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THE SCUDDER ORATION ON TRAUMA

Unlocking the mysteries of the burn wound

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". . . let me assure you that the present day atmosphere of the clean, airy, not offensively odorous burn ward, populated by bright-eyed, responsive, eager patients, is in sharp contrast to the malodorous wards filled with glassy-eyed, hollow-cheeked, unresponsive patients that characterized our facilities only a decade and a half ago."

In brief . . .

In this Scudder Oration on Trauma delivered at the 1977 Clinical Congress on Tuesday, October 18, Dr. Moncrief traces the developments that have brought about dramatic improvements in the care of burn patients over the past twenty years. He also cites several of the pioneers in burn care who have helped unlock many of the mysteries of the burn wound.

Renowned for his work in the treatment of burn injuries, Dr. Moncrief is clinical professor of surgery at the University of Texas Health Sciences Center in San Antonio. Among his many accomplishments, he headed the Army Burn Center at San Antonio from 1961 to 1967, where his research group developed antibacterial medicines for local application in the control of burn infections.

The Scudder Oration on Trauma is named after Dr. Charles L. Scudder of Boston, a founding member of the College and first chairman of the Committee on the Treatment of Fractures which later became the Committee on Trauma. Dr. Scudder gave the first oration in this series at the 1929 Clinical Congress.

To be selected to give the Scudder Oration on Trauma is an honor and a privilege which I never expected. Indeed, to be included among those luminaries that have preceded me in this capacity connotes a recognition that I hope is justified. I shall do my best to fulfill the responsibility thrust upon me and uphold the fine traditions of Dr. Scudder and those who have been previously honored.

Two mentors

The subject of thermal injury lay in limbo for many years within the medical profession and efforts at improving the care of the burn victim were often miniscule and almost universally ineffective. My own interest began in my junior year in medical school when it became obvious to me that there must be a better way to treat burns than scrubbing them with green soap and leaving them in a rotting dressing.

But, lacking much knowledge or initiative, my thoughts drifted elsewhere until I met with two individuals who influenced my professional life and career so markedly. The first was the late Carl Moyer, whose interest in the problem is known to you all. Often described as "Lincolnesque," he had the long, gangling figure of "Abe" but none of the somnolent look. His was a look of quizzical expectation, an active and intuitive and inquisitive look that cried out for answers and stimulated productive search.

The second was Curtis Artz. This ebullient, effervescent, constantly moving banty rooster can well be depicted by the country ditty, "I'm little but I'm loud, I'm puny but I'm proud!" His ability to choose the right people and to vigorously support and encourage their efforts has given many the opportunity to be productive and progress in their chosen fields.

To both these men I owe a deep debt of gratitude and respect. But to another group I also owe the same. And that is to all those outstanding men and women with whom I have had the honor, pleasure and privilege of working over the years and whose loyalty and devotion and talent have done so much to propel me to this position.

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Need for change

For most of my professional career the study and treatment of thermal injury was a discouraging and seemingly hopeless task. So much so that I completely abandoned the effort some 20 years ago. Such a course is not difficult to understand when one realizes that at that time 42% of all those admitted to our burn treatment facility died. Often death occurred after four to six weeks of around-the-clock toil, enough time to develop a close attachment and identification with both patient and family.

The emotional upheaval of all concerned with such a steady diet was heartbreaking, and many, including myself, succumbed to the stress. But much of that has changed now, and it is about the developments that have brought about that change that I wish to speak to you today.

For those of you only recently come upon the scene, let me assure you that the present day atmosphere of the clean, airy, not offensively odorous burn ward, populated by bright-eyed, responsive, eager patients, is in sharp contrast to the malodorous wards filled with glassy-eyed, hollow-cheeked, unresponsive patients that characterized our facilities only a decade and a half ago.

But what changed all this? Events which in retrospect were predictable and much too long in coming. It merely took a combination of the right person in the right place at the right time. Not truly serendipity but a prepared mind looking for the answer—and looking in the right way in the right place.

It was long known that the burn victim was dying primarily from infection. Indeed, 75% of all deaths were thus unequivocally categorized. But why such infection and where was its focus? For without such knowledge successful therapy would be impossible.

Burn wound sepsis

With his elucidation of the concept of "burn wound sepsis," Carl Teplitz et al opened the door to a flood of advances in the therapy of thermal injury that are even now continuing at

breakneck speed. His exquisitely detailed morphologic and bacteriologic studies are classics of the highest order.

Defining "burn wound sepsis" as microorganisms growing in the burn wound in quantities of 100,000 or more per gram of tissue, and actively invading the subjacent unburned tissues, Teplitz finally presented us with a distinct entity which could be unequivocally identified and its etiology traced. In addition, the myriad of organisms involved could be identified and treatment modalities that effectively combat the bacterial population could be sought.

