Does ‘Prison Napalm’ work? Measuring the cooling temperature of sugar solution burns in a porcine model

Jamie A Mawhinney[1]*, Adrien Yvon[1], Ojas Pujji[1], Whitney Chow[1], Nick Freemantle[2], Timothy S Burge[1]

[1]*Department of Plastic Surgery, Salisbury District Hospital, Salisbury, UK*

[2]*Institute of Clinical Trials and Methodology, University College, London, UK*

*Corresponding author: Department of Plastic Surgery,

Salisbury District Hospital

Odstock Road

Salisbury SP2 8BJ

United Kingdom

Email: jamiemawhinney12@gmail.com

Tel: 01722 334480

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Abstract

Non-accidental scalds sustained with sugar solution are potentially devastating and often associated with assaults within prisons where they are commonly known as ‘Napalm’ attacks. However, little is known about the mechanism behind such injuries. Proposed explanations have included a higher initial temperature, increased viscosity compared to water and lower emissivity, although these have yet to be demonstrated in any experimental model. We therefore set out to measure the post-exposure cooling temperature of the dermis after exposure to different concentrations of boiled sugar solution in a dead porcine model.

Dead pork belly tissue was pre-heated to human body temperature (36.3-38.4ºC). Five solutions with different concentrations of sugar (0, 250, 500, 1000 and 2000g/L) were heated to boiling point using standard commercially available kettles and then poured directly onto the tissue. Intradermal temperatures of the dermis were measured at one-minute intervals for a duration of 10 minutes.

At one-minute post-exposure, average intradermal porcine temperatures were 46.7ºC, 47.9ºC, 48.9ºC, 50.8ºC and 51.7ºC respectively for increasing concentrations of sugar solution. The rate of cooling was similar in all solutions with an average loss of 1.5ºC per minute. Using a generalised mixed model accounting for concentration and time period, it was identified that increasing sugar concentration resulted in statistically higher temperatures of burn ($p=0.006$).

Our report finds that higher concentrations of boiled sugar solution caused a higher initial temperature of burn but did not influence cooling rates. This suggests that ‘Prison Napalm’ attacks will indeed cause more severe burns than those utilising plain water, but not for all the widely believed reasons. We therefore recommend that access to kettles in prison cells should be limited, but where such access is deemed a right, consideration should be given to temperature restricted devices, as is the case in other countries.

Keywords

Scald; sugar water burns; sugar solution burns; prison; assault; kettle.

Introduction

In the United Kingdom (UK), distinct to many other jurisdictions around the world, prisoners have a legal right to have kettles provided in their cells[1]. However, an unfortunate side effect of this is that boiling water is readily available for assaults on inmates and staff. One particular mechanism of assault common to the prison population is burns involving boiled sugar solution, referred to as 'Prison Napalm'. Such attacks are widely reported in the non-medical press, although there is much less data in the scientific literature[2]. The resulting scald injuries are seen frequently in UK burn units and are often severe with prison lore suggesting that the addition of sugar results in worse injuries due to the formation of a viscous paste. Potential mechanisms for more severe burns include a higher initial temperature of solution, increased liquid viscosity and lower emissivity of heat to the surrounding environment, and therefore greater transfer to the underlying tissue. However, to the best of our knowledge, this has not yet been assessed in any experimental model, although previous reports assessing the cooling temperature of hot beverages did find no apparent difference with or without added sugar[3].

In this report, we set out to measure intradermal cooling temperature after exposure to different concentrations of boiled sugar solution in a dead porcine model.

Materials and Methods

Post-exposure cooling temperatures of dead pork belly dermis were measured over 10 minutes at 1-minute intervals following exposure to boiled sugar solution. Dead pork belly tissue was prepared into equal 10cm x 3cm units and pre-heated to human body temperature (36.3-38.4ºC). The units were held at an angle of 45º to mimic a scald scenario with solution runoff. Five solutions with increasing concentrations of sugar (0, 250, 500, 1000 and 2000g/L) were heated to boiling point using standard commercially available kettles (Cookworks® Plastic Kettle) and then poured directly onto the tissue. This is an electric kettle which automatically switches off when the solution has reached boiling point.

The time was started at exposure and intradermal post-exposure temperatures of the dermis were measured using a meat digital thermometer (Char-Boil® 140 537). Results were analysed using a generalised mixed model, accounting for concentration and time period, with observations within subjects linked using random intercept terms.

