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FOCUS ON: BURNS CARE

The management of major burns – a surgical perspective

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SUMMARY

In the UK, 1000 patients per year will need resuscitation and inpatient treatment for burns. The mortality is still relatively high but has improved significantly over the last 50 years. A greater understanding of the pathophysiology together with improvements in resuscitation, critical care and surgical techniques have all contributed to survival. For larger burns (greater than 25% total body surface area) there is a profound release of cytokines and chemokines. This results in a marked systemic inflammatory response syndrome, leading to edema, effects on multiple organ systems, a hypermetabolic response and suppression of the immune system. Early surgical care is based around the ABCD philosophy (as guided by Advanced Trauma Life Support and also Emergency Management of Severe Burns). An assessment system based on depth is vital for clinical decision making and prognosis. Many centers now aim for early excision and grafting of burns. Early excision modifies the host responses by removing devitalized tissue that might otherwise invoke deleterious effects, but its removal in itself may also provide a major insult. Several variations in approach are possible to modify the impact of excision and an approach tailored to the individual is appropriate. Covering the excised burn area can be achieved with wide range of materials from allograft to synthetic skin substitutes. Key to successful burn care is a directed multi-disciplinary model for providing appropriate expertise on individual sites, together with the development of burn care networks to facilitate effective delivery of burns services across an entire region.

Thirteen-thousand patients visit Emergency Medicine departments in the United Kingdom annually with a burn injury. One-thousand will require inpatient admission and fluid resuscitation. Despite advances over the last 60 years 300 will die and the majority of these will be elderly.[1]

The burn size lethal to half a specified age group (LD_{50}) has increased from 45% in 1950 to approximately 80% in 1990 for a 21-year-old man.[2] In the pediatric population a 98% total body surface area (TBSA) has a 50% chance of survival. Improvements in initial resuscitation through critical care and the operating theatre have helped achieve this.

Change has been driven by an understanding of the pathological processes involved and a more comprehensive approach to their remedy.[3]

1. The burn wound

Tissue destruction by thermal or chemical injury initiates the pathophysiological processes associated with burn injury. When the volume of tissue destruction involves 25% TBSA the profound release of cytokines and chemokines such as histamine, serotonin, bradykinin, nitric oxide, tumor necrosis factor and interleukins precipitate systemic inflammatory response syndrome (SIRS). A subset of SIRS patients develop multi- organ dysfunction syndrome (MODS) and a few will suffer multi-organ system failure.[4] Why certain patients deteriorate despite high standard care is unknown.

This profound inflammatory response causes edema and fluid sequestration secondary to increased microvascular permeability in both burned and unburned tissue. This affects all organ systems, resulting in myocardial depression, respiratory failure independent of inhalational injury, immunosuppression and renal impairment.

The burned patient exhibits suppression of innate and acquired immune systems. This may be a consequence of the body's own attempts to modulate the hyperinflammatory response potentially exacerbated by initial treatments such as opioid analgesia,[5] repeated blood transfusions and anesthetic agents.[6]

In burn injuries of 40% TBSA or greater there are profound metabolic consequences that are more dramatic and prolonged than in other critically injured patient groups. Increased core temperature, glycogenolysis, lipolysis, proteolysis, oxygen and glucose consumption all characterize the hypermetabolic response and are mediated by hormonal derangements.[7] Holistically this manifests as immunosuppression, poor wound healing and a decrease in lean body mass, with effects that persist long after the burn wounds have healed, impairing rehabilitation.

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"Modern methods of burn treatment have not altered the nature of burn-induced hypermetabolism but have significantly reduced its magnitude."[8] Early excision and wound coverage, nursing in a warm humid environment, preventing sepsis and resisted exercise (exercise against resistance – isometric) have all been shown to moderate the hypermetabolic response.[9] Pharmacological agents such as oxandrolone[10] and propranolol[11] have a role reducing weight loss and energy requirements respectively.

Enteral feeding has not been shown to reduce the hypermetabolic response in human studies but helps to ameliorate the deleterious effects. Early enteral feeding, within hours of injury, has been shown to be safer than parenteral nutrition, maintain gut integrity, reduce mortality and if delivered distal to the ligament of Treitz can be continued intraoperatively.[12]

Our understanding of the burn wound revolves around the three zones of injury proposed by David Jackson in 1953: the zone of hyperemia (peripheral), the zone of stasis (intermediate), and the zone of coagulation (central).[13] This represented a move away from consideration of burn intensity to a system based upon burn depth.

