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# Water Cooling, Ice Pack Application, and Cold Wet Compress Treatment of Burn Wounds in Children before Admission, Effects on Tissue Healing and Safety Research: Systematic Review and Meta-Analysis

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**Abstract**

**Background:** Burn injuries are caused by electricity, heat, radiation, cold, friction, or chemicals and lead to tissue destruction due to energy transfer from the sources to the tissues and cells. The present study aimed to perform a systematic review and meta-analysis of water cooling, ice pack application, cold and wet compress treatment of burn wounds in children before admission and to evaluate their effects on tissue healing and safety.
**Methods:** We systematically searched PubMed, CINAHL, Cochrane Library, and Embase from inception to March 2023. Review Manager (version 5.4) was used to assess the risk of bias in the selected studies, and a meta-analysis of all dichotomous and continuous outcomes in the selected studies was performed. Out of 590 studies, seven studies based on the PRISMA protocol in the meta-analysis were included.
**Results:** Based on the duration of cooling, no significant differences in the depth and size of burn wounds were found. Moreover, we established that cooling burn wounds significantly reduces tissue damage and limits the spread of burns to the surrounding tissues. A higher heterogeneity was observed in the selected studies based on methodology, implying different designs affecting our findings.
**Conclusion:** There is inconclusive evidence on the recommended optimum duration of cooling burn wounds. However, cooling burn wounds has a beneficial impact on reducing tissue damage and limiting the spread of burns.

*Keywords:* Burn Wounds, Systematic Review and Meta-Analysis, Tissue Healing

## 1. Background

Burn wounds, as a major cause of morbidity, lead to disability and low quality of life for the survivors (1, 2). Burn injuries are associated with inflammatory and immune responses caused by distributive shocks and changes in cell metabolism. Burn injuries are caused by electricity, heat, radiation, cold, friction, or chemicals, leading to tissue destruction due to energy transfer from the sources to the tissues and cells (2, 3). Distinct pathophysiological and physiological responses accompany the destruction of tissues. For instance, oils and greases cause instant and deep burns compared to scald injuries that appear superficial due to the rapid release of heat energy (1-3). Children are susceptible to deep burn wounds because of thinner skin layers and subcutaneous tissues compared to adults. Deep burn wounds in children can be treated with ice packs, water coolants, or cold wet compression before hospitalization.

Water cooling of burn wounds is highly effective in reducing tissue damage and the size of wounds because it eliminates scarring and reduces pain. However, the level of tissue damage depends on the time of pouring running water from the onset of the burn. Venter et al. (4) suggested that cooling a fresh wound with water was effective in limiting tissue and cell damage. The immediate application of water cooling effectively lowers the sensation of pain, subsequently, inhibits the destruction of cells; however, a delayed application of water could be deleterious and increase tissue damage by reducing blood flow to the cells.

Schwada et al. (5) proposed that excessive application of cooling water and ice cubes or ice packs could be harmful to tissues and cells. However, there are inconsistencies and lack of clarity on the temperature of the cooling water or ice cubes, the time of application after injury and the effects of delay. A study by Venter et al. (4) used an experimental model to examine the effects of tap water (kept between 12-18°C) and ice (kept at 1-8°C). They showed that both techniques have a beneficial cooling effect and reduce tissue damage in burn wounds.

According to Bleakley et al. (5) the application of ice cubes on soft tissues reduces damage to tissues and lowers the sensation of pain. Ice cubes lower the tissue temperature and have an overall effect of reducing inflammations and muscle spasms and inhibiting neural responses. Therefore, the recovery of soft-tissues is improved.

Sutton and Wright (6) proposed that scald injuries are common in children due to spillage of hot drinks and exposure to thermal sources of heat. The destruction of tissues can be estimated based on the depth of the burn and size of the wound in relation to the total body surface area (TBSA). The intensity and duration of the burnt wound is directly proportional to the depth and size of the wound (7, 8). Burn wounds from scalding injuries are typically smaller but deeper compared to trauma injuries that are large and vary in depths. Burnt wounds larger than 20% of TBSA are caused due to flames (7, 8).

