Thermal Injury with Contemporary Cast-Application Techniques and Methods to Circumvent Morbidity


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Thermal Injury with Contemporary Cast-Application Techniques and Methods to Circumvent Morbidity

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Background: Thermal injuries caused by application of casts continue to occur despite the development of newer cast materials. We studied the risk of these injuries with contemporary methods of immobilization.

Methods: Using cylindrical and L-shaped limb models, we recorded the internal and external temperature changes that occurred during cast application. Variables that we assessed included the thickness of the cast or splint, dip-water temperature, limb diameter and shape, cast type (plaster, fiberglass, or composite), padding type, and placement of the curing cast on a pillow. These data were then plotted on known time-versus-temperature graphs to assess the potential for thermal injury.

Results: The external temperature of the plaster casts was an average (and standard deviation) of 2.7° ± 1.9°C cooler than the internal temperature. The external temperature of twenty-four-ply casts peaked at an average of 84 ± 42 seconds prior to the peak in the internal temperature. The average difference between the internal and external temperatures of the thicker (twenty-four-ply) casts (4.9° ± 1.3°C) was significantly larger than that of the thinner (six and twelve-ply) casts (1.5° ± 1°C) (p < 0.05). Use of dip water with a temperature of <24°C avoided cast temperatures that can cause thermal injury regardless of the thickness of the plaster cast. A dip-water temperature of 50°C combined with a twenty-four-ply cast thickness consistently yielded temperatures high enough to cause burns. Use of splinting material that was folded back on itself was associated with a significant risk of thermal injury. Likewise, placing a cast on a pillow during curing resulted in temperatures in the area of pillow contact that were high enough to cause thermal damage, as did overwrapping of a curing plaster cast with fiberglass. Attempts to decrease internal temperatures with the application of isopropyl alcohol to the exterior of the cast did not decrease the risk of thermal injury.

Conclusions: Excessively thick plaster and a dip-water temperature of >24°C should be avoided. Splints should be cut to a proper length and not folded over. Placing the limb on a pillow during the curing process puts the limb at risk. Overwrapping of plaster in fiberglass should be delayed until the plaster is fully cured and cooled.

Within the last two decades, advances in operative fixation for reconstruction or for treatment of a traumatic injury have greatly improved and thus diminished the need for cast immobilization. Despite these trends, casts are still commonly used in orthopaedics, and today residents receive less formal training in the art of cast immobilization. Potential complications associated with limb immobilization with plaster or synthetic casting tape are often overlooked. The prevalence of pressure ulcers, cast sores, and thermal injuries is not frequently reported in the literature, yet cast-related problems such as burns are familiar to most orthopaedic surgeons.

Plaster of Paris impregnated in fiber mesh has the following exothermic reaction to water: [Ca(SO₄)]₂⋅H₂O (plas-
chloride pipe. The exterior of each limb model was layered by this reaction can cause tissue damage. The amount of heat that is generated can be increased by many variables, including higher ambient temperature, the temperature of the reactants, and the concentration of reactants. These variables increase the rate of the reaction, thus producing more heat. Previously studied factors that increase heat production include increased layers of material (more than eight-ply), previously used dip water, and increased dip-water temperature.

Different commercial brands of plaster produce different amounts of heat, probably as a result of their individual reaction rates or plaster concentrations. Fiberglass tape is another material that is commonly used, and it has several benefits in comparison with plaster, such as being lightweight, radiolucent, and waterproof and having lower peak temperatures during curing. The peak temperature during curing rarely exceeds 45°C; thus, the risk of thermal injury from synthetic fiberglass tape is substantially less than that associated with the use of plaster.

Previous studies have confirmed the effects of thermal energy with regard to causing injury. Cell damage may occur at temperatures of >50°C. At the cellular level, this correlates with distorted cellular protein structure, altered metabolism, and changes in cell membrane permeability. We hypothesized that different cast and limb variables could lead to temperatures high enough to cause this type of thermal injury. In the present study, we utilized an experimental model to discover which variables cause temperatures above this safe threshold and what, if anything, could be done to prevent these thermal injuries.

