

CHAPTER - 3

BURN SEVERITY

3.1 INTRODUCTION

One of the most painful injuries ever experienced by human being is a burn injury. When a burn occurs to the skin, nerve endings are damaged causing intense pain sensations. In normal case, it causes external damage on the body surface. Severe burns can cause complex injuries affecting number of other functions such as respiration, fluid electrolyte and thermal regulation of the body, joint function, manual dexterity and physical appearance. In addition to the physical damages caused by burns, patients may also suffer from emotional and physical disability problems, which may last for a very long duration and in some cases, it becomes almost permanent.

Burns are classified based on the, method and degree of burn. Methods are related to causes viz. thermal, chemical, electrical and light and radiation. The burn injuries from the clothing fires are classified as thermal burns, whereas degree of burns termed as first, second and third degree burns or similar such terminology indicating its severity. Occurrence and development of skin burn injury, factors influencing its severity and theoretical/laboratory methods for measurements of burn injury severity are discussed briefly in the following sections.

3.2 CLASSIFICATION OF BURN INJURIES

Moussa *et al.*¹⁴ summarizes the phenomenon of 'burn injury' as the variations that occur in the human skin as a result of rapid heat transfer from the adjacent burning fabric. Skin functions as a heat generator, conductor, transmitter, absorber, radiator and vapourizer. The various thermal functions of the skin denote that it is highly prone to burn injuries. Stoll⁶⁶ noted that skin has a pain threshold temperature of 44°C; beyond which skin tissues become incapacitated. Fig. 3.1 shows the detail features of various layers in case of normal skin of human. Burn injuries are generally classified depending on extent of damage occurs to these layers of skin as follows:

3.2.1 First Degree Burns

First-degree burns are those where the skin is not actually damaged. That is, no skin cells are damaged and hence no scarring occurs. Sunburn is an example of such a burn. Burn injuries of this nature cause redness and pain Fig. 3.2.

3.2.2 Second Degree Burns

In case of a Second degree burns, the secondary skin appendages experience partial damage. Encyclopedia Britannica explains the secondary burn as those marked by blisters for example 'a scald caused by hot liquid', as shown in Fig. 3.3.⁶⁷

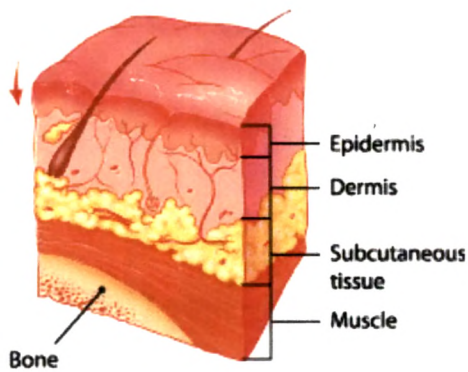


Fig. 3.1 Section of normal skin

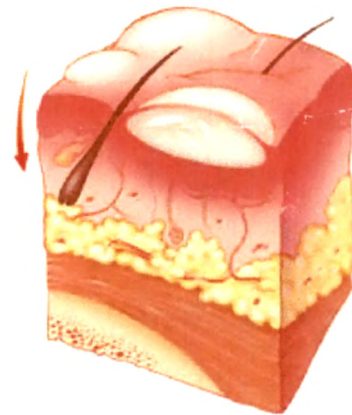


Fig. 3.2 Section of skin with first degree burns

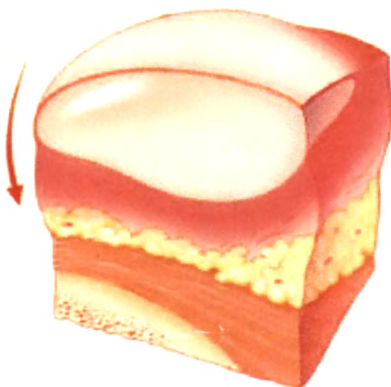


Fig. 3.3 Section of skin with second degree burns.

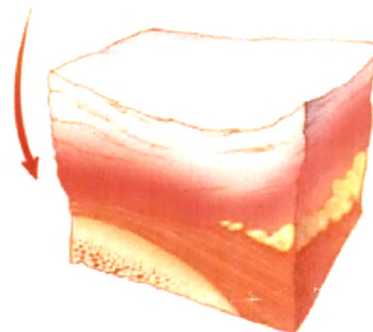


Fig. 3.4 Section of skin with third degree burns.

3.2.3 Third Degree Burns

A third degree burn occurs when the secondary skin appendages are destroyed. As Moritz⁶⁸ explained in a third degree burn both the epidermis and the dermis of the skin are destroyed and underlying tissues are also probable to be damaged, as shown in Fig. 3.4. Dissimilar to Moussa Bhatnagar's⁷⁷ and Lewin² annotates the burn injuries with respect to the depth of the burn injuries. First-degree burns are noted when the epidermis is affected up to a depth of 80 μ . The entire epidermis plus segments of the dermis damaged to a depth exceeding 80 μ is categorized as a second-degree burn. A third degree burn includes the destruction of the epidermis the dermis plus subcutaneous tissue.

