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Review

Cooling of burns: Mechanisms and models

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ABSTRACT

The role of cooling in the acute management of burn is widely accepted in clinical practice, and is a cornerstone of basic first aid in burns. This has been underlined in a number of animal models. The mechanism by which it delivers its benefit is poorly understood, but there is a reduction in burns progression over the first 48 h, reduced healing time, and some subjective improvements in scarring when cooling is administered after burning.

Intradermal temperature normalises within a matter of seconds to a few minutes, yet the benefits of even delayed cooling persist, implying it is not simply the removal of thermal energy from the damaged tissues. Animal models have used oedema formation, preservation of dermal perfusion, healing time and hair retention as indicators of burns severity, and have shown cooling to improve these indices, but pharmacological or immunological blockade of humoural and cellular mediators of inflammation did not reproduce the benefit of cooling.

More recently, some studies of tissue from human and animal burns have shown consistent, reproducible, temporal changes in gene expression in burned tissues. Here, we review the experimental evidence of the role and mechanism of cooling in burns management, and suggest future research directions that may eventually lead to improved treatment outcomes.

Contents

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1. Introduction

1.1. *The basic model of a cutaneous thermal injury: three zones*

The classical model for a burn was proposed by Jackson in 1953 [1], and comprises three concentric zones of injury: a central zone of necrosis, a surrounding zone of stasis, and then a further zone of hyperaemia surrounding the zone of stasis.

The model was derived from observations of human burns and their progression to healing. The necrotic area was coagulated tissue that progressed to form an eschar. The hyperaemic zone always healed rapidly. The zone of stasis between these two zones derived its name from the lack of circulation within the dermal capillaries. This was shown pathologically by erythrocytes packed in the superficial plexus, whilst clinically the skin blanched on pressure. Furthermore, there was reduced tissue oxygen consumption, shown clinically by the lack of cyanosis of the tissue if the limb had a tourniquet applied. This area could progress to full thickness necrosis, or re-reepithelialise from the skin appendages.

In humans, this progression takes place over 24–48 h post-burn. Longitudinal histological studies have demonstrated progressive deepening of the level of the zone of stasis as evidenced by the deepest occluded capillary over the first 48 h following a burn [2]. As this is after the dermal temperature has returned to normal (*vide infra*), it indicates that the ongoing damage is mediated by other mechanisms that have been set in motion by the thermal injury, but continue long after the thermal energy has dissipated.

Salvage of the zone of stasis is an area of great interest in the management of burns as this represents an element of the burn where intervention by the Burn Surgeon may influence the outcome in terms of healing and scarring. A productive approach is to identify interventions that empirically improve survival of the zone of stasis within the burn, validate these improvements with objective, quantifiable assays, and then seek ways to mimic or augment these interventions' effects in the management of burns.

1.2. *Cooling of burns: traditional medicine, basic science and first principles*

Conventional first aid treatment of burns involves irrigation of the affected area with cool water, and this has been advocated since Galen (AD129-199), Rhazes (AD 852–923) and Earle (1799). As long as the temperature remains above 44 °C, the burning continues [3]. There are numerous anecdotal accounts of prompt cooling of the burn resulting in reduced scarring or reduced mortality [4]. Such accounts are cited in the introduction of one of the first published cooling experimental models [5]. A case is cited in which a scald to the upper limb in a young girl sustained by immersion in boiling milk was immediately cooled to the elbow in icy water in accordance with Scandinavian traditional medicine. The scarring was much reduced below the elbow compared to above. It was postulated that the cooling had a beneficial effect by reducing the amount of thermal energy imparted to the tissues and so reduced tissue damage to the cooled areas.

Work with eggs found that cooling eggs previously immersed in boiling water in cool water resulted in less coagulation of the contents compared to those cooled in air, an effect exaggerated by the application of cloth wrappings to simulate clothing [5]. This supported the theory that the amount of heat delivered, and the rate of dissipation to a temperature below the critical threshold for tissue damage determined the severity of the burn. However, when the same study created scalds to the tails and backs of rats, cooling at low temperatures resulted in high mortality, even with tail scalds only representing a few percent total body surface area (TBSA), but better results in terms of histological necrosis and oedema. It was concluded that a balance was required between hypothermia and cooling the burn.

A retrospective study in humans has reflected this by demonstrating the tendency for scalds caused by more viscous liquids and with more delay to cooling – therefore with more prolonged contact and more sustained energy delivery – to be more likely to cause a burn requiring skin grafting, a marker of increased burn depth [6]. While an human model for CWT for burns showed only analgesic benefit [7], the choice of burning at 65 °C for 15 s would probably create full-thickness burns not responsive to cooling [8], and retrospective case series have shown that CWT reduces the need for grafting [4,9–11].

In this review, we will first summarise the evidence regarding the thermodynamic and molecular effects of cooling burns. Next, we will review the literature regarding cellular, humoral and gene expression changes in burns. Finally, we propose directions for future research that combines these two areas, and may produce novel treatments aimed at improving the outcome for patients with intermediate thickness burns.