THERMAL DAMAGE IN BURNS AND ITS RELATION TO PLASMA LOSS

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A number of investigations have been made on plasma loss and concentration of the blood in burns [2 - 7, 11 - 14]. However, there is no agreement as to whether these signs are inevitably associated with severe burns. Experimentally, shock due to burns has been observed repeatedly without there being any plasma loss or hemoconcentration [3, 6, 7, 11, 17].

One of the features of the topography of tissues affected by burns is the reduction with depth of the extent to which the tissues have been heated, i.e. there is a vertical temperature gradient [15, 16]. The temperature gradient is different in different burns. Despite the fact that temperature measurements were first made more than 20 years ago, particularly in frostbite [1], in animals, experimental burns have usually been applied without making simultaneous temperature measurements, and without a description of the damage inflicted [8]. Therefore the relationship between plasma loss and the damage by heat to the tissue has not been sufficiently studied. In order to understand the different conditions of plasma loss and hemoconcentration in different burns, it is important that this problem should be cleared up.

We have studied edema and hemoconcentration in burns of various patterns in 78 rabbits.

METHOD

In the first set of experiments on 30 rabbits burns were inflicted on the outer ear by immersing a 5 cm length of ear in water at 50 - 85° for 20 seconds. In the second set of 13 experiments, burns were applied by thermal irradiation of 20 - 25% of the surface area of the body (back and sides of the trunk) by means of a special apparatus developed in our laboratory [10]. The skin was first removed with a depilatory agent. In the third and fourth sets of 9 experiments each, burns of the same area were induced by steam at 90 - 92° from an autoclave (exposure time: 50-60 sec). In the fourth set of experiments, while the burn was being inflicted, air was injected subcutaneously, so that the damage was confined to the skin. In the fifth set (9 experiments) both hindlegs, comprising 12 - 15% of the body surface, were burnt; 1 liter of water at 90 - 92° was poured on to each limb for 35 - 40 seconds.

Copper-constantan thermocouples were used to measure the tissue temperature during the burning: in the first set of experiments they were introduced subcutaneously, and in the others they were inserted both beneath the skin and at various depths in the muscle. In the experiments of the second, third, fourth and fifth groups the burns were graded according to the depth to which the tissues had been heated. Twenty-four hours after the burns had been inflicted the following measurements were made: in the first group of experiments the extent of the edema was determined from the volume of the pinna, while in the remaining series the extent to which the blood had thickened was determined from a red cell count. In some of the experiments, histological studies of the damage tissues were made (V. M. Pinchuk).

RESULTS

The first set of experiments, in which the pinna was burnt, showed that the extent of the resultant edema was related to the severity of the thermal damage to the tissues. When the subcutaneous temperatures were below 48.5°, no edema developed (Fig. 1). It appeared only at temperatures of 49 - 52°. Between 50 and 57°, with increasing tissue temperature, edema rose sharply, and at 55 - 61° the volume of the ear increased by 150 - 360%. At higher temperatures there was less edema, sometimes none at all. Figure 2 shows the appearance of two rabbit pinnae two days after the burn was inflicted. Heating the tissues to 56° caused a great edema from the whole ear, but at 73° coagulation necrosis occurred without any edema of the pinna. At temperatures between 50 and 61°, edema occurred both in the region of the burn and outside it. At higher temperatures, if there was any edema, it occurred only in the part which had not been heated. Evidently, it arose through plasma entering the tissue from the capillaries at the boundary between the burnt and healthy areas, where through the temperature gradient along the ear the tissue was heated to 50 - 60°.

In burns in which the tissues were heated to 53 - 61°, after 24 hours, histological examination revealed profound circulatory disturbances: the vessels were widely dilated, blood flow in the capillaries was arrested, and there were thrombi in the large vessels. There was also a marked exudative inflammation which spread through the tissue not directly exposed to heat. More intense heating to between 61 and 65° led to rapid coagulation of tissue and to a mild inflammatory reaction which was shown only at the edge of the burn.