Results

Results are shown in Table 1 and summarised in Figure 1. Starting temperatures of the samples were similar. One-minute post-exposure, higher intradermal temperatures were seen across the five solutions with higher concentrations of sugar. The rate of cooling was similar in all solutions with an average loss of 1.52ºC per minute. Using a generalised mixed model accounting for concentration and time period, it was identified that increasing sugar concentration resulted in statistically higher temperatures of burn for the duration of the experiment ($p=0.006$). Neither mass of sample, nor pre-exposure temperature improved fit and were excluded from the final model. The log (1+concentration) was used as this improved model fit as assessed by Akaike's Information Criterion.

Cumulative heat exposure was also assessed by calculating the area under the temperature-time graph (Figure 2). A threshold of 42ºC was taken as the threshold for protein denaturation. This demonstrates that heat exposure in the highest concentration of sugar solution group was 5.13 times higher than that seen in the pure water group.

Discussion

Despite the widespread reporting of 'Prison Napalm' injuries in the media, to the best of our knowledge, this is the only experimental assessment of the mechanisms involved in sugar solutions burns in an *in vitro* model. We have demonstrated that increasing concentrations of boiled sugar solution cause a higher initial temperature of burn but did not influence cooling rates. This suggests that 'Prison Napalm' attacks will indeed cause more severe burns than those utilising plain boiling water, but due to the initial contact of sugar solution rather than the effect of prolonged contact of solution viscosity or emissivity. By considering the area beneath the temperature-time curve, we identified that the highest concentration of sugar solution resulted in around a 5-times greater cumulative exposure to heat over 42ºC than plain

boiling water, which would likely have a substantial effect on the depth of the resultant burn. The authors believe that this would probably equate to one grade of clinical depth of burn deeper, for example superficial partial thickness to mid-dermal, or mid-dermal to deep dermal.

There is limited data of on the epidemiology of sugar solution burns in the general population as they are not reported in national data. Similarly, in prisons these incidents are also not reported specifically but we are able to infer the scale of such assaults in general from data produced by the Ministry of Justice in the form of the Safety in Custody Statistics. In the years 2000 to 2019 inclusive, there were 33,559 serious injuries resulting from assaults in prisons in England and Wales[8]. Of these, 2,563 are reported as being due to 'scald or burn'. Furthermore, during the same period in the same population, there were 57,847 assaults using any type of weapon, 2,710 were due to attacks with 'dangerous liquids'. This therefore indicates a significant number of reported could be due to sugar solution burn or similar mechanisms.

Similarly, despite the widespread reporting of these injuries in the non-medical media, we have found only limited date considering sugar solution burns in the scientific literature[2]. It is possible that this is at least partly due to concentration of these injuries in the prison population, away from large academic centres and therefore less likely to be reproduced in medical journals. It is also possible that, again due to these injuries being largely limited to prisons, such individuals may be less likely to give consent for these cases to be published.

The factors that affect the cooling rate of a liquid include thermal conductivity, specific heat capacity, and thermal emissivity. Thermal conductivity is the ability of a solution to conduct heat energy, in this case sugar solution to dead porcine skin[4]. The thermal conductivity of water is higher compared to that of sugar solution, theoretically suggesting pure water to transfer more heat energy and therefore leading to coagulative necrosis and worse burn depth. The specific heat capacity relates to the amount of heat needed to raise the temperature of 1 gram of substance by 1 degree Celsius. Liquids having a higher specific heat capacity will transfer higher amounts of heat energy causing deeper burns. Water has a higher specific heat capacity compared to sugar solution which theoretically can lead to deeper burns[5,6]. Finally, thermal emissivity relates to its effectiveness in emitting energy as thermal

radiation. Water has a high emissivity coefficient indicating its efficiency at transferring heat. To the best of the authors knowledge, the emissivity of sugar solution specifically has not been studied therefore a comparison cannot be suggested. Taking these theoretical variables into account it may suggest water to be a more potent burning solution compared to sugar solution. However, the largest factor here appears to be the raised boiling point of sugar solution compared to water which has been demonstrated in our study. The boiling point of a solution depends on several factors, in particular addition of solutes such as sugar in this model. The increased molarity of the solution requires higher energies to break bonds between the solute and solvent leading to a higher boiling point. Comparing this to adding salt to water the boiling point is increased at an even higher rate due to salts ability to dissociate and form strong ionic bonds requiring further energy to boil[7]. The limited reports in the scientific literature assessing this area specifically have demonstrated that the starting temperature and the volume of fluid are the greatest factor in determining the rate of cooling[9]. Other research in similar areas found that the presence of milk in hot drinks lowers the starting temperature and increases the rate of cooling with no effect of sugar[3,9], and that beverages in plastic and polystyrene cups retain more heat and start at a higher temperature although cool at a similar rate to those in cups made of other materials[10].