3.3 PROCESS OF SKIN BURNS

Once the effects of skin burns are fairly well understood, then the process by which they occur must be understood and can be predicted. Available methods for predicting the onset and severity of skin burns use empirical correlations of experimental data rather than a type of approach derived from first principle. The experimental set-ups used for each study varied, as to the resulting correlations. In general, the experiment involved in applying a heat source, to a section of skin is usually by radiation. The skin could be human skin on the volar surface of the forearm of test subjects or for more intense exposures; pigs and rats were used.⁸⁸⁻⁹⁰ In some tests the skin was blackened to absorb almost all of the incident radiation. If the skin is not blackened during the tests, then a lower absorptivity of the skin must be used while calculating the incident flux.⁸⁸

The effect of the initial temperature of the skin can be very significant, and a small change of even 1°C can alter the results of the skin burn. Normal human skin temperature is 32.5°C. Damage will begin to occur to the skin, when the temperature of the basal layer reaches to about 44°C. The basal layer is at the base of the epidermis and is approximately 80 μ m below the skin surface.⁹¹ The rate at which damage to the skin occurs will increase logarithmically with a linear increase in temperature. Stoll and Chianta illustrate this effect with the

example that “damage occurs a hundred times faster at 50° C than at 45° C and at a temperature of 72° C the skin is destroyed almost instantaneously. Therefore, the amount of damage done to the skin is a function of the skin temperature as well as the amount of time for which the skin temperature exceeds 44° C. This means that the burn occurs during the heating and cooling phase of the exposure. At lower intensity exposures, 90% of the damage is done during the heating phase, while at higher intensity exposures 65% of the damage can be done during the heating phase. This does not seem so strange when considered from a practical viewpoint. The rapid application of ice to an exposed area can prevent a blister by eliminating about one third of the burn damage.

3.4 SKIN BURN INJURY FACTOR

The first and currently most widely used model of skin damage was proposed by Henriques and is a single order Arrhenius expression.⁹¹ He proposed that the rate of epidermal injury can be “modeled as a rate process governed by an activation energy and pre-exponential constant” as accordingly the injury factor (Ω) is given by equation.

$$\frac{d\Omega}{dt} = P \exp\left(\frac{-\Delta E}{RT}\right) \quad (3.1)$$

The Equation 3.1 can be integrated to yield a function that gives the total damage to the skin⁹¹

$$\Omega = \int_0^t P \exp\left(\frac{-\Delta E}{RT}\right) dt \quad (3.2)$$

The severity of the burn is determined by the total damage calculated by equation 3.2. Henriques²¹ stated the injury criteria as listed in Table 3.1. The calculated total damage to the skin would depend on the activation energy (ΔE) and pre-exponential term (P) used for the burn damage integral.

Table 3.1 Criterion for Degree of Injury

Criterion	Degree of Injury
$\Omega \leq 0.5$ at 80 μm	No tissue damage
$0.5 < \Omega < 1.00$ at 80 μm	First degree burn
$\Omega \geq 1.00$ at 80 μm and $\Omega < 1.00$ at 2000 μm	Second degree burn
$\Omega \geq 1.00$ at 2000 μm	Third degree burn

The values of ΔE and P as obtained by Henriques are 6.28×10^8 J/kmol and $3.1 \times 10^{98} \text{s}^{-1}$ respectively. T is the absolute temperature in kelvin and $R = 1.986$ cal/moleK. Like Henriques, numerous other studies also have been conducted using the burn damage integral. Using these values, the burn injury factor can be estimated to predict the degree of burns.

3.4.1 Skin Burn Severity

Injury may occur at anytime if the skin temperature remains above 44°C. This temperature refers to the sensitivity of the basal layer of skin to damage, about 80 μ below the surface, where the base of the blister forms. Extrapolation of data indicates that at a tissue temperature of about 72°C the skin is destroyed virtually instantaneously. The thermal properties and the injury criterion are shown in Table 3.2.⁷⁶

The external skin region contacted by fabric is the stratum corneum, composed of 12-15 dead kertonised cell layers generated by the underlying living epidermis. The important determinants in the production of burns are thermal flux (the rate at which thermal energy is transferred to the skin) and the duration of exposure time. The severity of burns depends on the integral of the time temperature profile and has been studied by number of workers.^{69, 70,92,93} Blood flow has significant effect on the burn injury severity. The amount of heat that can be dissipated from the body core, the effective thermal flux on the skin and hence the burn injury severity, are determined by the rate of blood flow to the skin. Also the successful heating of the skin depends upon an adequate supply of blood to the microcirculatory capillary vessels.