The sequence of events, as described by Teplitz, are as follows: during the immediate post-burn phase the burn wound is essentially devoid of bacterial flora but within hours colonization of the surface of the burn wound is apparent and readily demonstrable by Giemsa's stain as colonies of bacteria scattered on the wound surface.

These organisms, which consist primarily of the gram positive cocci, proliferate rapidly and invade the remaining hair follicles, eventually rupturing through into the perifollicular tissues. At three to four days post-burn the flora become mixed gram positive and gram negative and by the end of the first week the gram negative rods predominate. By then, in the untreated wound, the involvement is extensive, lymphatic invasion is present in the subcutaneous fat, and perivascular and perineural lymphatic involvement is characteristic when the subjacent unburned tissue is involved. With such widespread bacterial proliferation and active penetration, death ensues in inevitable fashion.

As pointed out by Teplitz, bacterial invasion is primarily by way of the lymphatics, and not until late in the advanced stages is significant blood stream involvement noted. Indeed, in half the deaths due to burn wound sepsis the bacterial involvement is limited entirely to the burn wound and adjacent tissues. Thus routine autopsies that do not include the detailed studies of sections of the burn wound or blood cultures drawn for a diagnosis or therapy, cannot be expected to produce accurate information in more than half the population.

This knowledge of the origin of the septic processes that lead to the demise of so many victims of thermal injury greatly expanded our understanding of burns, but left us with the unhappy realization that systemic therapy directed to the burn wound was ineffectual in combating the problem. Actually, in one large series, patients treated with huge doses of systemic antimicrobials did no better than those who received none.

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Avascular nature of burn wounds

The dilemma continued until the studies by Order et al demonstrated the avascular nature of the burn wound and the mechanism of conversion from partial-thickness to full-thickness skin loss. Utilizing a modified Schlessinger technique, the vascular network of the burn wound tissue was cleared with a saline flush and then injected with a mercury barium mixture that delineated the arterial circulation. These carefully done studies clearly demonstrated the series of events taking place within the burn wound subsequent to thermal injury.

Following the inception of the burn (scald) there is an immediate cessation of flow through the vessels as a result of thrombotic occlusion. In the full-thickness injury this persists and is never reestablished, but by three weeks post injury the neovasculature of granulation tissue appears at the junction of burn eschar and subjacent unburned tissues to initiate the reparative processes. Should burn wound sepsis supervene, however, the granulation tissue barrier is breached and fatal sepsis ensues.

In the partial-thickness wound, the initial loss of functional circulation is restored beginning at 24 hours post-burn with a slow and scattered reappearance of patent vessels. This continues to improve if other factors do not reverse the process so that by one week post-burn full circulatory integrity is restored.

This sequence of recovery can be interrupted by two factors which will convert the partial-thickness burn to full-thickness skin destruction. The first of these is infection which is characterized by bacterial invasion of the wound with intense perivascular inflammatory cell infiltration and progressive thrombosis of nutrient vessels with subsequent tissue necrosis. The second factor is drying of the wound. The initial vascular recovery process is apparently a very delicately balanced event and the effect of exposure to drying is enough to cause a progressive thrombosis of the vessels in the local area, and tissue necrosis.

This latter is a process by which the "zone of stasis," as described by Jackson, is converted to a "zone of necrosis." The therapeutic implications of this will be discussed later.

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Antimicrobial search

Armed with the knowledge that burn wound sepsis was the prime factor in the death of burn patients and that systemic antibacterial agents could not be delivered to the burn wound in effective concentration (because of the avasculature of the burn wound), it became apparent that antimicrobials that could be applied topically to the burn wound would be effective only if they would actively penetrate the tissues in an effective concentration, had a range of activity encompassing the mixed flora of the burn wound, and were locally and systemically nontoxic, and preferably, were easy to use and inexpensive.

The search began. Unknown to each other, Dr. Moyer's group and our own undertook laboratory and clinical trials and almost simultaneously developed effective formulations which are still in use. Moyer's 0.5% silver nitrate compresses and the 11% mafenide cream developed at the Institute of Surgical Research (formerly surgical research unit) have subsequently been joined by other formulations and techniques, but the same general principles remain: deliver the antimicrobial in effective concentration where it is most needed—directly to the burn wound.

The results of such therapy have been particularly gratifying, not only in sharply reducing overall mortality, but in bringing about the striking metamorphosis in the character of the burn ward environment as previously described.

The reduction in mortality is most dramatically demonstrated in comparing the results of such treatment in children and adults. Since children are at risk from burn wound sepsis 2.5 times as frequently as adults, effective control of the microbial flora of the burn wound will be reflected much more strongly in the figures derived from the population below 15 years of age. Such factors must be strongly borne in mind when attempting to evaluate the results of therapy in a patient population which is a mixture of all ages.