**Materials and Methods**

**Experimental Model**

A cylindrical limb (forearm) and an L-shaped limb (leg and foot) were constructed with polyvinylchloride pipe. Three diameters of the cylindrical limb—standard (48 mm), small (27 mm), and large (89 mm)—were tested. The L-shaped limb was constructed with 48-mm-diameter polyvinylchloride pipe. The exterior of each limb model was layered with a polyurethane-coated carbon fiber heating element (Thermion; Thermion Systems International, Stratford, Connecticut) consisting of a fine mesh of conductive carbon fibers that, when supplied with power, produce a uniform heat distribution; a constant temperature of 33°C to 35°C (human skin temperature) was maintained.

Type-T wire thermocouples, adhesive and insulated types (Physitemp Instruments, Clifton, New Jersey, and Omega Engineering, Stamford, Connecticut), were then used to monitor temperatures at selected points on the artificial limb models (under the casts) and on the exterior of the casts. The manufacturer (Omega Engineering) reports the maximum range of standard limit of error on type-T thermocouples to be 0.75% or 1°C, whichever is greater. A four-channel thermometer data-logger (MadgeTech, Warner, New Hampshire), which has a high accuracy (± 0.5°C) and resolution (0.1°C), was chosen for this study. Data points were acquired every ten seconds. Thermochromic liquid crystal thermometers (Telatemp, Fullerton, California, and Thermographic Measurements, Flintshire, United Kingdom) with a temperature range of 30°C to 60°C were also placed on the external surface of the cast at various points. On selected runs, readings from the external liquid crystal thermometers were obtained at roughly sixty-second intervals.

**Model Validation**

Our experimental limb model was tested against upper-limb casts worn by one of us (A.D.H.). This cast was applied in extension, centered on the elbow, and extended 6 in (15.2 cm) proximally and distally, and its dimensions (circumference, ~24 cm; diameter, 76.4 mm) were between those of the standard and large upper-limb models. Adhesive T-type thermocouples (Omega Engineering) were applied to the skin and to the exterior of the casts with the same data-logging system. On the basis of our in vitro data, two separate attempts were made to apply a cast of twelve-ply thickness with use of 50°C dip water and cotton padding, but as a result of increasing temperature and discomfort these runs were aborted prematurely. Triplicate runs were then conducted with twelve-ply casts applied with use of lower dip-water temperatures of 37°C and 22°C to 24°C. The average ambient temperature (and standard deviation) during the reported human-limb runs was 24.3°C ± 0.7°C. Internal temperatures were measured in the middle of the casts at the medial epicondyle and the anterior antecubital fossa. External temperatures were measured over this area with a thermocouple probe and an adhesive liquid crystal thermometer (Telatemp).

**Experimental Design**

Several variables were tested in this study, including limb diameter, limb shape (cylindrical and L-shaped), plaster thickness, cast type (plaster, fiberglass with a waterproof liner, and composite [plaster overwrapped with fiberglass]), dip-water temperature, and placement of the cast on a pillow during curing. We evaluated different methods to avoid thermal injury, including the application of ice and isopropyl alcohol to curing casts. In addition, we attempted to determine whether the risk of thermal injury in the concavity of an L-shaped cast was decreased by placement of a circumferential overwrapping splint on the convexity of the limb, thus decreasing the thickness of the cast material in the concavity. Each variable was tested a minimum of three times with use of fresh dip water for each trial; the average ambient temperature for each trial was 22.4°C ± 2.1°C.

