# A Review of Scald Burn Injuries

**Authors**

Lauren J. Vallez
Brian D. Plourde
John E. Wentz
Brittany B. Nelson-Cheeseman
John P. Abraham

University of St. Thomas
School of Engineering
2115 Summit Ave
St. Paul, MN 55105-1079

**Affiliations**

John P. Abraham
jpabraham@stthomas.edu

**Abstract**
Burn injuries are common and sometimes serious injuries that afflict persons of all ages, gender, socio-economic classes, and geography. Much effort has been placed into burn reduction campaigns and education. Nevertheless, there are very few studies that clearly connect liquid scald temperatures with burn depth. Here, a review of literature, presentation of recent experiments and description of calculations are provided. From this review, tools are presented that serve three purposes. First, data on cooling rates of various beverage sizes and compositions are reviewed. This information enables a determination of the temperature of a beverage at the time of a spill, provided the service temperature is known. Second, the results provide the prediction of burn depths for various spill temperatures with a focus on the temperatures that are required for burns to reach the mid-dermal region. Finally, the results are presented in easy-to-use graphs and tables so that it is possible to find what circumstances make severe burns likely. These data allow beverage service companies, parents and guardians, burn education organizations, and others to reduce the likelihood that severe burns will occur.

**Keywords:**
Burn injury; scald; burn prevention; hot beverages;

## Introduction

Approximately 486,000 patients seek medical treatment at hospital emergency departments for burn injuries each year. It should be noted this estimate does not account for burns treated at clinics, community health centers, or private medical offices (ABA 2016). Burns can range greatly in severity depending on type, location, surface area, and depth of the burn. The chosen method of treatment for a burn relies heavily on the depth of the burn (Advanced Burn Life Support Course Provider Manual 2007; Singer et al., 2014; Enoch et al., 2009; Cubison et al., 2006). Minor surface burns may require no care, while more serious burns may require painful treatments such as skin grafts. Although there are simple methods to estimate the surface area of a burn after injury, it is much more difficult to measure the depth of the burn (Enoch et al., 2009; Jaskille et al., 2010; Heimbach et al., 1984; Gibran et al., 2012; Hlava et al., 1983). Since burn depth by visual inspection is often unclear (Merz et al., 2010; Singer et al., 2000; Durant et al., 2008; Heimbach et al., 1984; Palla et al., 1981), possibly resulting in incorrect treatment, predictions of burn depth are presented for various on liquid temperatures and exposure times.

## Classification of Burns

There are two commonly used burn classifications. One is simpler and more established than the other, but is less exact. This classification is known as the *degree* categorization. *First-degree burns* occur only in the epidermis, the layer at the surface of the skin. *Second-degree burns* enter into the dermal layer. *Third-degree burns* pass through the epidermis and dermal layers and may enter into the next layer, composed mainly of fat and connective tissues, called the hypodermis. *Fourth-degree burns* pass deep into subcutaneous tissue and may go beyond into muscles, ligaments, or bone.

The other form of classification includes more categories and over time, has also come into common use. This classification splits dermal burns into two different categories, which is advantageous since their treatments vary greatly. Under this classification, *superficial burns* are equivalent to *first-degree burns*. *Second-degree burns* are separated into *superficial partial-thickness burns* and *deep partial-thickness burns*. *Superficial partial-thickness burns* extend into the outermost half of the dermal layer. *Deep partial-thickness burns* extend past the halfway point and into the lower layer of the dermis, the reticular layer. *Full-thickness burns* are equivalent to *third-* and *fourth-degree burns* (Baxter et al., 1988; Ahrenholz et al., 1995; Monafo et al., 1996; Durrant et al., 2008). Figure 1 gives a visual representation of the skin layers and corresponding burn categories.

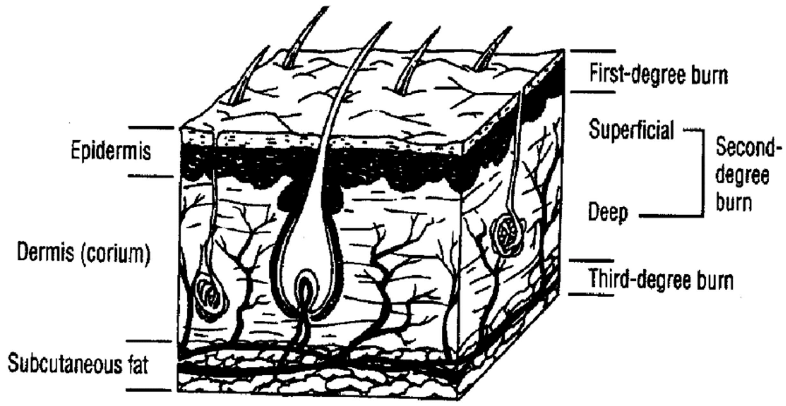


**Figure 1** Depiction of various burn depths (Adapted from reference Roth et al., 2004 with permission of the publisher).