The standard procedure for treating burn wounds involves four criteria, including removal of any clothing or coverings from the burnt areas, applying a cool running water, covering the wounds, and seeking medical attention. The administration of first aid burns is often inaccurate and inconsistent due to insufficient procedures and guidelines. Studies (8-10) have suggested that the application of cool running water in the first aid treatment of burns effectively mitigates the destruction of cells and tissues. Furthermore, burns higher than 20% of TBSA are associated with secondary complications such as hypothermia. Hypothermia is induced when the thermoreceptors situated in the reticular dermis are impaired, which affects temperature regulation. The reticular dermis is affected when the epidermis is destroyed by deep burns.

The rationale of our study is to perform a systematic review and meta-analysis to examine the effects of water cooling, ice pack application, and cold wet compress treatment of burn wounds in children before admission, effects on tissue healing and safety. The gap in the existing literature is inadequate information regarding the effects of ice cubes and cold wet compress procedures in the management of burn wounds in children. We seek to examine the effects of the size of burn, depth of burn, skin grafting, and re-epithelialization.

The main objective can be segmented into the following specific objectives:

1. To analyze the effect of water cooling, ice packs, and cold wet compress in managing burn wounds.
2. To examine the appropriate duration of application of these procedures for the safety and recover of tissues and cells after burns.

## 2. Objectives

## 3. Methods

*3.1. Search Strategy and Information Sources*

Our systematic review and meta-analysis were performed based on the Cochrane Handbook for Systematic Reviews (11, 12). Moreover, we reported through the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) protocol (13, 14).

A comprehensive systematic inquiry was conducted across three prominent databases: PubMed, CINAHL, Cochrane Library, and Embase, spanning until March 2023. The search strategy incorporated specific keywords, namely, "Water Cooling," "Ice Pack Application," "Wound Burns," and "Cold Wet Compress." It is important to note that supplementary studies were not sought through the examination of the references within the encompassed studies.

*3.2. Eligibility Criteria*

Our study was structured according to the Population, Intervention, Comparison, and Outcome (PICO) framework. The population encompassed all studies involving pediatric participants. The intervention encompassed the utilization of water cooling or the application of ice cubes. To identify the relevant studies, we applied specific inclusion and exclusion criteria.

*3.3. Inclusion Criteria*

1. Studies examining thermal burns in pediatric population and evaluating the administration of initial medical assistance, such as water cooling or ice cubes
2. All randomized controlled trials (RCTs), non-randomized controlled trials (non-RCTs), and cohort studies published in English
3. Studies providing information on the temporal extent of water or ice cube cooling, or the methodologies involving cold wet compress procedures

*3.4. Exclusion Criteria*

1. Studies exclusively focused on burns in adult populations
2. Studies lacking the utilization of cooling mediums or the implementation of initial medical interventions
3. Studies which were not in English
4. Studies failing to provide details concerning the duration of cooling methods involving water, ice cubes, or cold wet compress techniques
5. All case series, animal studies, trials, and ongoing investigations

*3.5. Outcomes*

Our primary and secondary outcomes were evaluated using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) procedure. Our primary outcomes involved size of the wound and depth of the burn. We defined size of the wound as the proportion of TBSA burnt and measured it as a continuous variable. In contrast, we defined the depth of burn as the dermal thickness and measured it as a dichotomous variable.

Our secondary outcomes involved pain, wound tissue healing, adverse outcomes, and any complications. Pain was defined as the feeling of sensation or taking medications. Adverse outcomes were associated with negative events such as hypothermia. Wound tissue healing was used to define the number of days taken for re-epithelialization to occur after treatment. We established those outcomes related to complications, included fasciotomy, skin-grafting, infections or organ dysfunctions.

*3.6. Data Extraction and Collection*

Two independent reviewers for data extraction were adapted, and information concerning study design, sample size, and outcomes were obtained. Furthermore, the risk of bias of each included study was assessed, and any discrepancies were resolved through consensus.

