Reversal of Capillary Stasis and Prevention of Necrosis in Burns

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It has been suggested that the ultimate depth of burn necrosis might be minimized by prevention or reversal of the progressive capillary stasis which occurs in the early postburn hours. To study the role of wound dehydration in determining burn depth, 5% body surface area, 75 C, 10-second burns (in which the zone of stasis included the full thickness of skin) were inflicted on the backs of guinea pigs and subsequent mechanical trauma was prevented. At various times postburn, water content, (and after India ink perfusion) depth of capillary stasis and histological structure of burn were studied in the following groups: 1) blister intact; 2) blister removed; and 3) blister replaced by several different types of dressing. Reversal of capillary stasis was least and necrosis full-thickness in depth in undressed wounds with blister removed. Reversal of capillary stasis was complete and necrosis absent with blister replaced by fresh split-thickness porcine skin and correlated with prevention of wound dehydration. Similar, though less complete, prevention of necrosis occurred with blister intact or replaced by sialastic film. Other dressings were associated with deep necrosis or gross infection. These and other data suggest that in the zone of stasis, capillary stasis may be reversed and necrosis avoided by appropriate prevention of wound dehydration. Clinical correlations are suggested.

EVEN BRIEF CONTACT with high temperature heat sources such as flame or molten metal commonly produces immediate coagulation of a variable depth of skin.[11] In addition, just below the tissue undergoing immediate coagulation necrosis is a "zone of stasis" where progressive microvascular stagnation leads to deepening capillary occlusion (stasis) during the first day or so postburn.[6,15] Believing that prevention or reversal of capillary stasis might diminish the ultimate depth of burn necrosis, some authors have advocated the use of anticoagulants[13,14] or desludging agents.[1] Others have suggested that tissue death in the zone of stasis is not due to stasis per se but to the direct effects of heat,[7,17] implying that such efforts would be futile.

This experimental study presents evidence that the primary cause of necrosis in the zone of stasis is neither heat nor vascular occlusion, but wound dehydration. The study further demonstrates that in this zone, capillary stasis may be reversed and necrosis prevented by appropriate prevention of wound dehydration.

Materials and Methods

Standard Burn Preparation

In groups of 12, white male guinea pigs weighing 337 ± 46 gm (mean ± 2 standard deviations) were anesthetized by intraperitoneal injection of sodium pentobarbitol (35 mg per kilo). Guinea pigs were used because among common small laboratory animals, their skin exhibits the least variability in thickness.[19] To avoid epithelial trauma due to shaving, dorsal trunk hair was clipped and the remaining stubble washed off in tap water after application of a calcium thioglycolate containing depilatory. A 5% body surface area, 75 C, 10-second scald burn was then inflicted on the depilated area using a specially designed restraining apparatus.[18]

Although in guinea pigs, heat-injured epidermis is not spontaneously separated by blister fluid at the dermal-epidermal junction, its adherence is greatly weakened[16] and it is easily separated at this junction by gentle shear-

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ing pressure. In preliminary studies it was found that the burned animal itself frequently caused disruption of this "blister" and injury to deeper portions of the burn. In this study, such trauma was prevented by placing each animal in a separate cage immediately postburn after it had been fitted with an elastoplast trunk binder having a padded aperture surrounding and protecting the burn.

Determination of Water Content, Depth of Capillary Stasis, and State of Healing

At specified times postburn, each animal was reanesthetized and a centrally located 1 cm^2 specimen of burned skin including the panniculus carnosus biopsied and immediately weighed. The percentage of burn water content was determined from the weight loss measured after drying the specimen to constant weight at 50 C for 48 hours. After biopsy, each animal underwent cannulation of the ascending aorta and perfusion with 60 cc of India ink at 400 mm Hg. By trial and error, this combination of perfusion volume and pressure was found necessary to insure complete filling of all patent skin capillaries. Burn specimens adjacent to the biopsy site were then removed for histological examination of the state of healing and depth of capillary stasis (as indicated by the absence of intracapillary India ink).