Table 3.2 Thermal Properties at Various Layers of Skin

Property	Epidermis	Dermis	Subcutaneous Tissue
Thickness (μm)	80	1920	5000
Thermal conductivity (W/mK)	0.209	0.380	0.210
Specific heat (J/kgK)	3600	2400	3000
Density (kg/m^3)	1150	1200	1000

The heat transfer during the burning process is very complex. When the skin is exposed to the heat flux, the heat flows through the keratin layer and into the underlying tissue. Not unexpectedly, the epidermis is the first structure to be damaged when the body is exposed to heat. Once the epidermal limit is reached, additional heat transfer can result in destruction of deeper lying structures. Of the three categories of coetaneous receptors in the skin structure, thermo receptors respond to warmth, coolness and changes in temperature and no receptors respond to severe stimulation that actually damages the skin tissue, resulting in a sensation of pain.⁹⁴ The severity of a burn is also predicted by the thickness of the skin, which varies, with the age of the victim. Total heat transfer is, therefore important in evaluating the garment flammability. Studies indicate that the total transfer of heat from flammable clothing at a sufficient rate is more than adequate to induce critical skin damage.⁹²⁻⁹⁴ However, with specific relevance to burning fabrics, Stoll *et al.*⁹⁵⁻⁹⁷ have studied in detail the physiological and related pathological effects. They established a relationship between heat flux and human tissues response up to the second-degree burn.

3.5 HEAT TRANSFER

All fabrics can transfer heat to the skin by radiation, convection or conduction modes. Each mode of heat transfer is subjected to different physical principles, but the effect of the total heat absorbed by the underlying skin is the same. If the resultant skin temperature rises is sufficiently high and maintained sufficiently long, injury results.²⁹ The degree of heat transferred from the source depends also on the orientation of the skin. Heat transfer increases as skin surfaces are oriented more perpendicular to the flames until

the maximum is reached, at the 90°. The graphical representation of increased heat transfer as receiver orientation to flames approaches the perpendicular.

Miller and Meiser⁴⁶ have defined the two terms; heat emission and heat transfer distinctively. Heat emission refers to energy given off by a material during flaming combustion although the destination of this energy is not specified. Heat transfer, on the other hand, implies and by necessity requires the identification of a specific target.

According to Freestone,⁹⁹ the rate of heat transfer through a material is a function of heat source temperature, heat flux and thermal characteristics of the material e.g. specific heat, thermal conductivity, heat of chemical reaction, heat of fusion, heat of vapourization, structural geometry, etc. The thermal conductivity and specific heat capacity of all polymeric fibres are of the same order of magnitude. Thus, fabric thermal conductivity/insulation is largely independent of the fibre type and it has been well established that the heat insulation property of a fabric is a function of its thickness and its ability to maintain that thickness.^{98,99} Moreover, the thermal conductivity of a fabric largely depends on the entrapment of air within the fabric structure. Thus fabrics comprising thermoplastic fibres may transfer substantially more heat than flammable non-thermoplastics fabrics like cotton because of the strong conductivity mode of transfer provided by the shrinking fabric and loss of entrapped air and eventual melting of the polymeric fibres. On solidifying these also give out latent heat of fusion which considerably adds to their hazard to the wearer, not only from additional heat to the underlying skin but also adhesion of the clothing to the skin.

Heat transfer has been defined as the process by which heat energy is exchanged between separate bodies or between regions of the same body at various temperatures. The rate of heat transfer according to Freestone depends on the form of heat and the heat source temperature as well as the thermal characteristics of the material in question. Waldock¹⁰⁰ claims that most burn injuries are caused by ambient and radiant heat. Scott broadly

defined ambient heat as atmospheric heat, where as radiant heat is that which is radiated from a specific heat source such as an open flame or an iron press

Backer *et al.*¹⁴ identified three primary methods of heat is transferred to skin.

i) Convection of hot gases within the air gap towards cooler skin and conduction through a thin layer of stagnant air adjacent to the surface of the skin, ii) Radiation from the production of solid particles (melted particles and glowing char) and gases from the combustion of the fabric and iii) Condensation of the products of pyrolysis (char and melted particles) as well as steam from the combust fabric at sufficiently small spacing to cause flames quenching. Alvares and Blackshear¹⁰¹ highlight the existence of a parallel problem regarding the process of heat transfer from burning fabrics to skin. It is recognized that 'thermal damage to skin and the ignition of cellulosic materials follow similar response parameters'. That is critical rates of energy deposition need to exist before the skin will exhibit damage or before the cellulosic material will ignite.

Lewin¹² proposes that heat transfer is related to the size of the burn and depth of burn injury extent. The size of the injury may however determine the level of disability when the epidermis is affected up to a depth of 80 μm . The entire epidermis plus segments of the dermis damaged to a depth exceeding 80 μm is categorized as a second-degree burn. A third degree burn includes the destruction of the epidermis, dermis and the subcutaneous tissue.

Thus, the severity of a burn injury is dependent upon several factors such as percentage of total area of the body burned, the thickness of the burn, and the location of the burn, all these factors influence the severity of the burn injury on the victim. The larger the area of a body suffering from 2nd degree burns, the greater is the probability of death. Moreover, the deeper the burn, the slower is the recovery and the greater is the danger of permanent scarring. Development of a burn morbidity index, encompassing the above factors is in progress. However, until a better index is developed, percentage total area of body will be used to indicate the severity of the injury.