Plaster casts were applied over three or four layers of cotton padding, and we tested cast thicknesses of six, twelve, and twenty-four-ply. Four-inch (10.2-cm) plaster bandages (Specialist Extra Fast Setting Plaster; BSN Medical, Charlotte, North Carolina) were used in each plaster-cast experiment, and dip-water temperatures of 22°C to 24°C and 50°C were tested. The effects of limb diameter were assessed by testing the large (89-mm-diameter), standard (48-mm-
diameter), and small (27-mm-diameter) limbs with a twelve-ply plaster cast applied with 50°C dip water. The internal and external cast temperatures were measured at the convexity and concavity of twelve-ply plaster casts applied with 50°C dip water to the L-shaped limbs. Similar methods were used for the splint studies, which involved use of twelve layers of the same plaster and cotton padding and overwrapping the splint with cotton and an elastic wrap. In these studies, the splint was purposely made too long so that one end could be folded back on itself. In the splint experiments, the dip water was maintained at 37°C. Four runs were conducted for the splint experiments because of data-collection problems during one run.

The effects of placing a plaster cast on a pillow were assessed by removing the limb from the stand after application of the cast (twelve-ply plaster, 50°C dip water) and placing it on a standard hospital pillow (a polyester and vinyl shell with polyester fill) covered in a pillow case (50%/50% cotton/polyester blend). Internal and external cast temperatures were monitored on the side facing the pillow, and the internal cast temperature was measured on the side facing the ambient air (top).

The risk of thermal injury with use of synthetic casting tape (Scotchcast Plus; 3M Health Care, St. Paul, Minnesota) and either a normal cotton or a Gore-Tex liner (W.L. Gore, Flagstaff, Arizona) was assessed. These casts were applied with use of six-ply casting tape dipped in 50°C water. The effects of a composite cast were tested by immediately overwrapping a twelve-ply plaster cast with three-ply fiberglass, with both dipped in 50°C water.

Intervention testing was performed only on plaster casts (twelve-ply, dipped in 50°C water). These tests included placement of standard reusable ice packs filled with ice between the pillow and the cast’s surface. We also tested the effect of fully saturating the cast with isopropyl alcohol when the internal temperature reached a level between 43°C and 46°C. Additionally, we tested whether the temperature rises in the concavity of an L-shaped limb would be ameliorated by applying a convex splint of six-ply plaster to the convexity prior to circumferential wrapping with six-ply plaster.

**Data Analysis**

From selected variables, peak temperatures and times were determined from the temperature graphs and were compared among the internal thermocouple, the external thermocouple, and the liquid crystal thermometer (when used). We also compared lag time and differences in peak temperature.

Several authors have developed methods for evaluating potential thermal injury as a result of thermal conductance. In their classic studies, Henriques and Moritz described time-temperature relationships based on porcine and human experimental data and mathematical calculations.

More recently, Suzuki et al. found similar results in experiments on rats. Williamson and Scholtz studied human subjects to determine blister formation as a relationship of time and temperature, and Lavalette et al. used the results of William-son and Scholtz to generate a mathematical basis for blister formation in order to study the thermal effects of cast application. We used the classic work of Henriques and Moritz as well as that of Lavalette et al. to qualitatively analyze the risk of thermal injury. Each set of authors provided an equation or data for a reference line, which was plotted on a log time-versus-temperature graph to represent the threshold at which thermal injury can be predicted to occur. Henriques and Moritz equated this injury with transepidermal necrosis, and Lavalette et al. equated it with the degree of burn. If the experimental data clearly crossed the reference lines, the limb was considered to be at risk for injury. We initially plotted our experimental data on the graphs of Lavalette et al. and subsequently also evaluated many of these variables on graphs based on the equations and data of Henriques.

For clarity, only the reference lines presented by Henriques and Moritz are shown in this article. (Graphic representation of the other methods of burn evaluation can be found in the Appendix.) Statistical differences in the risk of burns between variables were then determined with use of the Fisher exact test. The significance of differences in peak temperatures was determined with use of the Student t test. P values of <0.05 were considered significant.