Survey of the Effect of Various Dressings

In this country, local wound care most commonly includes early removal of burn blisters. Therefore, on the seventh postburn day (PBD), water content, depth of capillary stasis, and state of healing of burn were studied in groups of animals treated during the postburn period in one of the following ways: 1) blister intact; 2) blister removed immediately postburn by gentle digital shearing pressure; 3) blister removed immediately postburn and replaced by a light gauze dressing holding in contact with the wound a sterile sheet of saran; 4) polyethylene film; 5) vaseline impregnated fine mesh gauze; 6) sialastic film bonded to a single layer of fine mesh gauze in contact with the burn;* or 7) fresh split-thickness porcine skin.†

Detailed Comparison of Exposure vs. Split-thickness Porcine Skin Dressings

At various times postburn (4 minutes, 2, 4, 8, and 16 hours, and 1, 2, 4, 7, and 14 days postburn), water content, depth of capillary stasis, and state of healing of burn were determined in groups of 12 animals treated during the postburn period with blister removed immediately postburn, and subsequently 6 treated open and 6 treated with porcine skin.

Effects of early removal of porcine skin dressings were studied by determination of depth of stasis and state of healing on the seventh PBD in groups of animals having the burn blister replaced by porcine skin dressings immediately postburn and subsequently removed at 2, 4, and 6 days postburn.

Results

The Standard Burn

The time and temperature combination chosen for the standard burn (10 seconds and 75 C) produced no coagulation of skin immediately postburn: grossly the burn blanched on pressure and histologically, circulation remained intact in the most superficial capillaries. In fact, except for separation of squamous epithelium, occasional slight disruption of the dermal-epidermal junction, and reduction of basophilia in epithelial cells, burned skin was not histologically distinguishable from normal skin immediately postburn (Fig. 1).

During the early postburn hours, however, capillary flow ceased in progressively deeper layers of skin until by 16 hours postburn, capillary stasis extended well beyond the deepest hair follicles and almost to the panniculus carnosus. The zone of capillary stasis in the burn preparation used in this study, therefore, included the full thickness of skin, although patent arterioles remained visible here and there within the zone of capillary stasis as illustrated in Fig. 2, 16 hours postburn.

Effect of Various Dressings

In surveying burns treated for one week with blister intact, blister removed, or blister replaced by several different types of dressing, it was found that depth of necrosis was greatest (full-thickness without surviving hair follicles) and healing least (incomplete or absent epithelialization from the wound edges) in undressed wounds with blister removed. Conversely, at 1 week postburn, there was no evident necrosis and complete epithelialization from surviving hair follicles in wounds with blister replaced by split-thickness porcine skin. Similar, though less complete, reepithelialization from surviving hair follicles and prevention of necrosis occurred with blister intact or replaced by sialastic film. Other dressings were associated with full-thickness or deep partial-thickness necrosis (vaseline dressings), or gross purulence (saran, polyethylene film).

Comparison of Exposure vs. Porcine Skin Dressing

As maximum conservation of tissue in burns with blister removed appeared to occur in those treated with porcine skin, and the deepest necrosis appeared to occur in those left exposed, a more detailed comparison of the two

* Provided by Edwards Laboratories, Santa Ana, California.
† Provided by Burn Treatment Skin Bank, Phoenix, Arizona.