**Causes of Burns**

Causes of burns can be categorized into three major types: thermal, chemical, and electric. The most common cause is thermal, specifically elevated temperatures. Elevated temperatures may be from hot objects, cooking utensils, fires/explosions, hot liquids, or gases and can occur in kitchens, restaurants, factories, businesses, or outdoors. Elevated temperatures due to hot liquids are specifically known as scald burns and will be the focus of this paper because of their frequency.

**Misunderstanding of Burns**

Much research has been done on burn depth. Studies performed in the 1940s presented water temperatures and exposure times that could lead to burns (Moritz et al., 1947a; 1947b; Moritz 1947; Henriquez 1947). Unfortunately, this data has been misinterpreted by many (Maguina et al., 2003; Sever et al., 2010; Bynum et al., 1998; American Burn Association; The Burn Foundation; Accurate Building Inspectors 2005; Public Service Enterprise Group; Regional One Health; Burn Prevention Network). In Moritz et al., 1947b, the characterization of burns was either no irreversible damage or transepidermal injury. A transepidermal injury is similar to the onset of a *second-degree burn* or a *superficial partial-thickness burn* in that the burn passes through the epidermal layer and slightly into the dermal layer. Others have incorrectly described the Henriques-Mortiz data as corresponding to *full-thickness burns*, *third-degree burns*, or both *second* and *third-degree burns.* Computational research done recently on burn depth has agreed with Henriques and Mortiz original statements (Abraham et al., 2015; Abraham et al., 2011; Viglianti et al., 2014; Johnson et al., 2011; Diller 2011; Bourdon et al., 2016). Work done in (Abraham et al., 2015) shows that *deep partial-thickness burns* caused by elevated liquid temperatures must be from hotter temperatures than those presented in the aforementioned references.

This manuscript will provide a simple method for medical professionals to accurately predict burn depth for various liquid temperatures and exposure times. It will also give suggested temperatures of liquids to aid in burn prevention. In the following section, a detailed description of the analyses will be given.

**Burn Depth Calculations**
The focus of this study is on the potential for skin burns from heated beverages (such as coffee, tea, etc.). Beverages can often spill and impact human skin; when the temperatures are sufficiently high, the incidents result in scald injuries. As stated in the preceding section, severe burns are characterized by the injury reaching depths within the dermal layer (*partial-thickness burns*). From a practical standpoint, a commonly used demarcation of serve burns are those that extend approximately halfway into the dermal layer. Such injuries are termed "mid-dermal". As stated earlier, the mid-dermal layer is commonly used to differentiate *superficial partial-thickness* injuries from *deep partial-thickness* injuries. Burns that reach these depths and beyond are much more likely to require professional medical treatment, possibly skin grafting.

During a spill incident, the horizontal extent of exposure to heat is often quite large compared to the depth of the burn (which is on the order of millimeters). This is the case even if the region of the body is not flat, for instance an arm or leg. Curvature of the body is orders of magnitude larger than the burn depth. For this reason, burn injuries will be treated as a one-dimensional heat transfer process. The model used to predict burn depths is expressed mathematically as (Pennes 1948)

$$(\rho c)_t \frac{\partial T_t}{\partial t} = k \frac{\partial^2 T_t}{\partial x^2} + (\rho c)_b \omega (T_b - T_t) \qquad (1)$$

The leftmost term represents the unsteady temperature change within the tissue. The first term on the right is the heat conduction term. The rightmost term is related to blood perfusion through the tissue. The symbols $\rho$, $c$, and $k$ are the density, heat capacity, and thermal conductivity, respectively. The $\omega$ symbol is the rate of volumetric blood perfusion (per unit volume of tissue) which has the units 1/seconds. $T$ symbols represent temperature. The subscripts $t$ and $b$ are used to signify tissue and blood properties.

Solution of Equation 1, requires knowledge of the properties, thicknesses of various tissue layers, and thermal boundary conditions. These issues will be discussed shortly. The result from Eq. (1) is the timewise variation of temperature within the tissue which is then used to determine the state of tissue injury.