- Tissue involved in the zone of coagulation is unsalvageable despite modern treatment methods.
- Tissue within the zone of stasis has the potential for recovery if further damage can be avoided.[14]
- Tissue within the outer zone of hyperemia is viable and represents the host inflammatory response to injury.

Systemic disease, chronic illness and advanced age are all risk factors for conversion of the zone of stasis to one of coagulation. Most modern therapeutic regimens and dressings are designed to prevent desiccation, infection, hypoperfusion and edema in order to prevent deterioration of the zone of stasis and therefore minimize the zone of coagulation.

It is important to appreciate that the burn wound is dynamic, capable of progression in terms of depth and extension in size over the initial 48–72 h as the zone of stasis declares itself.

2. Burn assessment

The ability of a burn to heal itself is related to burn wound depth. The deeper the injury the fewer ectodermal appendages survive and the longer the time to healing. Thus partial thickness burns are sub-divided into superficial partial thickness, mid-dermal and deep dermal. The challenge is to identify those wounds that will heal themselves from those that will heal only with scarring and need intervention to speed healing and improve outcome.

Hypertrophic scarring can be predicted based on the time a burn takes to heal. Burns healed between 14 and 21 days have a 33% chance of developing hypertrophic scars whilst those wounds which take longer than 21 days to heal have an approximately 80% chance of developing hypertrophic scars.[15] These scars pose functional and aesthetic problems.

Healing without scarring is an achievable goal in superficial injury, but changes in pigmentation are more difficult to predict. Hypo- and hyperpigmentation are reported post superficial burn injury. Altered melanocyte function and reduced numbers may be indicated.[16,17]

An assessment system based on depth is vital for clinical decision making and prognosis. It also provides a common descriptive currency of burn injury for epidemiological, financial and clinical research.

A variety of methods have been described including clinical examination, thermography, spectroscopy, ultrasound, laser Doppler imaging (LDI), MRI and histological examination.[18]

Clinical examination is the commonest method utilized today, however, it has been shown to be accurate in only 60–80% of cases and most clinicians tend to overestimate depth.[19] Inaccurate initial assessment results in unnecessary operations for some with surgical removal of potentially viable dermis, and delayed treatment for others with the attendant waste of resources.

Laser Doppler imaging (LDI) is performed 48–72 h following the burn, is non-contact and uses laser light to assess microvascular flow. Paucity of flow is equated with depth of burn. Superficial burns have perfusion values greater than normal skin whilst deeper burns have lower blood flow values.[20] It has been shown to accurately predict burn wound depth in 97% of cases.[19] In early aggressive excision treatment regimens LDI may come too late to influence management decisions.

3. Burn care networks

The National Burn Care Review[1] advocated a coordinated network utilizing primary care, accident and emergency, burn facilities, burn units and burn centers with each component managing burn injuries appropriate to its resource mix within an equitable regional context.

From a surgical perspective the correct functioning of this network is imperative. Recognition of the volume of burn care performed in non-specialist centers is essential. This means providing education to referring centers with less experienced staff [21] and improving communication to ensure that patients who would benefit from specialist input are seen promptly.

In the USA and UK this has seen specific referral criteria defined that not only consider anatomical location and TBSA of burned tissue but also etiology, co-morbidities and skill set at the referring facility. Telemedicine has been an invaluable tool in facilitating this[22,23] and may even have a role to play in the follow-up of burn patients. [24]

Burn care represents a truly multi-disciplinary model. The role of the surgeon is as part of that team, neither more or less important than any other team member but perhaps uniquely placed to oversee the team structure and to co-ordinate the burn care network.

"Single clinicians change outlooks for individuals but effective networks can improve outcomes for populations." In the North American burn care systems the burn center director must be a surgeon. This person must direct the acute care of 50 or more acutely burned patients per annum and demonstrate an interest in burn care by completion of an approved fellowship or accumulated experience. They are in increasingly short supply.[25] The composition, training requirements and infrastructure required to declare status as a burn care center are strictly defined as part of a system for dealing with the trauma patient.[26]

There are obvious advantages to this approach beyond the obvious clinical benefit of experience and competence. The collection of burns injuries in one place offers research possibilities to advance burn care.[3] Research must answer questions relating to all aspects of burn care including the small burn not necessarily represented in studies based upon in-patient data.[27] This commitment to data capture is formalized in North America as the National Burn Repository with a minimum data set for all patients[26] and is being established in the UK as the British Isles Burn Injury Database (BIBID).