*3.7. Assessing Risk of Bias and Certainty of Evidence*

We evaluated certainty of evidence using the GRADE technique and adopted the GRADEpro Guideline Development Tool (GDT) (https://www.gradepro.org/) in determining the evidence tables. The GRADE technique examined publication bias, risk of bias, and inconsistencies. Furthermore, we deployed the Review Manager to examine the risk of bias, which was independently analysed by two reviewers.

*3.8. Data Synthesis*

We used Review Manager (RevMan 5.4) to analyse the data and produce corresponding plots. We reported dichotomous outcomes using risk ratios (RR) at 95% confidence interval, while continuous outcomes were reported as standardized mean differences or mean differences. Our study adopted a random-effects meta-analysis based on the Mantel-Haenszel method in dichotomous variables and the generic inverse variance method for continuous variables.

Additionally, we assessed heterogeneity by inspecting the forest plots and interpreting the I^2 statistic and Chi-square statistic. The Chi-square statistic was statistically significant at a *P*-value of less than 0.05, while the I-square statistic was statistically significant at I^2 > 75%. The synthesis was standardised by examining risk ratios and mean differences as effect sizes and their corresponding directions.

## 4. Results

*4.1. Study Selection*

The PRISMA protocol was applied in selecting the identified studies (see Figure 1). Our initial database search yielded 590 studies. We obtained excellent inter-rater reliability by applying a Kappa value of 1.0 after screening full texts of included articles.

Lastly, seven studies met the eligibility criteria and were included in the final analysis.

*4.2. Characteristics of Included Studies*

We included four studies from Australia and New Zealand (15-18) involving children who had sustained burns and were taken to hospital for treatment (see Table 1). One study was from New South Wales (21), one study from South Africa (20), and another study from Taiwan (19). The average TBSA of the included studies was below 10%, and about 70% of all the burns were situated within the superficial depths.