Thermal damage to tissue is a result of complex cascading phenomena that vary depending on the temperature. There is a wealth of available literature which has investigated these issues. Although not an exhaustive list, they include (Branemark et al., 1968; Linke et al., 1972; Takata 1974; Moussa et al., 1977; Sapareto et al., 1984; Higgins et al., 1988; Dewhirst et al., 1984; Brown et al., 1992; Dewey 1993; Agah et al., 1994; Agah et al., 1996; Dewhirst et al., 2003; Wright 2003; Bhowmick et al., 2004; Greenhalgh et al., 2004; Diller 2005; Feng et al., 2008; He 2011; Yarmolenko et al., 2011). The complex physiologic processes which occur during the incident make quantification of injury a difficult problem. Traditionally there are two commonly used approaches; the first is based on an Arrhenius damage model and the second utilizes the *cumulative equivalent exposure* approach. The former is more commonly applied to higher temperature exposures whereas the latter is commonly employed for lower temperature, hyperthermia situations. Recent summaries relating these two methods are given by (Viglianti et al., 2014; Dewhirst et al., 2015).

Based on its record when applied to hot-liquid exposures, the quantification from Moritz and Henriquez will be used (Moritz et al., 1947a; 1947b; Moritz 1947; Henriquez 1947). Those studies resulted in the following injury formulation

$$\Omega(x,t) = \xi \int_0^t e^{-\left(\frac{\Delta E}{RT}\right)} d\lambda = \ln\left(\frac{C(0)}{C(t)}\right) \tag{2}$$

where $R$ is the ideal gas constant and $\lambda$ is a variable of timewise integration. The symbols $\xi$ and $\Delta E$ are tissue injury parameters which are $\xi = 3.1\text{e}98$ and $\Delta E$ = 6.28e8 (J/kmole). The functions $C(t)$ and $C(0)$ are the viable cell concentrations at time $t$ and at an initial time, respectively.

In the original publications, a value of $\Omega = 1$ evaluated at the base of the thermal layer was associated with transepidermal necrosis. However, in many following studies, Eq. (2) has been extended beyond its original intent so that values of $\Omega = 1$ have been interpreted as local permanent injury. The fact that Eq. (2) has been extended beyond its initial purpose has not been recognized by many researchers and should be viewed with some skepticism. On the other hand, the fact is that the extension of Eq. (2) has resulted in excellent agreement between injury calculations and observations from actual burn studies. It is this history of excellent performance that has justified its use and extension in the literature and in this manuscript. It should be noted that many scientists have proposed different values of $\xi$ and $\Delta E$ which in some cases improves upon the performance of Eq. (2). However, the fact that these parameters were developed from experiments on porcine and human skin with hot-water scalds (the same situation focused on here) motivates their use.

Among recent validations of the approach taken here are Johnson et al., 2011, Viglianti et al., 2014, and Abraham et al., 2015; Abraham et al., 2016a for scald incidents and in Lovik et al., 2009; Sparrow et al., 2010; Smith et al., 2010; Lovik et al., 2011a; 2011b; Abraham et al., 2016b; Stark et al., 2016 for medical implants underneath the skin where animal model experiments showed excellent agreement with numerical predictions.

The first step in the simulation is the input of tissue thicknesses and thermal properties. A four-layer tissue model is used; Table 1 lists these quantities for the various tissue zones (Johnson et al., 2011).

**Table 1 – Properties and thicknesses of tissue layers (adapted from Johnson et al., 2011; Abraham et al., 2011.)**

| Property | Epidermis | Dermis | Subcutaneous | Muscle |
|---|---|---|---|---|
| Thickness (mm) | 0.08 | 2 | 10 | 30 |
| Thermal conductivity, k (W/m °C) | 0.22 | 0.4 | 0.2 | 0.45 |
| Heat capacity, $c_p$ (J/kg °C) | 3600 | 3600 | 2500 | 3800 |
| Density, ρ (kg/m$^3$) | 1200 | 1200 | 1000 | 1000 |
| Blood perfusion rate, ω (1/s) | 0 | 0.00125 | 0.00125 | 0.00125 |

In the equations, the symbols $\rho$, $c$, and $k$ are the density, heat capacity, and thermal conductivity, respectively. The $\omega$ symbol is the rate of volumetric blood perfusion (per unit volume of tissue) which has the units 1/seconds.

The tissue layers were subdivided into a multitude of computational elements that was sufficient to avoid numerical error in the calculations. Details of the discretization are provided in Johnson et al., 2011, Abraham et al., 2015; Abraham et al., 2016a and are not repeated here.