**Results**

**Model Validation**

In our tests of the casts on the human subject (one of the authors), we documented slight differences between the skin and the exteriors of the casts. The average maximum temperature differential (the difference between the average maximum skin-surface temperature and the average maximum cast-exterior temperature) for twelve-ply casts applied with use of dip-water temperatures of 37°C and 22°C to 24°C was −0.5°C and 1.2°C, respectively (see Appendix). The curve patterns for the experimental model were similar to those for the human arm (see Appendix).

**Experimental Testing**

We found that casts consisting of only fiberglass material did not generate enough heat to induce thermal injury regardless of the dip-water temperatures or the type of cast lining tested. Thus, the remaining data pertain only to plaster material.

Monitoring of the internal and external cast temperatures during application of the plaster showed the external temperature of the cast to be an average (and standard deviation) of 2.7°C ± 1.9°C cooler than the internal temperature. The maximum difference in the temperatures was 7.0°C. The external temperature of the thicker (twenty-four-ply) casts peaked at an average of 84 ± 42 seconds prior to the peak in the internal temperature. Shorter lag times were found with the thinner casts. The difference between the internal and external cast temperatures of the twenty-four-ply plaster casts (4.9°C ± 1.3°C) was significantly larger than that of the thinner casts (1.5°C ± 1°C) (p < 0.05). Use of the liquid crystal thermometers generated similar results, measuring an average difference of 2.7°C ± 3.4°C (Fig. 1).
With regard to the plaster casts, we found that maintaining the dip-water temperature at <24°C would likely prevent thermal injury regardless of the plaster cast thickness. Similarly, application of plaster that was thinner than twelve-ply appeared safe with use of multiple dip-water temperatures. However, a risk of injury was found in one run with use of 50°C dip water and twelve-ply plaster. Increasing the dip-water temperature to 50°C and the cast thickness to twenty-
Fig. 3
Representative plot for casts made of various materials applied with a 50°C dip-water temperature. Use of synthetic material did not produce dangerous temperatures regardless of the lining material. Casts constructed of twelve-ply plaster did not produce dangerously high temperatures unless they were immediately overwrapped with fiberglass tape.

Fig. 4
Representative plot for a curing cast placed on top of a standard-issue hospital pillow. Dangerously high internal temperatures can be produced on the bottom surface of the limb when a curing cast (twelve-ply plaster dipped in 50°C water) is placed on a pillow. *Note that the exposed top peak temperatures remain significantly cooler.
four-ply consistently yielded temperatures that were high enough to cause burns \((p < 0.05)\) (see Appendix). Similarly, if a twelve-ply plaster splint was applied and the end was folded over, creating a twenty-four-ply area, the risk of thermal injury in that area was significant \((p < 0.05)\) (Fig. 2). While the average peak temperature was slightly higher for the small limbs \((50.9°C ± 1°C)\) and lower for the standard \((50.5°C ± 1°C)\) and large \((49.9°C ± 1.7°C)\) limbs, these differences were not significant. Application of a cast to an L-shaped limb consistently produced higher temperatures in the concavity \(average, 60.1°C\) and lower temperatures on the convexity \((52.1°C)\). The peak temperature could be decreased significantly \((p < 0.05)\) by reinforcing the convexity with a slab of plaster and reducing the number of circumferential wraps by 50\% \((six-ply)\) on the concavity.

Overwrapping a curing plaster cast with fiberglass caused temperatures high enough to cause thermal injury \((p < 0.05, compared with the temperatures of plaster and fiberglass alone)\) (Fig. 3). Similarly, placement of a limb with a twelve-ply cast on a pillow yielded temperatures on the interior surface that were high enough to cause thermal damage. In these runs, the peak temperatures on the top, uncovered part of the limb were significantly lower than those on the bottom \((p < 0.05)\) (Fig. 4). This increase in temperature was averted by simply placing ice packs between the pillow and the cast (Fig. 5). Application of isopropyl alcohol to the exterior of the casts that were prone to lead to thermal injury did not significantly decrease the interior peak temperature or decrease the risk of injury (Fig. 6).