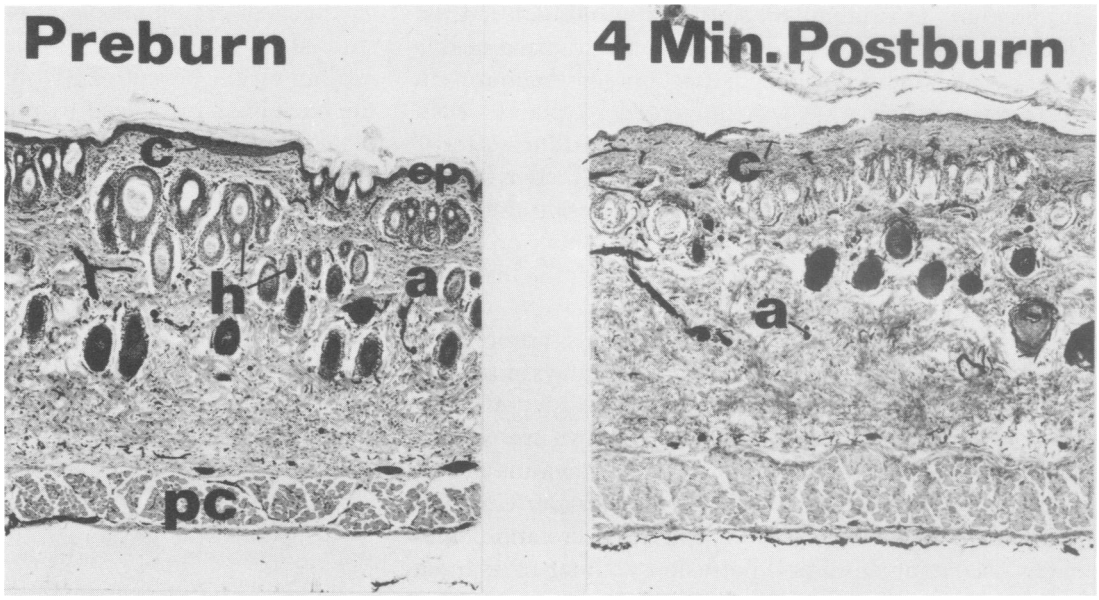

FIG. 1. Guinea pig skin before and 4 minutes after burning showing, by the presence of India ink perfusate, persistent circulation in superficial capillaries. ep = surface epithelium; pc = panniculus carnosus; h = hair follicles; a = patent arteriole; c = most superficial patent capillary (H & E × 40).

groups was carried out at frequent intervals postburn and is illustrated in Fig. 2.

In both groups by 16 hours postburn (and with little change at 24 hours postburn) capillary stasis progressed to full thickness in depth, i.e., below the base of hair follicles and almost to the panniculus carnosus. After the first PBD, however, a striking difference became evident in the capillary circulation of exposed and porcine skin treated burns: In porcine skin treated burns, by the second PBD, circulation was restored in previously occluded capillaries surrounding the deepest hair follicles. By the fourth PBD, in this group, capillary circulation was intact almost to the dermal surface and it was fully restored by the seventh PBD. In exposed burns, however, while some reversal of capillary stasis did occur, it never extended more superficially than it had by the second PBD, and never to the deepest hair follicles, let alone to the original dermal surface. The extravasation of perfusate evident in Fig. 2 at 2 days postburn was a consistent finding in both groups and suggests a temporary lapse of tolerance to