The initial temperature of the tissue was taken from steady state calculations so that deep within the tissue the temperatures were 37 °C while at the skin surface, the temperatures were approximately 34 °C. Boundary conditions are required at both the exposed skin surface as well as at the deep tissue layer (muscle). At the innermost surface of the muscle, an isothermal condition of 37 °C was employed reflecting the normothermic body temperature. At the skin surface, a timewise temperature variation attained from experiments on tissue surrogates and living tissue was applied. Here, a brief description of the experiments from Abraham et al., 2016a will be provided.

The experiments were performed wherein water of various volumes was heated to temperatures up to boiling. Next, the water was poured into beverage containers (cups) of various volumes and constructions. The volumes ranged from 8 ounces – 16 ounces (237 ml – 473 ml). The cup constructions were polystyrene and paper. Some experiments involved cups that had a plastic covering, whereas others had no covering. All experiments were performed in a natural convective environment with an ambient temperature of 20 °C and were in replicate so that statistical quantities could be obtained.

An outcome of the experiments was the cooling rate of the heated liquid for each cup. An abbreviated set of results is provided in Tables 2-5. These tables show, respectively, the temperature at various times following service and for various initial temperatures. For instance, Table 2 corresponds to a 237 ml (8 ounce) beverage cup without a plastic cover. According to the table, if the beverage is initially served at a temperature of 70 $^{o}$C (158$^{o}$F), then the fluid will cool to 58.1 $^{o}$C after a 5-minute cooling period and to 50.4 $^{o}$C after 10 minutes of cooling. Similarly, the other tables present information for other volumes and other capping situations. The utility of Tables 2-5 is that they provide the spill temperature for any situation of service temperature and cooling time prior to a spill incident.

**Table 2 Cooling of an 8 ounce (237 ml) heated beverage without a protective cap (adapted from Abraham et al., 2016a)**

| **Cooling time (min)** | **Service Temperature, $^{o}$C ($^{o}$F)** | | | | | |
|---|---|---|---|---|---|---|
| | **70 (158)** | **75 (167)** | **80 (176)** | **85 (185)** | **90 (194)** | **95 (203)** |
| 0 | 70 | 75 | 80 | 85 | 90 | 95 |
| 5 | 58.1 | 61.9 | 61.9 | 69.5 | 73.4 | 77.2 |
| 10 | 50.4 | 53.4 | 53.4 | 59.5 | 62.5 | 65.5 |
| 15 | 45.1 | 47.6 | 47.6 | 52.6 | 55.2 | 57.7 |
| 20 | 42.4 | 44.6 | 44.6 | 49.1 | 51.4 | 53.6 |
| 25 | 42.2 | 44.4 | 44.4 | 48.9 | 51.1 | 53.3 |

**Table 3 Cooling of an 8 ounce (237 ml) heated beverage with a protective cap adapted from Abraham et al., 2016a)**

| **Cooling time (min)** | **Service Temperature, $^{o}$C ($^{o}$F)** | | | | | |
|---|---|---|---|---|---|---|
| | **70 (158)** | **75 (167)** | **80 (176)** | **85 (185)** | **90 (194)** | **95 (203)** |
| 0 | 70 | 75 | 80 | 85 | 90 | 95 |
| 5 | 62.5 | 66.7 | 66.7 | 75.2 | 79.5 | 83.7 |
| 10 | 56.9 | 60.6 | 60.6 | 67.9 | 71.6 | 75.3 |
| 15 | 52.5 | 55.8 | 55.8 | 62.3 | 65.6 | 68.8 |
| 20 | 49.5 | 52.5 | 52.5 | 58.4 | 61.3 | 64.3 |
| 25 | 47.7 | 50.5 | 50.5 | 56.1 | 58.8 | 61.6 |

**Table 4 Cooling of a 16 ounce (473 ml) heated beverage without a protective cap (adapted from Abraham et al., 2016a)**

| Cooling time (min) | Service Temperature, $^oC$ ($^oF$) | | | | | |
|---|---|---|---|---|---|---|
| | **70 (158)** | **75 (167)** | **80 (176)** | **85 (185)** | **90 (194)** | **95 (203)** |
| 0 | 70 | 75 | 80 | 85 | 90 | 95 |
| 5 | 61.5 | 65.7 | 69.8 | 74.0 | 78.1 | 82.3 |
| 10 | 55.9 | 59.5 | 63.1 | 66.7 | 70.3 | 73.9 |
| 15 | 51.9 | 55.1 | 58.3 | 61.5 | 64.7 | 67.9 |
| 20 | 49.6 | 52.5 | 55.5 | 58.5 | 61.4 | 64.4 |
| 25 | 48.9 | 51.8 | 54.7 | 57.5 | 60.4 | 63.3 |