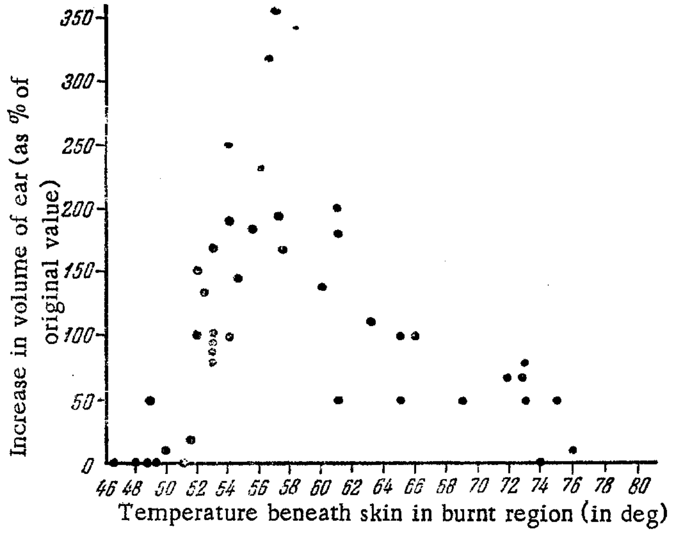

Fig. 1. Relationship between the edema and the severity of the burn. Increase in volume of the pinna 24 hours after immersion in water at different temperatures. Each point represents one observation.

The extent of the edema depended not only on the temperature reached, but also on the time for which it was maintained. In ten rabbits, immediately after a burn applied to both ears by water at 60° and immersion for 20 seconds, one ear was placed for one minute in iced water. Because the period taken for the tissue to return to normal temperature was shortened, the volume of the cooled ear increased 30 - 60% less than did the control ear.

In the experiments described, the whole thickness of the soft tissues was heated. In burns inflicted on the trunk and limbs, as has already been mentioned, there was a temperature gradient from high to normal temperature. Therefore, in these cases it could be foreseen from the results of the first set of experiments that the extent of plasma loss in the different tissue layers would be varied and would depend on the temperature reached. This result was confirmed by the following experiments.

Figure 3 shows diagramatically the distribution of the burn and the extent to which the blood was thickened in burns of the 2 - 5th series of experiments. It can be seen that in the 2nd and 3rd series, during the burning, the skin temperature exceeded 60°. The drop from 60° to 37° in the second series, and to 41° in the third series occurred over a thin layer of tissue, which included the subcutaneous tissue and the upper muscular layers.

The closely similar results on the thickening of the blood corresponded to the similar temperature distribution within the burn. In the great majority of experiments, the number of erythrocytes increased 24 hours after the burn to 110 - 150% of normal.

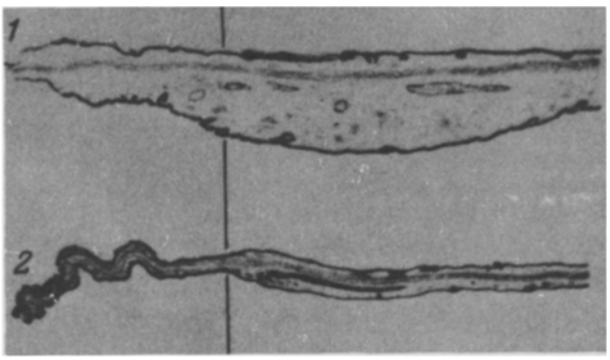

Fig. 2. Rabbit ears (longitudinal section) two days after inflicting a burn by immersion in boiling water for 20 seconds. Temperature in the tissues during the burning was (1) 56°, and (2) 73°. The line shows the outline of the burn.

Different results were obtained in experiments of the fourth series, in which air was introduced under the skin during the burning. In these experiments, in only two rabbits was there some small increase in the thickness of the blood, while in the remaining seven it was actually diluted. The explanation is that in animals of this group, just as in the third group, the skin was heated to above 60°; however, the difference was that because of the air cushion, the deeper-lying tissues were not much heated.

Thus, results of the first four series of experiments indicated that most plasma leaves the blood stream when tissues are heated to 50 - 61°. At temperatures above 61 - 65°, coagulation occurs, and the blood flow in the tissue ceases, so that there is no plasma loss. When the period of increased temperature is extended, the permeability of the vessels may increase markedly, even at temperatures below 50° [16, 19].