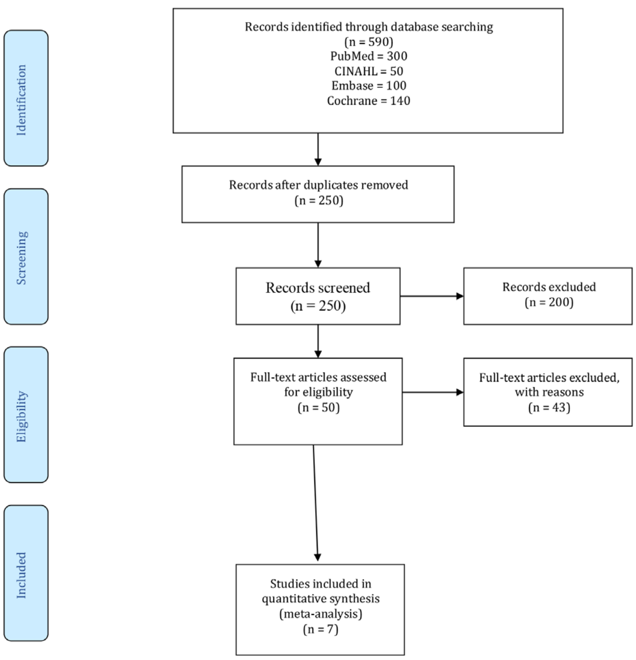


**Figure 1**

**Table 1.** Characteristics of the included studies

| Author | Year of Publication | Country of Origin | Study Design | Sample Size | Intervention | Controls | Main Outcomes |
|---|---|---|---|---|---|---|---|
| Wood et al. | 2016 | Australia and New Zealand | Register based Cohort Study | Children aged 16 years (N = 2, 320). Water Cooling = 2289. Median TBSA (5.5%) | Water Cooling for atleast 20 mins (N = 964) | Cooling between 1 to 10 mins (N = 731). Water Cooling between 10 to 20 mins (N = 594). | The possibility of wound repair was reduced in children subjected to cooling compared to those who were not |
| Griffin et al. | 2019 | Australia | Cohort Based | Children aged below 16 years in a burn centre. N = 2310 underwent water cooling. The TBSA was less than 5%. | Water Cooling for atleast 20 mins (N = 1, 815) | Cooling between 1 to 10 mins (N = 334). Water Cooling between 11 to 19 mins (N = 161). | The full thickness depth of burn wounds was reduced in burns cooled for longer than 5 minutes. The requirements for skin grafting was reduced in burns subjected to cooling for atleast 20 mins compared to other durations of cooling. |
| Fein et al. | 2014 | Australia | Cohort Based | Children aged less than 4 years. N = 66 subjected to water cooling. The TBSA was less than 5%. | Water Cooling of atleast 20 minutes | Cooling between 1 to 10 mins (N = 10). Water Cooling between 11 to 19 mins (N = 7). | The destruction of tissues and cells was significantly reduced which increased wound healing and reduced requirements for skin grafting. |
| Cuttle et al. | 2009 | Australia | Cohort Based | N = 489 Children at a burn centre. N = 289 Water cooling as a first aid. The mean TBSA was less than 10%. | Water Cooling for atleast 20 mins (N = 28). Water cooling for less than 20 minutes (N = 25) | Cooling between 1 to 10 mins (N = 56). Water Cooling between 10 to 15 mins (N = 72). | Cooling burn wounds for longer than 20 mins reduced the duration taken to re-epithelialization in children who did not undergo grafting. |
| Fiandeiro et al. | 2015 | South Africa | Retrospective Review | N = 90 Children. 25.6% Subjected to Inadequate Cooling. 32.3% with no cooling | Cool running water | N/A | Cooling of burns reduced tissue destruction and mitigated cell damage. Wound healing was improved |
| Harish et al. | 2019 | New South Wales | Cohort Based | N = 4918 Patients. N = 2859 received first aid. | Cool running water | N/A | It was associated with a statistically significant reduction in burn wound depth but was not associated with a reduction in TBSA or requirement for grafting (. In patients not requiring grafting, those who received adequate first aid were healed on average 10% or 1.9 days faster . Adequate first aid in patients requiring grafting was associated with a 15% increase in TBSA that was not grafted |
| Tung et al. | 2005 | Taiwan | Descriptive Epidemiology | N = 3993 Children aged less than 7 years. 7.7% had TBSA greater than 40%. | Cool running water | N/A | Adequate first aid by water cooling affected the outcome of the patient group with burn extent less than 30% TBSA, which was shown by the decrease of length of stay. |

Wood et al. (16) reported clinical outcomes of 2,320 children below 16 years and had sustained burn injuries. The study compared children who were subjected to water cooling for at least 20 min

(N=964) against other durations of exposure (for instance, at most 5 min (N=210), at most 10 min (N=521), and at most 19 min (N=594)). Furthermore, the study reported 31 missing outcomes on the duration of exposure to water cooling. Water cooling was defined as a constant water flow for at least 20 min. Skin grafting was the adverse outcome described in this study.

A study by Fein et al. (17) consisted of burn casualties examined by paramedics. The sample size was composed of children below 5 years and mostly infants. The adverse outcome described in this study was hypothermia.

A study by Cuttle et al. (18) consisted of 459 children and analysed the duration of exposure to cooling using four criteria; less than 10 min (N=56), less than 15 min (N=72), exactly 20 min (N=25), and more than 20 min (N=28). Furthermore, there were 278 children with reported outcomes for wound tissue healing. The adverse outcome described in this study was skin grafting.

A study by Griffin et al. (15) involved interviews to families with children who had sustained burns and were admitted to hospital. The interviews examined the first aid administered and the quality of wound healing. The study was performed on 2,495 children who were randomly assigned into various durations of cooling ranging from less than 5 min (N=136), less than 10 min (N=198), less than 19 min (N=161), and at least 20 min (N=1815). However, there were 185 cases which did not report the duration of exposure to cooling. The adverse outcome described in this study was skin grafting.

### *4.3. Risk of Bias*

Our study established a moderate risk of bias, inconsistencies, and indirectness in the selected publications. The certainty of evidence in the primary outcomes was moderate due to moderate risk of bias. We identified selection bias and confounding of evidence as high risk because children who had sustained minor superficial burns were not or less likely to be administered to the hospitals and burn centres. Moreover, indirectness was high because most studies did not define an objective measurement for the duration of exposure to water, ice or cold wet compress. The primary outcomes were associated with inconsistencies because there was a difficulty in classifications and missing cases that were not classified (see figures 2 and 3).