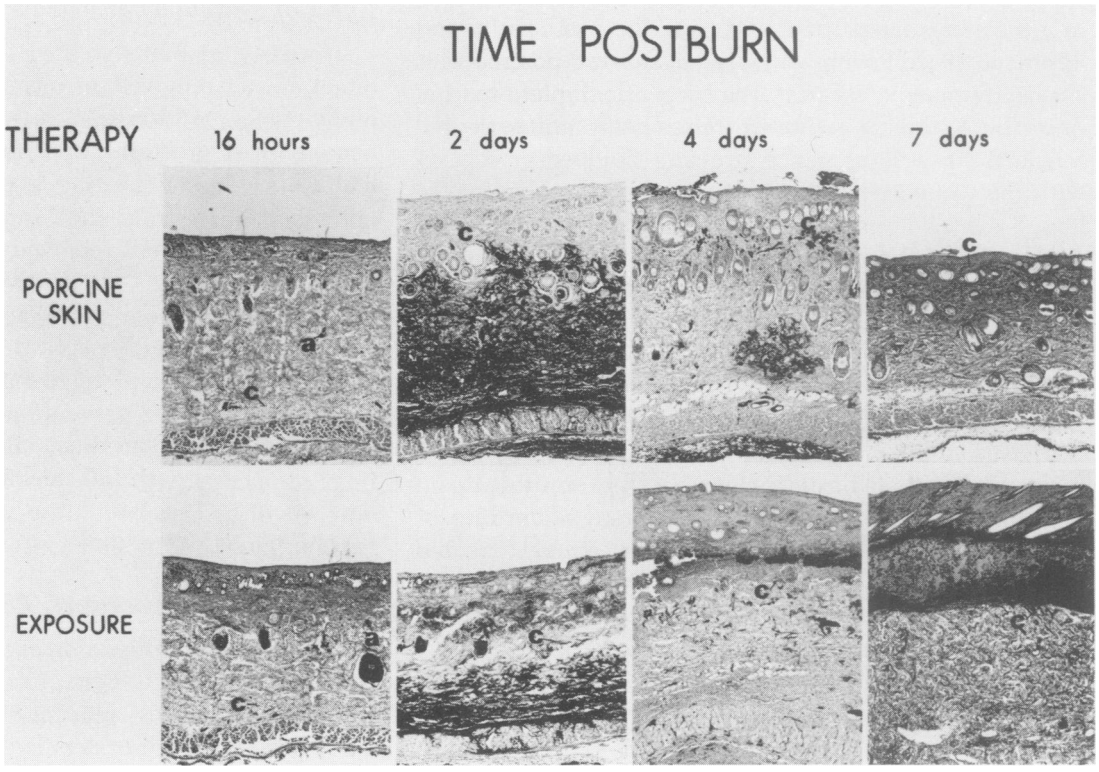

FIG. 2. Guinea pig skin following India ink perfusion at various times after burning and blister removal showing reversal of capillary stasis and prevention of necrosis by application of porcine skin. Abbr. as in Fig. 1 (H & E × 17).

intraluminal pressure when occluded vessels first reopen.

Figure 2 also illustrates that burns in the porcine skin treated group exhibited no signs of dehydration, and reepithelialization was complete by the seventh PBD. Furthermore, nuclei and basophilia which faded histologically from hair follicle epithelium with the cessation of capillary flow, reappeared as capillary stasis was reversed in this group. In contrast, by 16 hours postburn, and in some specimens by 8 hours postburn, the histological changes associated with dehydration were obvious in the upper one-quarter of exposed skin, and progressed to include the base of hair follicles by 2 days postburn. By the fourth PBD, and even more obviously by the seventh, the strata of burn dehydrated by exposure became obviously necrotic and began to separate from the underlying tissue which showed no evidence of surviving hair follicles. Figure 3 illustrates that in correlation with these histological findings, the water content of exposed burns was significantly lower than that of porcine skin treated burns by 16 hours postburn, and remained so until after the first week postburn.

In summary, therefore, subsequent to full-thickness dehydration, revascularization of hair follicles did not occur in exposed burns and the full thickness of skin became necrotic. By comparison, porcine skin treated burns in which no dehydration occurred showed no necrosis, full reversal of capillary stasis, return of hair follicle epithelium to histologic normalcy, and full epithelial resurfacing by the seventh PBD.

When porcine skin applied to deblistered burn immediately postburn was removed 2, 4, and 6 days postburn, at 1 week postburn depth of necrosis was less and revascularization was more complete the later porcine skin dressings were removed. However, the complete healing and absent necrosis seen in burns with uninterrupted coverage by porcine skin was never achieved.

Discussion

From his careful work on guinea pig burns in 1949, Sevitt[15] concluded that capillary stasis in burns was "irreversible," and that "the most deeply situated hair follicles become necrotic (if not already so from direct heat effects) when stasis involves the capillaries in the deepest part of the dermis and full-thickness loss of the skin follows."[17] In 1953, Jackson's[6] now classic observations of human burns with blister removed led him to confirm Sevitt's conclusions: as he summarized it in a later review, "Treated by creams or by exposure, the zone of stasis and the coagulated zone inevitably separate as slough."[7]

In 1969, however, Jackson himself began to have "second thoughts" about the nonviable state of the zone of stasis.[7] He observed the following paradox when tangential excision of a recent burn revealed a dermal surface within the zone of stasis: the same dermal surface which

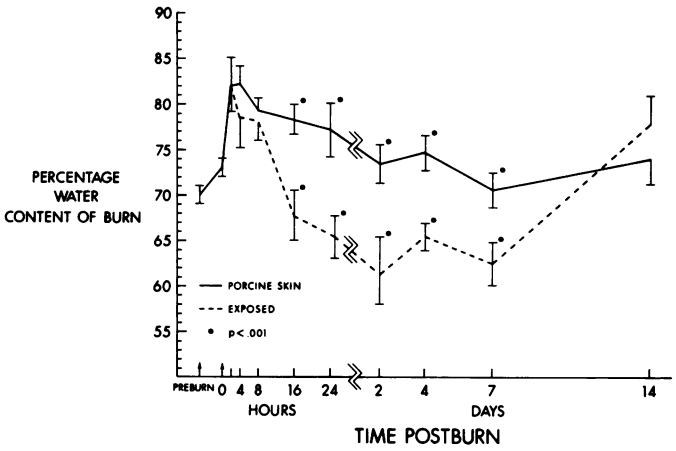

FIG. 3. Water content of deblistered guinea pig burns during 2 weeks of exposure or coverage with porcine skin. Mean and 95% confidence limits are indicated for each value except where clarity required omission of overlapping confidence limit brackets.

looked "dead" histologically and became a dry brown slough if ungrafted and dressed with vaseline gauze ("It must be dead"), also bled from a few scattered arterioles and accepted autograft ("It must be alive").