**Table 5 Cooling of a 16 ounce (473 ml) heated beverage with a protective cap (adapted from Abraham et al., 2016a)**

| Cooling time (min) | Service Temperature, $^oC$ ($^oF$) | | | | | |
|---|---|---|---|---|---|---|
| | **70 (158)** | **75 (167)** | **80 (176)** | **85 (185)** | **90 (194)** | **95 (203)** |
| 0 | 70 | 75 | 80 | 85 | 90 | 95 |
| 5 | 65.0 | 69.5 | 74.0 | 78.5 | 83.0 | 87.5 |
| 10 | 61.5 | 65.7 | 69.8 | 74.0 | 78.1 | 82.3 |
| 15 | 58.8 | 62.7 | 66.6 | 70.5 | 74.4 | 78.3 |
| 20 | 57.0 | 60.7 | 64.4 | 68.1 | 71.8 | 75.5 |
| 25 | 56.0 | 59.6 | 63.2 | 66.8 | 70.4 | 74.0 |

The results listed in Tables 2-5 are very close matches to previously published work which increases confidence in the results (Mercer 1988; Ramanathan et al., 1994; Warner et al., 2012).

Next, experiments were performed wherein fluids of various temperatures were spilled upon both tissue surrogates and living tissues that were instrumented with temperature sensing devices (high-quality thin gauge type E thermocouples). All experiments were performed for a single layer of cotton cloth that covered the surrogate or living tissue. The results from these second-stage experiments were then employed as thermal boundary conditions on the exposed skin in the numerical model. Figure 2 has been prepared to summarize the boundary and initial conditions. The various layers are drawn schematically and not to scale.