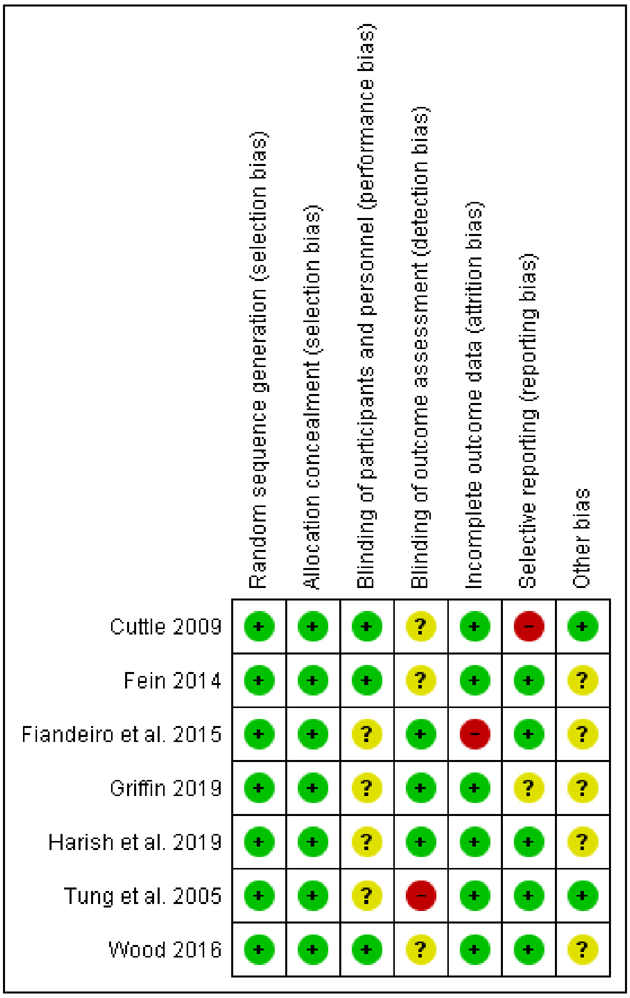


**Figure 2.** Risk of bias summary: review authors' judgements about each risk of bias item for each included study

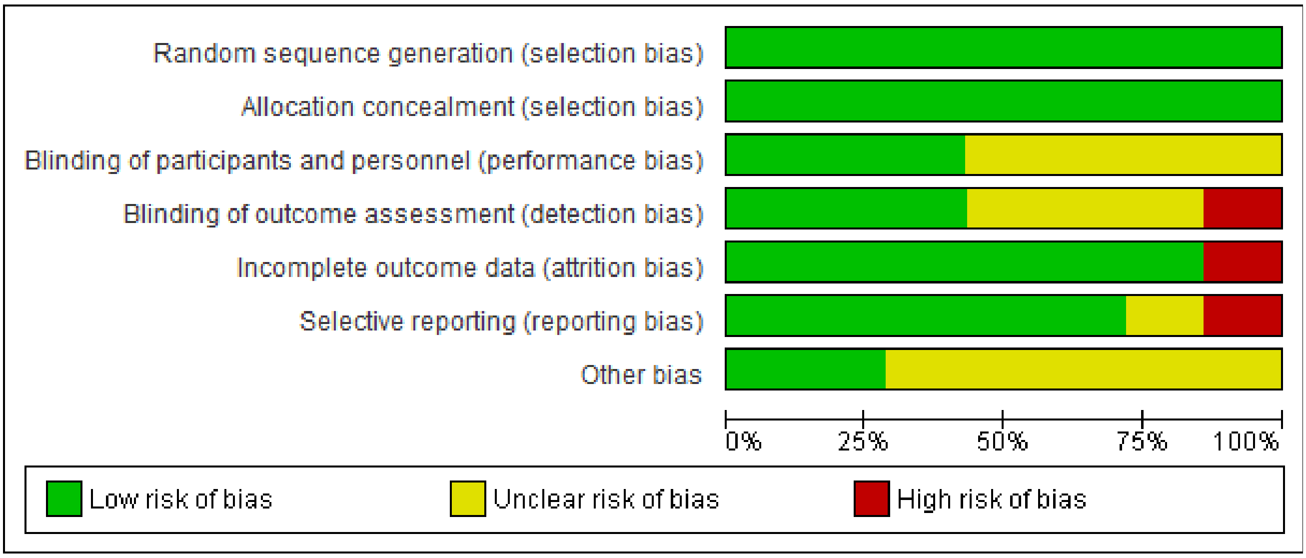


**Figure 3.** Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies

*4.4. Results of Individual Studies and Syntheses*

The meta-analyses were performed to evaluate the outcomes of size of burn wounds, depth of burn wounds, wound healing, and pain.

*4.5. Size of Burn Wounds*

We evaluated three studies (15, 16, 17) on the primary outcome of size of burn wounds as a proportion of TBSA. We pooled all the random effects and found no significant differences in the wound sizes of burns where cooling was performed for at least 20 min compared to cases where cooling was done for less than 20 min (SMD=-0.05, 95% CI, -0.15 – 0.04; see Figure 4).

*4.5.1. Subgroup Analysis*

There was a higher heterogeneity between the subgroups of cooling durations (at least 20 min and below 20 min). The findings of sensitivity analysis showed that cooling burn wounds for at most 10 min had a beneficial impact of reducing the size of wounds and destruction of tissues compared to cooling the burns for more than 10 min (SMD=-0.04; 95% CI, -0.15–0.07). Additionally, cooling of burns within 10 to 20 min had an effect of reducing tissue destruction and lowering the levels of pain and inflammation.

*4.6. Depth of Burn Wounds*

We evaluated two studies that examined the depth of burnt wounds in children (see Figure 5). The cohort study by Wood et al. (16) consisted of children who were at least 16 years old and sustained burns in three distinct categories, including superficial thickness, mid-dermal thickness, and deep-dermal thickness. In contrast, the second cohort study by Griffin et al. (15) consisted of children aged 4 years who had sustained burns in four distinct categories of superficial thickness, superficial partial thickness, deep-dermal, and full thickness.

