputacione (ricerche sperimentali). Minerva Chir. *8*: 452, 1953.

Cronholm, B.: Phantom limbs in amputees. Acta psych. et neurolog. scand. Suppl. 72, 1951.

Ferrero, R. & Abeatici, S.: Su alcuni aspetti istologico dell'innervazione arteriosa nei monconi d'amputazione (ricerche sperimentale) Minerva Chir. *8*: 525, 1953.

Haber, W. B.: Observations on phantom-limb-phenomena. Arch. neurol. psych. *75*: 624, 1956.

Hulth, A. & Olerud, S.: Studies on amputation stumps in rabbits. J. Bone and Joint Surg. *44 B*: 431, 1962.

Leriche, R.: Etude critique des mecanismes de la douleur chez les amputés. Journal de Chirurgie *66*: 5, 1950.

Loon, H. E.: Biological and biochemical principles in amputation surgery. Prosthetics International. Copenhagen 1960, pp. 41–48.

Simmel, Marianne, L.: The conditions of occurrene of phantom limbs. Proc. Amer. Philosoph. Soc. *102*: 492, 1958.