As a result of our study, we recommend that prisoner's access to kettles be limited wherever possible in order to minimise the potential for such attacks. In UK prisons kettles have been a longstanding provision deemed necessary in order to maintain an individual's basic human rights, although this differs in many other jurisdictions around the world. Indeed, according to the United Kingdom HM Prison and Probation Service Incentives Policy Framework, flasks for boiling water or kettles are amongst the "minimum" list of what a prisoner should have[1]. This policy recommendation was made in 2012 by Prisons and Probation Ombudsman Nigel Newcomen, and accepted by the National Offender Management Service despite its "cost implications"[11,12]. Interestingly, health and safety implications were not considered at this point. In other countries, for example in Russia, access to kettles if often prohibited[13]. An alternative to the outright banning of kettles is limiting access of prisoners to kettles with set temperature restrictions, unlike standard devices which utilise a two-plate design

system and deactivate when the liquid is boiling, rather than at a specified threshold. Based on our research, this would nullify the effect of any added sugar due to the normalisation of the starting temperature of the burn.

The major limitation of our study is that this was performed in a dead porcine model, and therefore the tissue subjected to the burn was not vascularised during the experiment. The tissue was also not freshly prepared but reheated from chilled, which may have led to some tissue degradation. Because of this, the heat dissipation of the burn is likely to have behaved differently than in a true *in vivo* experiment. Furthermore, the immediate physiological response to the burn will not have been assessed. However, such an experiment on living subjects is unlikely to pass the appropriate ethical standards and therefore it is necessary that the effects on live tissue be extrapolated from *in vitro* models such as ours.

Conclusions

In this study, we have demonstrated that boiled sugar solution does have the potential to cause higher temperatures of burn, although this is more likely due to an effect on the initial temperature of burn rather than any effect on cooling due to viscosity or emissivity. This suggests that 'Prison Napalm' attacks will indeed cause deeper burns than those utilising plain water, but not for all the widely believed reasons. We therefore recommend that access to kettles in prison cells should be limited, but where such access is deemed a right, consideration should be given to temperature restricted devices, as is the case in other countries.

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Ethical Approval

The animal tissue obtained for this experiment was bought over the counter from a high street retailer, and therefore ethical approval was not required.

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Correspondence

Jamie Mawhinney; jamiemawhinney12@gmail.com; Department of Plastic Surgery, Salisbury District Hospital, Salisbury, UK; 01722 334480

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Tables

Table 1. Tabulated results for intradermal temperature post-exposure to five different concentrations of sugar solution measured at one-minute intervals. Each value represents the mean of three experiments performed for each solution. Concentrations are expressed here as the ratio of sugar/water.

Sugar Solution	**Time Post-Exposure (mins)**											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Rate (°C/s)**
Water	37.40	46.67	45.57	43.60	41.77	39.97	38.37	36.83	35.53	34.33	33.20	-1.50
0.25	37.43	47.93	45.90	44.03	42.33	40.67	39.17	37.80	36.53	35.43	34.37	-1.51
0.5	37.13	48.87	47.30	45.50	43.87	42.37	40.97	39.57	38.27	37.00	35.87	-1.44
1	37.67	50.77	49.43	47.63	45.77	43.93	42.43	41.03	39.73	38.50	37.40	-1.49
2	36.97	51.70	49.50	46.93	44.73	43.00	41.50	40.17	38.93	37.77	36.73	-1.66

Figures Legends

Figure 1. Cooling time of porcine dermis after exposure to sugar solution. Intradermal temperature was measured every minute post-exposure to five different concentrations of sugar solution. Each value represents the mean of three experiments performed at each solution. Concentrations are expressed here as the ratio of sugar/water. Results were compared with a generalised mixed model accounting for concentration and time period identifying that higher concentrations of sugar solution resulted in higher intradermal temperatures $p=0.006$.