The familiarity that burn centers have with the management of major skin injury also provides an obvious role to play in the management of necrotizing infections with large volume soft-tissue loss[28], toxic epidermal necrolysis[29] and purpura fulminans.[30]

4. Early surgical care

Early surgical care is based around the ABCD philosophy so familiar to clinicians from advanced trauma life support (ATLS)

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and the emergency management of severe burns (EMSB). Surgical procedures in the immediate post-injury period are mainly concerned with securing an airway, and escharotomy.

4.1. Airway

Oro-tracheal in adults and oro-tracheal/naso-tracheal in children are the modern first line methods to provide a secured airway. Failure to secure an adequate airway by these advanced methods necessitates needle cricothroidotomy, tracheostomy or a combination of these methods. This can be as an emergency procedure in the pre-hospital arena[31] or in the emergency department.[32]

Prolonged orotracheal intubation may be associated with complications and therefore conversion to a formal tracheostomy is usually performed for the long-term management of the airway in critically ill burns patients. There have been anxieties about the use of tracheostomy in burns but recent studies examining the use of tracheostomies in adult burn patients have failed to demonstrate an increase in the rates of sepsis and mortality.[33]

Any burn in the anterior neck should be excised and grafted at an early stage in consideration for the possibility of future tracheostomy insertion.[34]

4.2. Escharotomy

The unyielding eschar of full thickness burn injury exerts a tourniquet effect on extremities[35] and constricts the thorax and the abdomen.[36]. Classically but not exclusively this occurs in circumferential full thickness burn injury. Failure to release the eschar leads to poor tissue perfusion, deficient oxygenation and ultimately necrosis. The most frequently occurring extremity complications due to inadequate escharotomies are amputation and sepsis.

Constricting eschar around the chest impairs ventilation and adversely impacts on gas exchange. Likewise if the eschar affects abdominal wall compliance then an abdominal compartment syndrome may occur with impaired cardiorespiratory function and poor renal perfusion. It can be simply diagnosed with intravesical manometry.[37]

In the extremities recognition of this serious condition and prompt restoration of circulation is required. Experimental data suggests that nerve undergoes irreversible damage in 12–24 h and muscle within 4–12 h.[38] This is particularly important if there is delay in reaching the burns centre. In an Australian pediatric trauma population, where a third of the patients required transfer for burns, patients spent an average of 5 h at the referring hospital prior to transfer.[39] Therefore with time on scene and transfer to the initial facility it may be necessary to salvage the limb by decompression at the primary receiving facility prior to transfer.

4.2.1. Escharotomy procedure

This means division of the eschar, utilizing incisions down the long axis of the limb in mid-medial or mid-lateral lines through the dermis[40] or down to deep fascia.[41] The literature regarding the exact nature and extent of these escharotomies is less than clear and occasionally contradictory. So it is no surprise that in one pediatric population escharotomies were performed poorly in outlying facilities prior to transfer to a burns centre.[42]

Despite the insensate nature of the eschar these should be performed in an operating theatre under general anesthetic as a sterile procedure with aseptic technique and the ability for hemostasis and replacement of blood loss. The escharotomies should extend into unburned tissue, across joints.[43]

Compartment syndrome can occur in a burned limb[44] and also in the unburned limb of a patient with major burns. This is thought to be due to generalized edema and increased microvascular permeability[42] and may be exacerbated by over aggressive fluid resuscitation.

Recent commentators have called for the term escharotomy to be abandoned in favor of the concept of "limb decompression"[41] encouraging the surgeon to have a high index of suspicion for compromised limb vascularity despite escharotomy and a low threshold for performing formal fasciotomies.[45] Decompression would include escharotomy and consideration of laparotomy in patients in whom an abdominal compartment syndrome was suspected.