*4.6.1. Subgroup Analysis*

We found a higher heterogeneity between the subgroups of the depth of burn wounds based on the duration of cooling. However, we could not establish the direction of the effects. The meta-analysis was limited by contradictory findings of the included studies. For example, a study by Griffin et al. (15) showed that deep dermal thickness was lower in children whose burns were subjected to a cooling of at most 20 min compared to those whose burns were subjected to a cooling of more than 20 min (RR = 1.24, 95% CI, 0.80 – 1.90).

We carried out a sensitivity analysis to examine the performance of depth of wounds cooled for at least 20 min with those wounds cooled for 5 min, 10 min, and 15 min. There were no significant changes in the depth of burnt wounds across cooling categories.

*4.7. Tissue Healing*

We assessed tissue healing based on the number of days taken for re-epithelialization to occur in non-grafted children. We examined two studies (15, 18) who reported the tissue healing in children. In a pooled random effects model, we observed no statistically significant differences in tissue healing between burns cooled for at most 20 min and burns cooled for at least 20 min (SMD = 0.10, 95% CI, -0.07 – 0.27).

The findings of our sensitivity analysis showed no significant changes in tissue healing when the duration of exposure was changed from 5 min, 10 min, 15 min, and 20 min. Moreover, the subgroup analysis showed a smaller effect of heterogeneity between the subgroups.