K. F. Dogaeva [3] thinks that the contradictory findings concerning plasma loss and thickening of the blood are due to ignoring the severity of the burn and considering only the area. However, in classifying burns according to severity, only one criterion is used, that of the depth of the cutaneous necrosis [19]. When there is necrosis of the whole thickness of the skin, independently of the nature of the damage, and independently of the depth and severity of damage to subcutaneous tissues, it is referred to as a fourth degree burn. Nevertheless, in our experiments, in burns of the pinna, necrosis of the whole thickness of the skin, i.e. a fourth degree burn, occurred when the tissues were heated either to 53 - 61° or 63 - 76°; the difference was that at 53 - 61° before the necrosis there was disturbance of the circulation, and a marked tissue edema, whereas at 63 - 76°, necrosis and circulatory arrest occurred in the tissues at the time of burning, and as a consequence the weak exudative inflammation developed subsequently only at the boundary between the dead and healthy tissue (V. M. Pinchuk). When we consider also that the permeability of the capillaries may increase even when the tissues are not heated sufficiently to cause necrosis, it then becomes clear that the extent of the plasma loss in the experiment should be related not to the severity but to the topography of the burns.

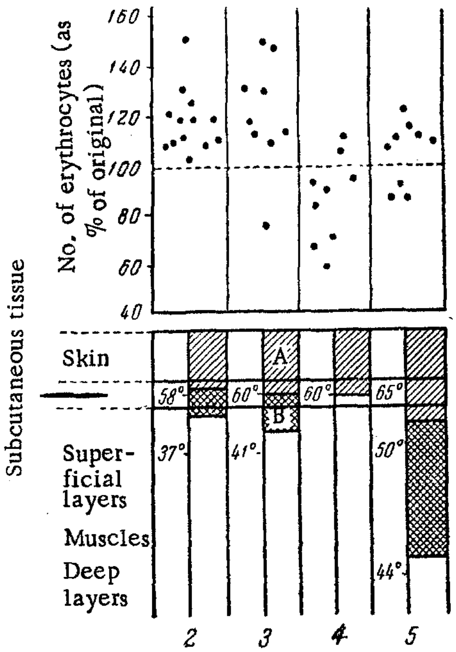

Fig. 3. Relationship between the degree of thickening of the blood and the topography of the burnt tissue. 2 - 5) Number indicating series of experiment; 2) burn by radiation; 3) burn by steam at 90-92°; 4) vapor burn when air was injected subcutaneously; 5) burn by water at 90-92°. A) Tissues heated above 60°; tissues heated to 45-60°.

Apart from area and topography, other factors are concerned in plasma loss and thickening of the blood. In the fifth set of experiments, in which both hindlimbs were burnt, although the heat penetrated into the soft tissues (at a considerable depth the tissue reached the temperature of 45 - 60°), the thickening of the blood was not so marked as it was in the second and third series of experiments, and in three rabbits the blood actually became more dilute. The cause of these effects is evidently not to be found in the smaller area of the burn in this series. It can be understood that as the depth of the burn increases, the layer of tissue heated to 45 - 60° comes to lie deeper. Then, its extent compared with the area of skin damaged in body burns does not change, but when the burnt area of the limbs is circular, the extent may be much smaller. Further, in body burns, the plasma exuding from the capillaries enters both the damaged and healthy tissue, causing an increase in their volume. In burns of the limbs, this effect is suppressed by the tension in the skin, which constricts strongly when heated. Therefore, in our experiments, when large amounts of tissue were heated to 45 - 60°, as in the fifth set of experiments, the blood showed little or no thickening. In all probability, in burns of the limbs, the development of shock without any hemoconcentration, or even with some dilution of the blood [3, 6, 7, 11, 17], may be due to the intense heating of the tissues. The dilution of the blood observed in some of our experiments might be due to partial hemolysis of the erythrocytes, and possibly to the entry into the blood stream of tissue fluid, induced by a reduction of arterial pressure [11].

The facts we have expounded give reason to suppose that clinically the extent of the plasma loss, and hence the requirement of the patient for infusion therapy cannot always be correctly inferred from formulas in which the burn is assessed only in terms of its area and degree.

SUMMARY

Edema and hemoconcentration in burns with different distributions of the affected tissues were studied in experiments on 78 rabbits. The temperature in the tissues was measured by means of thermocouples. It was found that plasma loss occurred mainly in tissue layers heated to 50 - 61°. For a given area of burn, plasma loss and hemoconcentration may depend on the topography of the burnt tissues.

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