5. Burn centre care

Before the era of early excision and grafting burns were treated with removal of loose dead tissue and application of dressings. If infection could be avoided then superficial burns healed within 2 weeks but deeper burns took longer to heal. Full thickness burns lost their eschar due to enzymatic debridement by colonizing bacteria and split skin grafts were applied some 3–6 weeks following injury onto the underlying bed of granulation tissue.

The rates of graft loss were high and repeated attempts were often necessary in order to completely close the wound. Hypertrophic scars and burn scar contractures were an almost inevitable consequence of the treatment. The popularization of early burn wound excision in the 1960s by Jackson[46] and the 1970s by Janzekovic, in her series of 2615 patients,[47] with immediate resurfacing of the wound, revolutionized burn care.

Early excision removes dead and devitalized tissue decreasing mortality, morbidity, bacterial colonization, length of hospital stay, time away from work and expenditure.[48–51] Advocates of early total burn wound excision seek to modify the host inflammatory response to ameliorate SIRS and prevent organ dysfunction. Improved survival was noted in children with massive burns treated in this fashion.[52] But caution needs to be used in generalizing these results in elderly populations with TBSA burns greater than 20%.[53]

Debridement and early wound closure are sound surgical principles seemingly more relevant when the toxic nature of the burn wound is considered. Historically burns teams were loath to undertake these major procedures whilst the patient was still in the immediate post injury period and critically ill. Advances in anesthesia, fluid resuscitation and blood use have made this type of surgery safer.

5.1. Techniques

The burn wound may be addressed surgically by:

- tangential excision
- fascial excision
- amputation.

5.1.1. Tangential excision

The principle of tangential excision is to remove necrotic tissue while seeking to preserve viable dermis in the wound bed. It was based on the observation that deep donor sites could be successfully overgrafted with split thickness skin grafts.[54] Contours are better preserved, pain and length of hospital stay are reduced and additional reconstructive procedures are decreased.[47]

5.1.2. Fascial excision

This is quick and easy to perform and results in less blood loss. However, it leads to contour defects and lymphedema. It is indicated when underlying subcutaneous tissues are burned and should be considered in life-threatening invasive wound sepsis especially when fungal organisms are involved.

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5.1.3. Amputation

This is reserved for unsalvageable limbs. It eliminates function as well as the burn but should not be discounted and still has a place in military wounds and electrical injuries.

Whatever method is employed the burn wound is excised until devoid of necrotic/non-viable material and healthy bleeding tissue is evident with a viable wound bed. Tangential excision can result in copious blood loss. It has been observed that large volume blood and blood product replacement is associated with an increased mortality in major adult burns[55] and in pediatric burns of over 60% with a concomitant inhalational injury.[56] Blood product use can be minimized by reducing intraoperative bleeding and reducing the transfusion trigger.[57] Unfortunately there is no evidence that clinicians caring for burn patients have stringent transfusion triggers with average hemoglobin estimations of 8 g/dl, age, TBSA burned and cardiac disease all influencing decisions to transfuse.[55] One North American study demonstrated that 1.78 units of packed cells were transfused per 1000 cm^3 excised in order to keep the hematocrit between 25 and 31.[58] Various strategies have been employed to minimize blood loss and whilst no comparative evidence exists between differing approaches appreciating the problem and having a strategy significantly reduces transfusion requirements.[59]

Suitable limb wounds can be excised under tourniquet.[54,57,60] This requires experience in order not to excise healthy tissue. Adrenalin infiltration of the wound bed prior to excision and adrenalin soaks placed upon the excised wound cause vasoconstriction and reduced blood loss with no systemic upset even if used in combination.[61,62]

Systemic recombinant activated factor VII (rVIIa) reduces blood loss and transfusion requirements in the excision and grafting of large burns with no increased rate of thrombo-embolic complications.[63]

Excision of the burn within the first 24 h has been shown to significantly reduce blood loss with no increase in mortality in a pediatric population[64] and this may be due to high circulating levels of the potent vasoconstrictor thromboxane B_2 in the plasma of burn patients.[65]

So is complete burn wound excision and coverage the answer? In pediatric populations there is overwhelming evidence to support early excision.[52] In adult populations meta-analysis of available data confirms that early excision reduces mortality and length of hospital stay in patients without inhalational injury.[66]

The data regarding when and in what manner excisions should be performed is less clear. Complete burn wound excision within 24 h or serial excision over a period of days?