Figure 2. Cumulative heat exposure above 42°C. Cumulative heat exposure across the course of the experiment was calculated to be 80, 150, 250, 300 and 410 degree-seconds for increasing concentrations of sugar solution respectively. A threshold of 42ºC was taken as the threshold for protein denaturation and therefore as the lower limit for heat exposure in this instance.

Figure 1

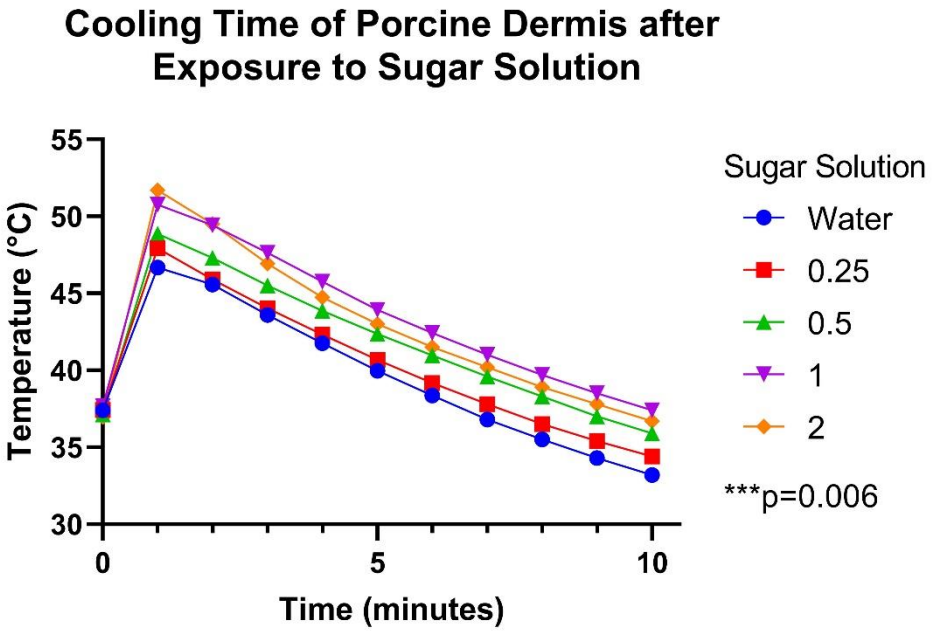
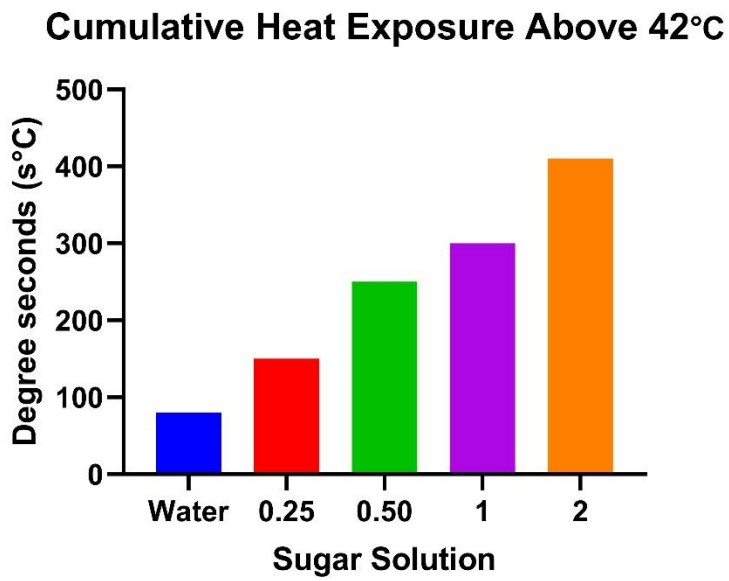

Cooling Time of Porcine Dermis after Exposure to Sugar Solution
Temperature (°C)
55
50
45
40
35
30
0
5
10
Time (minutes)
Sugar Solution
Water
0.25
0.5
1
2
***p=0.006

Figure 2.


Cumulative Heat Exposure Above 42°C
Degree seconds (s°C)
500
400
300
200
100
0
Water
0.25
0.50
1
2
Sugar Solution