**Discussion**

**Humans feel the painful stimuli of conducted thermal energy when temperatures are applied in the range of 47°C to 49°C.** On the basis of the results of experimental and theoretical modeling, it is thought that living tissues can accommodate some changes in temperature without damage. Henriques and Moritz defined this relationship more than fifty years ago, and their work is still being used to model thermal injury. Near the time of its inception, the time-temperature relationship was believed to reflect the thermal alteration in proteins, alteration in enzymatic and nonenzymatic metabolic processes, and non-protein-induced alterations in the physical properties of cells. Henriques suggested that his findings were similar to observations based on protein denaturation. Since then, Xu and Qian proposed that Henriques’ data could be modeled by attributing the damage to the deactivation of cellular enzymes. More recently, Despa et al. used computer modeling to determine which cellular macromolecules are most thermally sensitive. They found the lipid membrane to be the most thermally sensitive and believed DNA to be particularly thermally stable. The ability to model and pre-
dict thermal injury has been used to help prevent such injury.\textsuperscript{14,15}

While thermal injuries from the application of plaster casts are more likely to be encountered than reported in the literature, there have been reports of clinical and experimental findings.\textsuperscript{1,4,16} Previous investigators have evaluated risk factors associated with thermal injury, such as the brand of cast material, cast thickness, dip-water temperature, and placement of the limb on a pillow during the curing process. These studies focused only on the use of circumferential casts on similarly sized straight limbs, and the experimental limb used in some of these studies was essentially a water-filled glass cylinder. While this model can adequately maintain temperature and provide enough stability to allow application of a cast, it was not possible to test variables such as size and shape as we did in the present study. Recent technology also allowed easy real-time measurements to be made every ten seconds, thereby generating temperature curves that are better than those obtained in previous studies. In addition, we compared several different methods for predicting burns (see Appendix) and evaluated much of our data with two of them (those of Henriques\textsuperscript{10} and Lavalette et al.\textsuperscript{2}). Both methods led to identical results and conclusions for almost every variable tested.

In this study, the temperatures, temperature differentials (skin surface compared with the exterior of the cast), and curve patterns for the human limb were similar to those for the experimental limb. Small differences in limb size, cotton thickness, and ambient temperatures were noted, but the similarity between the experimental and human limbs demonstrates the usefulness of this model. Goto and Ogata measured the temperatures generated while applying splints to models and human limbs\textsuperscript{4} and found the mean peak temperatures in their model (54°C) to be significantly higher than those of the human limb (46°C). They, however, used only plaster splints and did not clearly describe their model, which was probably different from the one presented in our study. They also did not describe the method of statistical evaluation of their data; thus, it is difficult to make comparisons with the present study. It should be noted, however, that, despite the lower temperatures in the human subjects, several were found to have first-degree burns following the experiments.

Obviously, one could not ethically test the extreme variables presented in our report on a human subject as they could lead to injury. We attempted to use our higher dip-water temperature (50°C) to apply a mid-range-thickness (twelve-ply) cast to the arm of an investigator, but the test had to be aborted before completion (i.e., when the internal temperature reached 43°C to 47°C) because it became too painful. This experience correlated with the findings in our model, which predicted that those variables would generate temperatures on the verge of causing a first-degree burn. In addition, the values derived from the experimental model and the human limb were similar when we compared the internal and exterior temperatures of the thinner casts applied with lower dip-water temperatures. On the basis of the validation testing, we believe that our experimental model simulates changes in skin surface temperature when a cast is applied. Williamson and Schöltz described individual differences between some of the subjects in their study, but noticed that
general trends occurred. There may be some individual differences between subjects as a result of differences in age, body fat percentage, amount of muscle, osseous prominences, and vascularity. However, we believe that elucidating these differences in response to heat, high enough to cause damage, is not possible in human subjects for ethical reasons.