Evaporative water loss

The local burn wound undergoes many physical changes that are of consequence to the patient and must be recalled by the surgeon if he is to understand the systemic reflections of these events. One aspect of this was brought to light by Moyer at the first international burn meeting which was held in Bethesda, Maryland, in 1960. At that time he pointed out that the burn wound permitted passive evaporation of water in large quantities.

Calculating 560 kilo calories of energy expenditure for each liter of water evaporated, Moyer postulated that this demand would be large in the case of extensive burns that would evaporate an excess of three to four liters of water per 24 hours and that such demand was the basis for the hypermetabolism and large negative nitrogen balance so characteristic of this burn population.

His thesis provoked a tremendous amount of research activity directed at the problem, and while it has been subsequently shown that catecholamine release is the major factor in the metabolic drive, evaporative water loss is still an important clinical consideration.

Measurements of the magnitude of evaporative loss by vapor-pressure techniques, and measurements of insensible weight loss have clearly shown the course of events which follows destruction of the lipid-containing cornified layer of epidermis responsible for the water-retaining capacity of the skin—that thin layer of living and dead cells that allows us to live outside of our teleological origin in the oceans.

With initial thermal injury to the skin surface, there is an outpouring of serum and a measurable increase in vapor pressure at the surface of a partial-thickness wound. With the drying of the crust, water loss drops off precipitously and for the next two to three days the evaporative loss resembles that of the full-thickness burn wound which shows little evidence of evaporative loss initially. As either wound becomes hydrated again from the deeper tissues, evaporation begins in earnest reaching a peak at 10 to 14 days post-burn when the vapor pressure at the wound surface may be as high as 35mm of mercury in the full-thickness injury, and 15mm of mercury in a partial-thickness wound. Donor sites, incidentally, behave as a partial-thickness wound.

As the eschar separates in the full-thickness

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wound, the rate of evaporative loss lessens only to rise again as granulations are exposed. In the partial-thickness burn the healing wound is associated with gradually diminishing evaporative loss but even months later shows a measurable vapor-barrier defect. The grafted wound shows a rapid recovery since it retains its lipid layers intact.

Two effects

The magnitude of the fluid loss can be estimated by the formula: evaporative loss = (25 + % body burn) x M^2 body surface area. This evaporative water loss has two important effects: one local and the other systemic. The systemic effect is one of dehydration and unless watched for, can be insidiously complicating. Since evaporated water is salt free, the loss is directly reflected in serum sodium concentration and measurement of serum sodium is the most reliable guide to monitor.

The local effect is the one alluded to before —that is, the possible conversion of the "zone of stasis" to a "zone of necrosis" or the conversion of a partial-thickness injury to a full-thickness skin loss. In addition, the drying of even more superficial wounds can impair healing to a remarkable degree. This was dramatically demonstrated by studies done to evaluate initial local care of the burn wound.

Local care studies

Such studies were instigated following a lively discussion of the matter with Carl Moyer a number of years ago. This debate centered on the advisability of thoroughly debriding the devitalized but still adherent epidermis from a partial-thickness wound. Most surgeons, at the time, favored debridement probably because it produced a clean, glistening wound which had the pristine appearance of undamaged tissue.

Because of Moyer's strong doubt as to the propriety of such a step, studies were instituted to ascertain what really was best. These investigations compared the healing characteristics of such wounds debrided, left untouched, or debrided and covered with fresh allograft. The results obtained by serial biopsies were convincing.

The wounds from which the devitalized, adherent, but still protective epidermis had been stripped away showed edema of the subcutaneous fat and collagen, extensive inflammatory cell infiltration, loss of polarity of the epidermal cells and a disorganized pattern of maturation of the basal cells to squamous cells.

In the areas protected by allograft, or intact epidermal layers, the edema was absent, inflammatory cell infiltrate minimal, or absent, cellular polarity was well maintained, and the orderly maturation of cells of the epidermis proceeded unimpaired. In addition, the gross appearance of the protected wound was one of a much more advanced stage of healing as opposed to the edematous, red, angry-looking unprotected areas.

These initial studies by Miller et al were confirmed by others and formed the basis for the present widely used practice of immediate allografting of superficial partial-thickness burn wounds.

Tangential excision

The deeper partial-thickness wound does not fare well with such treatment techniques, however, because the dead superficial layers of skin are trapped beneath the allograft dressing and suppurative infection occurs. However, such a problem can be readily overcome by the tangential excision technique of Jancecovic. In this procedure, advantage is taken of the character of the burn wound, as described by Douglas Jackson. The zone of coagulation "necrosis" is removed by sharp dermatome skinning, layer by layer, until the deeper layers of the "zone of stasis" are approached and identified by punctate bleeding.