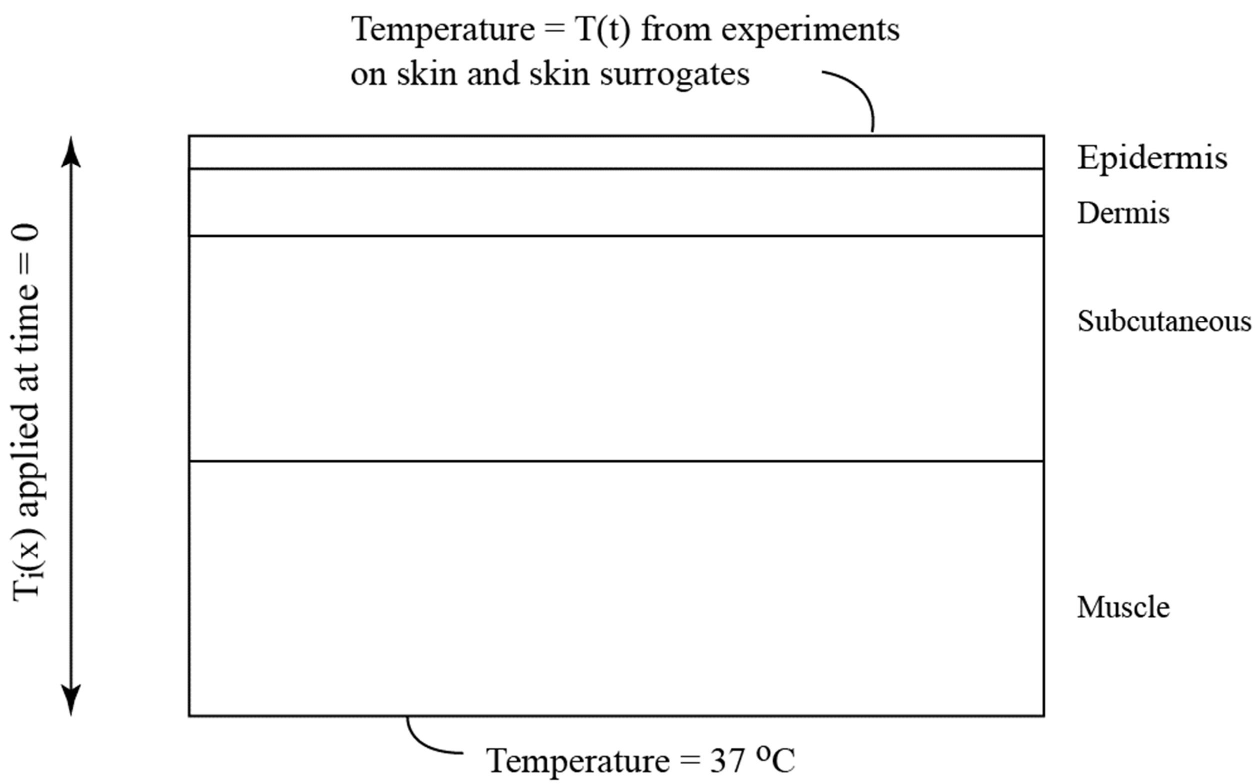


**Figure 2 – Schematic of the initial and boundary conditions used in the calculations.**

With the geometry, thermal properties, initial condition, boundary conditions and the numerical model now fully described, it is possible to present and discuss the key findings.

**Results and Discussion**

Perhaps the issue of most immediate importance is the depth of burn associated with various beverage temperatures.

Figure 3 has been prepared which provides the depth of burn for various spill temperatures. Annotations are provided for the spill temperatures which correspond to mid-dermal burns in both adults and in children. From the figure, it is seen that adult mid-dermal burns are caused by temperatures of ~82 $^{o}$C (180$^{o}$F) whereas mid-dermal burns in children are likely to be caused by temperatures of ~76 $^{o}$C (169$^{o}$C). Some care must be exercised when using

Figure 3. The figure is based on adult skin thickness that is 2 mm. Since skin thickness varies with age, (children and the aged have thinner skin than adults) a generalization is used. That generalization is that children skin is approximately 70% the thickness of adult skin. For younger children, toddlers, and newborns, this approximation is an overestimate (Conti et al., 1995; Seidenari et al., 2000).

In addition, the thickness of skin varies by body location. There are some bodily regions with thicknesses greater than 2 mm in adults but many areas where skin is thinner than this value. For thinner skin body regions, the temperatures required to cause mid dermal burns will be less than the values listed in Figure 3.

The results are related to spills of various volumes up to 437 ml (16 ounces). Larger volume spills would result in more severe burns. In addition, all results correspond to a single layer of cotton clothing. Clothing has the potential of reducing the skin temperature or, depending on the absorptivity of the clothing, can prolong the burn duration.