The present study appears to explain Jackson's paradoxical observations by contradicting Sevitt's conclusions.

In the preliminary phases of the present study, we, like Sevitt, found that our standard 75 C, 10-second guinea pig scald burn frequently produced full-thickness skin loss as well as full-thickness capillary stasis. It was then noticed, quite by chance, that full-thickness skin loss occurred *only* in those animals who had removed the blister from their burns, presumably by scratching or rubbing against the cage walls, etc. As Billingham pointed out, guinea pigs are notorious traumatizers of experimental wounds.[2] Because the burns on Sevitt's animals were both unprotected and, apparently ventral or ventrolateral in position, mechanical blister disruption would have been very likely. Such trauma may explain the full-thickness loss Sevitt found in burns exhibiting capillary stasis. Clearly it did for us, because with mechanical trauma eliminated and dehydration prevented by application of porcine skin to the deblistered burn, we found that full-thickness "irreversible" capillary stasis was completely reversed and necrosis avoided. Because almost as complete a reversal of stasis occurred with the original blister intact or replaced by a sialastic film, simple maintenance of wound hydration seems the most probable explanation for this phenomenon rather than some occult or peculiar property of living or biological membranes.

Let us reconsider Jackson's paradoxical observations in the light of our data. Like Jackson who removed water-retaining epidermis by tangential excision or by removal of the burn blister, we found that with epidermis removed the zone of stasis dehydrated and sloughed even

when covered by supposedly occlusive (vaseline) dressings. When Jackson prevented dehydration by application of fresh human skin graft to the excised or deblistered surface of the zone of stasis, circulation eventually returned to the surface as in our porcine skin treated burns and revascularized the graft. It is a tribute to Jackson that these manifestations of reversible capillary stasis were noted so accurately before the data of the present study were available. Had he not pointed it out, we might not have recognized the occasional patent arteriole and the histologic fading of nuclei and basophilia from epithelial cells in the zone of capillary stasis. It is tempting to speculate that the striking return of epithelial cells to histologic normalcy as stasis is reversed reflects the return of normal nuclear and cytoplasmic functions e.g., cell division and respiration.

Prevention of dehydration probably explains the now very frequent observation that superficial partial-thickness (second degree) burns heal more rapidly, with less scar and better pigmentation, etc. when blister is left intact[4] or replaced by homograft,[9] heterograft,[3,8] or even transparent adhesive tape.[10] As dehydration of exposed deblistered burns is evident as early as 8 to 16 hours postburn (and may be present though not evident earlier) and can also occur if porcine skin is removed too early, an early start and proper duration of treatment may be important to success. Occasional dissenting reports[5] concerning the value of porcine skin in treating second degree burns may be attributable to such factors.

It is instructive to consider in retrospect how the testimony of skilled observers suggested but did not previously lead to the conclusions of this study. The contributions of Sevitt and Jackson have been discussed. Miller[10] noted that after 72 hours of pallor (capillary stasis) under transparent adhesive tape or homograft, deblistered second degree burn in man became pink and could vascularize split-thickness homograft i.e., capillary circulation was reestablished. Order et al[12] briefly noted the reopening "by an inapparent mechanism" of previously occluded suprapannicular arterial circulation during the first and second postburn day in "second degree" rat burns, but did not extend this observation to the phenomenon of capillary stasis.

Perhaps most sobering has been our disregard for the testimony of historically our most valued observer, the patient himself. When in shock he asks for "Something . . . anything to drink!"; when burned he asks for "Something . . . anything to cover the burn!" When virtually every standard manual of emergency burn care advises: 1) "*Primo non nocere*"; and 2) "Remove the blisters from second degree burn," perhaps we should pause and listen to the patient telling us "It was better with the blister on," especially when some of those manuals go on to advise actively drying the wound with heat lamps, currents of warm air, etc. As available evidence appears to confirm the intuition of our patients, if for various reasons we still believe blisters are best removed from second degree burns, we must seriously consider subsequent application of porcine skin dressing, or some equivalent technique, to avoid wound dehydration.

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