At this point the wound is covered with isograft, allograft, or xenograft. Healing beneath the biological dressing occurs rapidly if hematoma and infection do not preclude it. Failure to cover such wounds immediately leads to the disastrous effect of drying—namely rapid conversion to full-thickness tissue loss. In my own experience, tangential excision has not been of value in full-thickness burns.

Reparative process

Some of the most remarkable and enlightening studies of the local wound have been detailed investigations of the process of scar tissue formation and remodeling of the burn wound carried out by Bauer, Larson, et al at the Shriners' Burn Institute in Galveston.

The troublesome, disfiguring, crippling effects of burn scar contracture and hypertrophy have plagued patients and surgeons for centuries. Now, at last, a better understanding of the

process allows for an intelligent approach and the anticipation of much improved results.

The reparative process, as observed by these investigators, follows an orderly and predictable pattern. Following initial injury and local circulatory stabilization, the vascular ingrowth of granulation tissue begins and is accompanied by migration into the wound of fibroblasts—cells which are to play an increasing role in the later stages of wound healing. These fibroblasts increase in numbers and produce the collagen, glycoproteins, and mucopolysaccharides that comprise the dermal fibers thus providing the tensile strength of the wound.

As the wound repair continues, Bauer describes the process thus: "The dermis of the burn wound healing tissue is malformed in respect to its microarchitecture. Instead of normal (size and shape) collagen fibers distributed uniformly throughout the depth of the mature burn scar, tremendous accumulations of fused collagen in the form of matts are observed. During the later stages of granulation, the forming dermal components can be observed to assume bizarre configurations of collagen. These patterns continue to enlarge so that in early scar formation bundles or tracts of collagen begin to assume a whorl-like arrangement. As this scar continues its development, characteristic nodules of fused collagen filaments and cells are observed in the deeper layers of the dermis."* These nodules are the characteristic features of hypertrophic scars and keloids.

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The whorls and nodules appear to be the result of the action of other cells within the burn wound—the myofibroblasts. These cells, which contain contractile elements similar to the smooth muscle, impart to the healing wound the powerful force of wound contraction. This results from the constant pull of the myofibroblasts upon the collagen bundles to which they are attached. This foreshortening tension allows collagen to assume the whorl-like configuration due to the natural helical structure of the collagen molecule.

Myofibroblasts are seen early in the burn wound, usually by the third day, but constitute only a small percentage of the cells making up the legions of repair. With the passage of time they become more numerous and "at the height of the wound contraction phase of repair and up to 120 days postburn the numbers may comprise 50-75% of the fibroblasts in the tissue. At the peak of scar contracture formation they may account for 100% of the total fibroblast population."*

Pressure techniques

As the wound matures and scar remodeling occurs, the broad bands or solid matts of collagen become fenestrated, the whorl configuration lessens, the collagen fibers become omnidirectional and much smaller and the number of contractural myofibroblasts diminishes. Grossly, the wound is softer and loses its red, inflamed appearance. Ordinarily, the entire process of healing and maturation takes about 12 to 18 months from initial injury. However, this can be greatly influenced by the pressure techniques introduced by Larson et al that have proven to be of such great value in the prevention or treatment of burn scar contracture or hypertrophy.

The precise mechanism by which pressure-induced remodeling occurs is unknown but may be due to the local ischemic effects of the pressure. It is postulated that the mast cells of the wound respond to the lower pO_2 by releasing collagenase and other enzymes which cause the dissolution of the ground substances and thus fenestration of the collagen. Also the ischemia may obviate the collagenase inhibiting effect of the alpha-2 globulins which are abnormally elevated in most burn patients.

Whatever the mechanism, pressure dressings maintained constantly until maturation is attained results in a soft pliable scar, and when combined with appropriate splinting will correct crippling and deforming scar contractures. Pressure of 25mm of mercury must be continued until the scar loses its red, angry appearance and is soft. Should the pressure not be sufficiently constant or discontinued too soon, scar contraction or hypertrophy, or both, will recur rapidly.

Summary

Such are some of the more significant advances in the understanding of the burn wound and the clinical implications of this knowledge. They provide a good example of the utilization of clinical and laboratory investigations to enhance the clinical care of patients and have brought about an amazing renaissance in the treatment of burn victims. I believe it is safe to say that more progress has been made in the burn field in the last twenty years than in all the preceding years combined. Much is yet to be ascertained, however, and the mysteries that remain still continue to confound us.

*Bauer PS et al. *Clinics in Plastic Surg* 4:389, 1977.