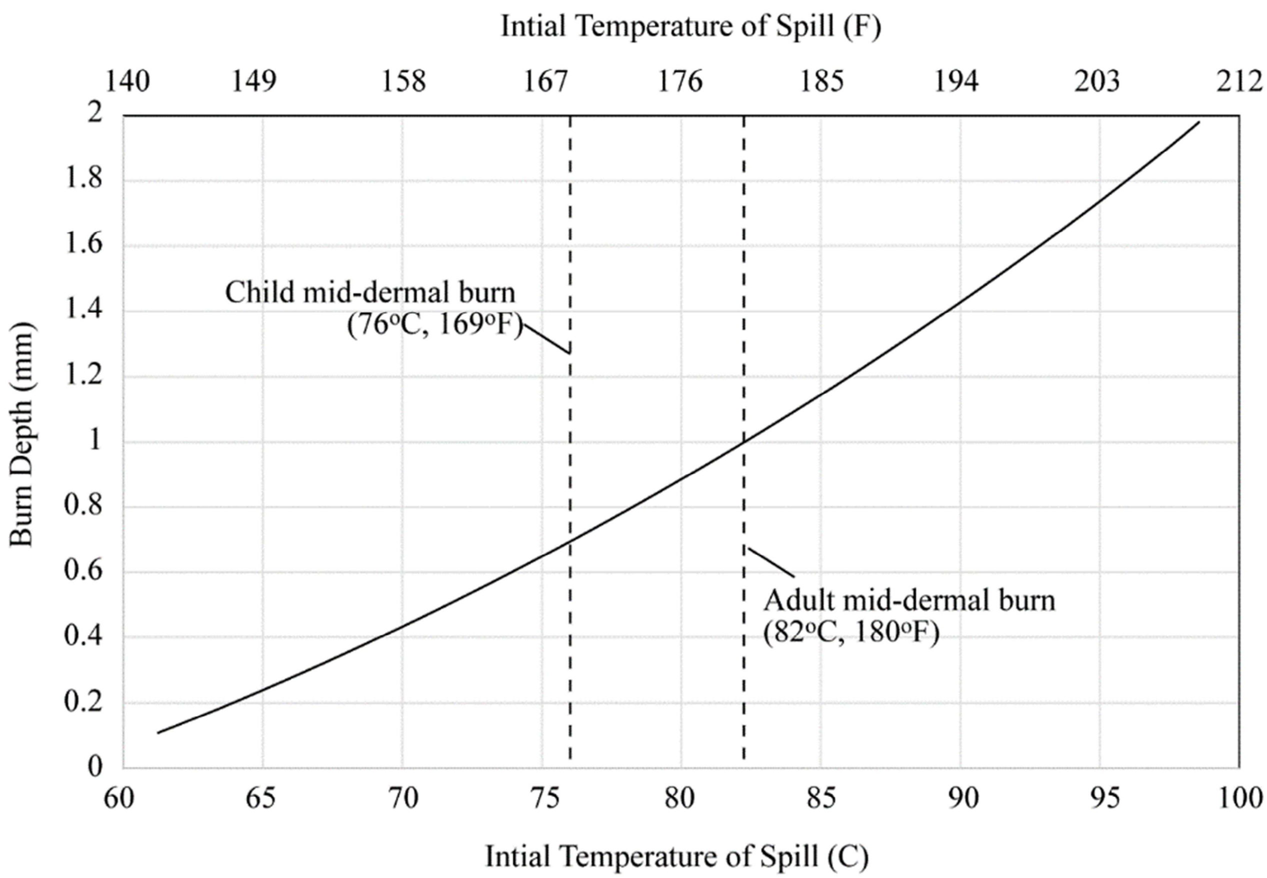


**Figure 3 Burn depth and spill temperature relationship with annotations for mid dermal burns in adults and children (for 2 mm thick adult dermal layers). Adapted from Bourdon et al., 2017.**

In an effort to connect the service temperature, cooling duration prior to a spill, and risk of injury, Tables 6-9 have been prepared. The four tables correspond, respectively, to 237 ml (8 ounce beverages) cooling with a protective cap, without a cap, 473 ml (16 ounce) beverages cooling with and without a cap. For instance, from Table 6 it is seen that an adult will be at high risk for a mid-dermal burn when served with a 95 $^{o}$C (203 $^{o}$F) 8-ounce capped beverage until 8 minutes of cooling have elapsed. If the service temperature were 90 $^{o}$C (194 $^{o}$F), a cooling duration of 5 minutes would be sufficient. The tables also list cooling requirements for children. All of these values are subject to the same limitations and cautions listed earlier. That is, they correspond to 2-mm thick dermal layers (children's dermis is ~70% that of an adult). Skin thicknesses vary by age, body location, ethnicity, and by individual. Despite these limitations, the results presented in Figure 3 and Tables 6-9 can be used as a guideline to reduce the potential that beverages or other hot liquids will cause serve burns.

It should also be noted that temperature/time exposures less than those shown in Figure 3 or in Tables 6-9 can still lead to painful and serious burns (even though the burns may not reach the mid dermal layer).

**Table 6 Cooling times required for various service temperatures for high risk mid-dermal burns, 8-ounce (237 ml) cups with a protective cap, adult dermal thickness of 2 mm (adapted from Bourdon et al., 2017).**

| Service Temperature | | Cooling Time for adult mid-dermal burns | Cooling Time for children mid-dermal burns |
|---|---|---|---|
| ($^{o}$C) | ($^{o}$F) | (minutes) | (minutes) |
| 95 | 203 | 8 | 12 |
| 90 | 194 | 5 | 9 |
| 85 | 185 | 2 | 6 |
| 80 | 176 | NA | 3 |

**Table 7 Cooling times required for various service temperatures for high risk mid-dermal burns, 8-ounce (237 ml) cups without a protective cap, adult dermal thickness of 2 mm (adapted from Bourdon et al., 2017).**

| Service Temperature | | Cooling Time for adult mid-dermal burns | Cooling Time for children mid-dermal burns |
|---|---|---|---|
| ($^{o}$C) | ($^{o}$F) | (minutes) | (minutes) |
| 95 | 203 | 4 | 6 |
| 90 | 194 | 2 | 4 |
| 85 | 185 | 1 | 3 |
| 80 | 176 | NA | 1 |