Complete early burn wound excision in 24 h with wound coverage is a substantial logistical undertaking in the massively burned patient and should be performed by a team of surgeons in a specialist center. Gold standard wound coverage is autograft applied as a sheet in sensitive areas such as the hands and face or meshed to cover larger areas. Meshed autografts (1:1.5; 1:3; 1:6) increase the surface area that can be covered but rely upon healing by secondary intention within the interstices with a poorer quality scar.

5.2. Allograft

In burns over 35% TBSA donor sites are soon exhausted. Allograft and artificial skin substitutes are used as interim measures to seal the wounds whilst donor sites recover prior to re-cropping. Methods to make donor autograft go further include the Alexander[67] and Meek techniques.[68]

The Alexander technique uses autograft meshed 1:6 "sandwiched" with allograft meshed 1:1.5 or 1:2 to help seal the wound post-operatively. The Meek technique expands available autograft by using it in a postage stamp format.

Allograft plays an important role when autograft is not available. It can be fresh, cryopreserved or stored in glycerol in a process known as lyophilization. Concerns that fresh allograft promotes an inflammatory wound reaction that delays re-epithelialization has seen a trend in some centers for the use of less viable glycerol treated allograft.[69] Allograft effectively seals the wound in the immediate post-excision phase, reducing heat loss, exudates and ameliorating the hypermetabolic response. Disadvantages associated with allograft include the inevitable rejection and the risk of infection present with all transplanted tissue.

Aggressive early treatment removes the burn eschar helping to prevent wound infection, moderate the immune response and commence healing immediately. Advocates of this technique maintain that the sickest patients necessitate an aggressive response.[70]

Serial excision is an accepted alternative approach. In serial excision as much as 20% TBSA of the burn wound is excised in each operative session with the aim to excise and cover the burn in a timely fashion. Clinical full thickness burns are excised first in order to reserve judgment on other burnt areas and avoid excising potentially viable tissue. In serial excision repeated returns to the operating theatre pose inevitable hazards to the patient. These include bacteremias, cardiovascular instability, blood product use and prolongation of the hypermetabolic response.

In massive burns:

- large areas such as the back, anterior trunk and lower limbs are excised and grafted first. If all are involved then an appropriate order may be back first, trunk second and limbs third.
- a conservative approach is taken to facial burns and consideration should be given to performing tarsorrhaphies for ocular protection.
- hand burns should be dressed and elevated with the hand splinted in the position of safe immobilization; consideration can be given to K-wire fixation of the digits to maintain joint posture.[71]

If excised burns were initially covered with allograft or skin substitutes these are excised and in massive burns unusual donor sites considered such as the axillae, scrotum, mons pubis and even the soles of the feet.[54] Donor sites will eventually lose their regenerative capabilities even when ultra-thin split skin grafts are taken.[72] Regimens for donor site care are myriad reflecting the lack of consensus as to the best dressing. It is important to keep the grafted burn wounds clean whilst healing occurs, with regular dressing changes, cleaning and microbiological surveillance. This also holds true for donor sites between harvesting to allow quick recovery and prevent deterioration.

Skin grafting may be inappropriate when exposed structures including tendons, nerves and bone need to be covered. Flap cover whether local distant or free all have a role in burn injury reconstruction.[73]

5.3. Skin substitutes

These provide temporary physiological wound closure thereby preventing desiccation, fluid loss and reducing pain prior to spontaneous wound healing or autografting. They have a role to play with allograft in the treatment of large partial thickness burns and also the dressing of large donor sites. However, due to their synthetic nature they remain a possible focus for infection[74] and are expensive. Thorough debridement prior to application is essential with hydrosurgery devices such as Versajet®[75] having a role in particular situations. As recently as 2002 artificially engineered skin substitutes were not in common usage in the United Kingdom.[76]

Biobrane® is a biosynthetic dressing composed of a nylon mesh that is bonded to a thin silicone membrane coated with porcine

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polypeptides. It is used as a temporary covering for clean, debrided superficial and mid-dermal burns[77] and donor sites and has also been utilized as an adherent dressing over meshed autograft. It is designed to adhere to the wound base and to be shed as the burn wound heals. It is superior to 1% silver sulfadiazine in treating pediatric partial thickness injury.[78,79]

Integra® is a dermal regeneration template composed of two layers. The outer layer is a removable silicon sheet, the inner layer is a bovine collagen matrix designed to act as a dermal analogue. This dermal analogue is vascularized forming a neo-dermis within 4 weeks.[80] Once formed the outer silicon layer is removed and a thin autograft placed onto the neo-dermis. Its use in acute burn resurfacing with cultured keratinocytes has also been reported.[81]

Matriderm® is similar in concept to Integra® but is marketed with the ability to place a graft at the index procedure. It is not in common usage in the United Kingdom.

