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Novel burn device for rapid, reproducible burn wound generation

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ABSTRACT

Introduction: Scarring following full thickness burns leads to significant reductions in range of motion and quality of life for burn patients. To effectively study scar development and the efficacy of anti-scarring treatments in a large animal model (female red Duroc pigs), reproducible, uniform, full-thickness, burn wounds are needed to reduce variability in observed results that occur with burn depth. Prior studies have proposed that initial temperature of the burner, contact time with skin, thermal capacity of burner material, and the amount of pressure applied to the skin need to be strictly controlled to ensure reproducibility. The purpose of this study was to develop a new burner that enables temperature and pressure to be digitally controlled and monitored in real-time throughout burn wound creation and compare it to a standard burn device.

Methods: A custom burn device was manufactured with an electrically heated burn stylus and a temperature control feedback loop via an electronic microstat. Pressure monitoring was controlled by incorporation of a digital scale into the device, which measured downward force. The standard device was comprised of a heat resistant handle with a long rod connected to the burn stylus, which was heated using a hot plate. To quantify skin surface temperature and internal stylus temperature as a function of contact time, the burners were heated to the target temperature (200 ± 5 °C) and pressed into the skin for 40 s to create the thermal injuries. Time to reach target temperature and elapsed time between burns were recorded. In addition, each unit was evaluated for reproducibility within and across three independent users by generating burn wounds at contact times spanning from 5 to 40 s at a constant pressure and at pressures of 1 or 3 lbs with a constant contact time of 40 s. Biopsies were collected for histological analysis and burn depth quantification using digital image analysis (ImageJ).

Results: The custom burn device maintained both its internal temperature and the skin surface temperature near target temperature throughout contact time. In contrast, the standard burner required more than 20 s of contact time to raise the skin surface

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temperature to target due to its quickly decreasing internal temperature. The custom burner was able to create four consecutive burns in less than half the time of the standard burner. Average burn depth scaled positively with time and pressure in both burn units. However, the distribution of burn depth within each time-pressure combination in the custom device was significantly smaller than with the standard device and independent of user.

Conclusions: The custom burn device's ability to continually heat the burn stylus and actively control pressure and temperature allowed for more rapid and reproducible burn wounds. Burns of tailored and repeatable depths, independent of user, provide a platform for the study of anti-scar and other wound healing therapies without the added variable of non-uniform starting injury.

1. Introduction

Severe scarring is estimated to affect as many as 70% of burn patients [1] and results in both cosmetic and functional deformities that negatively impact on the quality of life for those affected [2,3]. As a result, significant research has been conducted to develop therapies to prevent and treat scarring [3–10]. Despite the volume of scar research, a highly effective treatment has not yet been developed. A complication to scar research is the availability of an *in vivo* testing environment. Longitudinal studies in the human patient population lack controlled burn depth, size and location along with proper negative controls [3,5]. Rodent models do not possess the complex mechanical and biological environment observed in human skin and do not naturally form hypertrophic scars [11–15]. More recently, female, red Duroc pigs (FRDPs) have been proposed as a model for scarring [3,5,16,17]. Studies have confirmed that FRDPs form robust scars following deep cutaneous wounds and that these scars are similar in appearance to human hypertrophic scars. FRDP scars are thick, raised above surrounding skin, lack hair and contain elevated populations of myofibroblasts and mast cell [3,16,18]. Additionally, the pattern of inflammatory cytokine expression is similar between humans and female red Duroc pigs [3,16,18,19]. These structural and biological similarities between human hypertrophic and the thick scars on FRDPs provide a new platform for the study of scar development and anti-scar therapies.

One of the main obstacles in studying burn wounds in animal models is the difficulty in producing burns with uniform depth [20]. For consistent wound generation, it has been proposed that the initial temperature of burner, contact time, thermal capacity of burner material, and the amount of pressure applied to the skin all need to be tightly controlled [20]. A number of different burning devices have been created to satisfy this set of needs. Heating a metal or glass stylus in a water bath has been used in prior studies to generate cutaneous burn wounds [20–22]. One study created contact burns placing water heated to 92 °C in a plastic bottle on the skin surface for 15 s [23]. Although the operator and procedure were kept consistent, variability in injury depth and subsequently differences in healing time of local areas within each wound were reported [23]. To improve reproducibility, the addition of a pressure monitor to the standard burn device has been employed [20] resulting in more uniform wounds.

The goal of this study was to develop a new burn device that could provide real time pressure monitoring, in addition to real time control and monitoring of device temperature, for rapid generation of reproducible burn wounds. This device was then compared to a standard burn stylus comprised of a heated block. Time required to bring the device to temperature, ability to raise and maintain skin surface temperature throughout the burn experiment, and elapsed time between generation of consecutive burn wounds was examined. In addition, burn depth was assessed as a function of burn device, time, pressure and user.

2. Materials and methods

2.1. Burn devices

To create full-thickness wounds, 1 × 1 in stainless steel blocks were placed onto pig skin to create a thermal injury. Two different burn devices were utilized. The first was a standard burn stylus consisting of a stainless steel block (1 in.^{3}) connected to a metal rod and handle (Fig. 1A), which can be heated using a hot water bath or using a hot plate. A hot plate (Corning PC-420D, Tewksbury, MA) was used in this study to heat the block to 200 °C (Fig. 1A). The second device was a custom burner fabricated in house that consisted of a stainless steel block (2.5 cm^3) connected to a metal stylus, an electronic microstat (JUMO GmbH and Co. KG, Fulda, Germany) and electronic scale (Guangzhou WeiHeng Electronics Co. Ltd., Guangdong, China) (Fig. 1B). The custom burn device was electronically heated internally, and the electronic scale allowed for precise measurements of pressure applied to the skin surface. The housing surrounding the heating element and pressure gauge was constructed from aluminum to keep the added weight to a minimum (custom unit was 2.5 lbs heavier than the commercial unit). The housing unit can be handled without the use of thermally insulated gloves during operation.

2.2. Temperature logging system

Internal, mid-block temperature of the standard burner was logged in real time during initial heating, burning, and post-burn using a thermocouple (J-type, OMEGA, Stamford, CT) inserted in a centrally located hole in the stainless steel block