**Table 8 Cooling times required for various service temperatures for high risk mid-dermal burns, 16-ounce (473 ml) cups with a protective cap, adult dermal thickness of 2 mm (adapted from Bourdon et al., 2017).**

| Service Temperature | | Cooling Time for adult mid-dermal burns | Cooling Time for children mid-dermal burns |
|---|---|---|---|
| ($^{o}$C) | ($^{o}$F) | (minutes) | (minutes) |
| 95 | 203 | 11 | 18 |
| 90 | 194 | 7 | 12 |
| 85 | 185 | 2 | 8 |
| 80 | 176 | NA | 3 |

**Table 9 Cooling times required for various service temperatures for high risk mid-dermal burns, 16-ounce (473 ml) cups without a protective cap, adult dermal thickness of 2 mm (adapted from Bourdon et al., 2017).**

| Service Temperature | | Cooling Time for adult mid-dermal burns | Cooling Time for children mid-dermal burns |
|---|---|---|---|
| ($^{o}$C) | ($^{o}$F) | (minutes) | (minutes) |
| 95 | 203 | 6 | 9 |
| 90 | 194 | 4 | 6 |
| 85 | 185 | 2 | 4 |
| 80 | 176 | NA | 2 |

There is strong evidence that the immediate application of cooling can reduce the amount of scalding (Abraham et al., 2015), however some temperatures are so high that the scald injuries would be nearly instantaneous. It is, nevertheless our recommendation that following a burn injury, cold be applied as quickly as possible. This may mean application of water or other liquids through the clothing. Any delay in the application of cooling, such as to remove the clothes, can be deleterious to the victim. After the immediate application of cooling (or if no cooling is available) the source of heat should be removed (for instance removal of clothing that is saturated with hot liquid). The rule of thumb, "every second counts" should literally be understood by those who are present during a burn incident or work when burns occur.

What also should be understood from the vast literature on burns is that even small increases or decreases in temperature can make a marked difference. For instance, an increase of liquid by approximately 1 $^{o}$C (~2$^{o}$F) can lead to a near doubling of damage. With this estimate, reducing a beverage temperature by 10 $^{o}$F would approximately reduce the damage rate by a factor of 32.

Another takeaway from this review is that for large beverages, particularly those with covers, a long cooling duration may be needed to bring the temperatures below those that would cause serious injury. There is an obvious conflict with respect to the use of covers. They prolong the temperature "danger zone" but they may decrease the likelihood that a spill occurs. Also, larger beverages present a greater danger, not only because they require a longer cooling duration, but also because they increase burn depth and area.

Finally, the temperature levels which lead to near immediate burns may provide some guidance for beverage service. To the best knowledge of the authors, there are no national beverage scald temperature standards. However, the peer-reviewed scientific literature is clear on recommended temperatures from the consumer preference and safety standpoints. Recently published studies (Borchgrevink et al. 1999; Pipatsattayanutong et al., 2001; Lee et al., 2002; Brown et al., 2008; Jamnadas-Khoda et al., 2010) confirm the viewpoint that service of beverages at very high temperatures is unsafe and unnecessary. Further, we support the recommendation from Brown et al., 2008 regarding service temperatures that balance safety and consumer preference (~136 $^{o}$F or 58$^{o}$C).

A final note should be taken while interpreting the results of this review. As already stated, the calculations are based on a 2-mm thick dermal layer, a single layer of clothing, and spills limited in volumes up to 473 ml (16 ounces). As stated earlier, in practice, there is a wide range of skin thicknesses, clothing, volumes of liquid, and abilities for persons to remove the source of heating and apply cooling. Consequently, from a safety standpoint, these results may be considered conservative. For the young and elderly persons, whose skin is less thick, burns occur at lower temperatures and/or shorter durations. Additionally, very young or elderly may have movement limitations which would extend the exposure duration and prolong the burn. Also, the thickness of skin varies by body location and by ethnicity; spills which occur on body regions with thinner skin will require lesser temperatures and/or durations.

**Concluding Remarks**

Burns, despite their ubiquitous occurrence, are not fully appreciated. In particular, the very strong relationship between exposure temperature, exposure duration, and burn depth is rarely recognized. Here, a summary of the available information on liquid scald burns is given. The results allow persons to predict the cooling of variously sized beverages after their initial service and to relate the cooling duration to a spill temperature. The information allows spill temperatures to be input into a model that outputs expected burn depths. The combination of these data provide a method, within a reasonable degree of scientific certainty, to predict, avoid, or quantify scald incidents.

While the work here was carried out considering liquid as the spilled fluid, it is possible to extend the work to solids, gas, or radiative exposures through a modification of the thermal boundary conditions.

**Conflict of Interest**

Dr. John Abraham has served as an expert witness in burn injury lawsuits.

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