Limitations of this study should be pointed out. We may have underestimated the true thermal damage caused by each of the variables. The plots developed by Henriques and Williamson and Scholtz are based on a constant temperature maintained for a period of time. In our study as well as that by Lavalette et al., the temperature of the cast material followed a bell-shaped curve. One can only plot the data obtained during cast application on the curves presented by Henriques and Lavalette et al. if time zero is assumed to be the time of the peak temperature. This essentially ignores the thermal energy and its potential to cause injury as the cast is “heating up.” The curve during this process is rather steep and the overall thermal effects were thought to be minor, but they could have added to the overall effects that were measured. In addition, the previous burn data are based on small areas of tissue exposed to varying temperatures. None of the authors of these studies measured the effects of exposing an entire limb segment to an increased temperature. Also, each of our conclusions regarding the risk of thermal damage was based solely on in vitro data plotted on graphs developed primarily from in vivo studies. The validity of this type of transfer is unknown, and the effects on actual patients may be different; however, as stated previously, we believe the trends and conclusions would be similar. Despite the above concerns, we concur with the conclusions of Pope et al. that synthetic tape is relatively thermally safe throughout the range of dip-water temperatures tested. However, we updated these findings by showing that they hold true for the new waterproof cast padding.

We have shown that the external temperature of a cast correlates well with the internal temperature at the skin surface. Lavalette et al. noticed that the external temperature of the casts followed curves that were similar to, but lower than, the curves followed by the internal temperatures. However, in that study, no attempts were made to correlate the two temperatures and to use the external temperature to predict the internal temperature. In our study, we found a slight lag time between the peak internal and external temperatures and slightly lower temperatures were measured externally. Although these differences appear to increase with the plaster thickness, even with the thickest plaster tested, which was most likely thicker than generally would be used clinically, these differences were less than ninety seconds and 7°C, respectively. Monitoring the external temperature may provide the clinician a way to estimate the temperature inside of a recently applied cast or splint.

We hypothesized that a smaller limb would be more at risk for a burn than a larger limb; however, we could not demonstrate this. While the surface area of a limb or cylinder increases in a linear fashion with increasing limb diameter, the amount of plaster also increases. This is perhaps why we did not see a significant difference in thermal risk among limb sizes. On the other hand, we showed that, as a result of the increased amount of cast material that accumulates in the concavity of an L-shaped limb, the risk of thermal injury is increased in this area. Using a plaster slab for reinforcement over the convexity and limiting the number of circumferential wraps minimize the amount of plaster in the concavity and therefore decrease the peak temperatures in this area.

We believe that the splinting data in this study are im-

Fig. 7
Representative plot of the effect of alcohol application on internal and external cast temperatures. After application of alcohol, the external temperature quickly decreases; however, the internal temperature continues to rise.
portant as there is a risk of thermal injury when a fracture is splinted postoperatively. All too often, a splint is folded over when it has been cut to an inappropriate length, but this essentially doubles its thickness in a small area and thus increases the local exothermic reaction. Our recommendation is to trim excess plaster and resist the temptation to fold over the ends.

We have offered potential interventions for reducing thermal risk, such as placing ice packs between the limb and the pillow. Safer ways to avoid the risk of thermal injury in this setting would be to hold the limb or allow it to hang free during the curing process. The use of isopropyl alcohol to decrease the temperature of a curing cast has been reported anecdotally17. Our attempts to use it in this way revealed that, while the external temperature of the cast may go down, the internal temperature is minimally affected. In fact, the clinician may be fooled into thinking that the interior of the cast is cool because he or she can feel the external surface of the cast cooling (Fig. 7).

In conclusion, the data on plaster material that were derived with the current model support previous authors’ findings, in particular that application of thicker plaster casts with use of higher dip-water temperatures and placement of the limb on a pillow may lead to temperatures high enough to cause thermal injury. In addition, we were able to determine the temperature at various locations on the limb under the cast. This information is important so that clinicians realize that, while the temperature at one location of the cast may feel safe, the temperature elsewhere (i.e., in contact with the pil-

References