AlloDerm is an acellular dermal regeneration matrix derived from human skin and was developed on the observation that acellular dermal matrices do not undergo rejection. It is incorporated into the patient and a thin split thickness skin graft is placed upon it at the time of the index procedure. AlloDerm is similar in concept to Integra® but is more appropriate in patients where a one-stage procedure is beneficial[82] and can be used acutely.[83]

Since 1981 it has been possible to culture large numbers of keratinocytes from a small sample of autologous skin for burn wound resurfacing.[84] Transfer of confluent sheets of cultured epithelial autograft (CEA) is expensive, exquisitely sensitive to infection with variable graft take rates, but it can be life-saving in 60–70% TBSA burns.[85] CEA use has not gained universal approval and some centers only advocate it to achieve non-permanent life-saving wound closure. The sometimes less than ideal surface generated may be due to the cyclical nature of normal epidermis and the paucity and fragility of CEA imported stem cells. Methods to import stem cells into wounds are in development.[86]

There is some controversy as to how CEA is best utilized. Cultured keratinocytes have been sprayed onto wounds having been harvested from sub-confluent colonies in vitro. This technique, used in conjunction with widely meshed autograft, is purported to decrease healing time while maximizing donor skin usage. The area covered by sprayed cells may be much larger than sheets. However, as yet, there is a paucity of clinical evidence to show this. Sprayed keratinocytes may also be used to accelerate donor site healing. Recently there has been development of commercial products that immediately produce a suspension of cells from autograft skin harvested at the time of surgery (CellSpray®) while further research continues in their utilization with skin substitutes.[87] CEA impregnated sheets[85] have also been recently utilized in similar circumstances.

5.4. Future strategies

Enzymatic debridement of the burn wound was originally conceived during the Second World War and has obvious logistical advantages. It can be commenced in the immediate post-injury period by emergency clinicians, may preserve more dermis than surgical excision, reduce the requirement for limb decompression, negate the inflammatory burden of surgery and decrease blood loss. Various agents have been or are in the process of being examined and despite some encouraging results in children with non-infected partial thickness injuries[88] none are as yet in widespread usage.[89]

6. Outcomes

In modern burn care systems mortality is low. A European system quoted a mortality rate of 3.49% in those patients requiring inpatient care, with 75% of those people succumbing to their injuries within the first week .[90] Oddly the causes of mortality can only be speculated upon and are specific to the burn care system and its level of sophistication. The United States Government figures for burn mortality in 2001 had no cause of death documented in approximately half of cases. In those where a cause was recorded multi-organ failure made up 32% of cases followed by burn shock 14.6%, trauma wound 14.2%, pulmonary failure–sepsis 13.2%, cardiovascular failure 12.2%, and finally burn wound sepsis 4.7%.[91]

What is certain is that burns in an elderly population, the presence of an inhalational injury, polytrauma and persistent hyperglycemia are associated with an increase in mortality. [2,92–94] Almost all infants and children when adequately treated can be expected to survive.[95]

Therefore one could argue that in modern burn care networks we have moved beyond using mortality as an outcome endpoint and instead should be using those markers that measure the quality of life of burn survivors.[95,96] Modern goals should be centered around attempting to ensure an inpatient stay of 1 day per % TBSA burned in adults and less for the pediatric population. It falls to all involved in burn care to insure that "the quality of life is worth the pain of survival."[97]

7. Summary

Surgeons have an important role to play in the management of major burns, but only as part of a dedicated team. The era of early excision, improved resuscitation and strategies to counter sepsis has seen improved survival and reduced morbidity not attributable to any specialty group. Future innovations are required in the treatment of inhalational injury, securing earlier definitive, better quality skin cover and minimizing the burden of scarring.

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