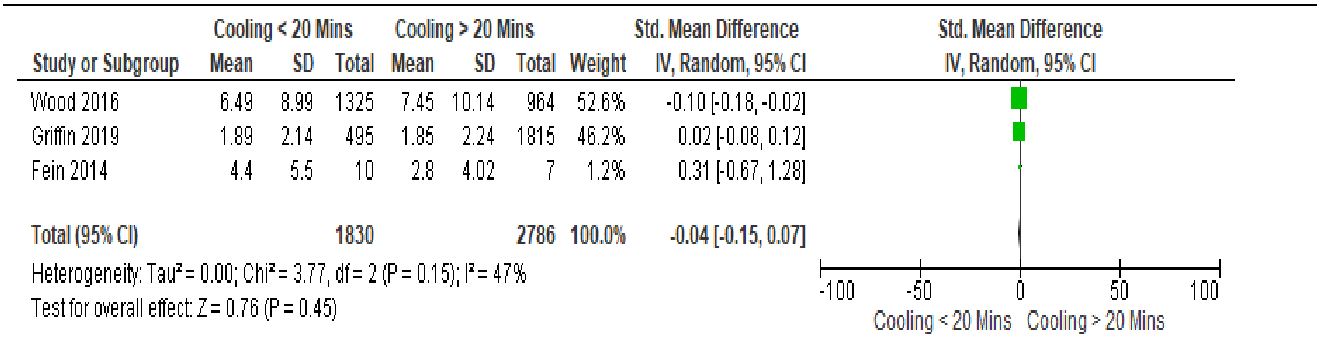


**Figure 4.** Forest Plot of Size of Burn Wounds as a Proportion of TBSA

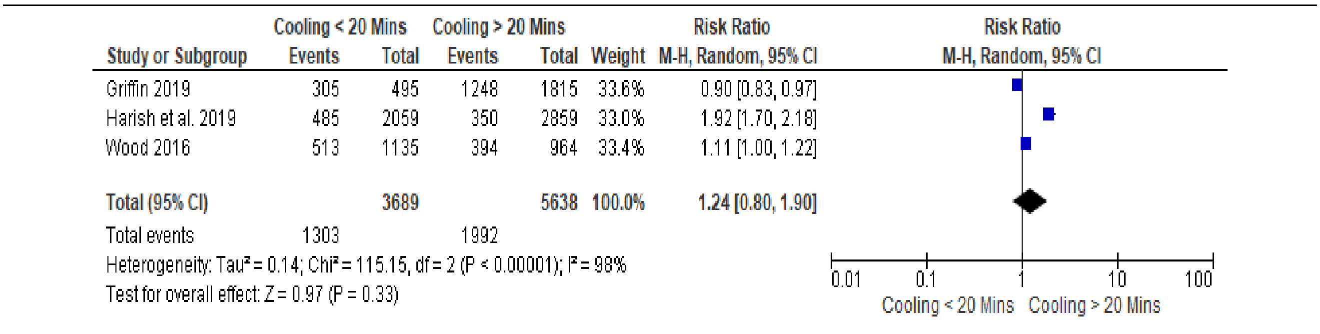


**Figure 5.** Forest plot of comparison of Depth of Burn Wounds

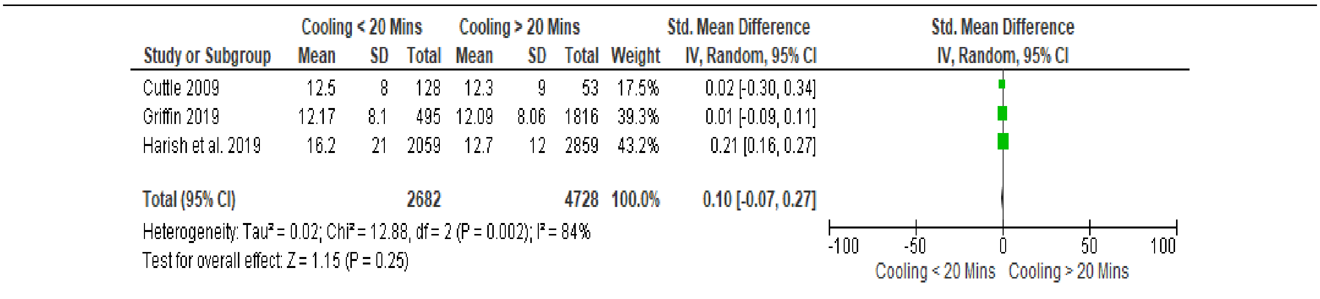


**Figure 6.** Forest plot of comparison of Tissue Healing

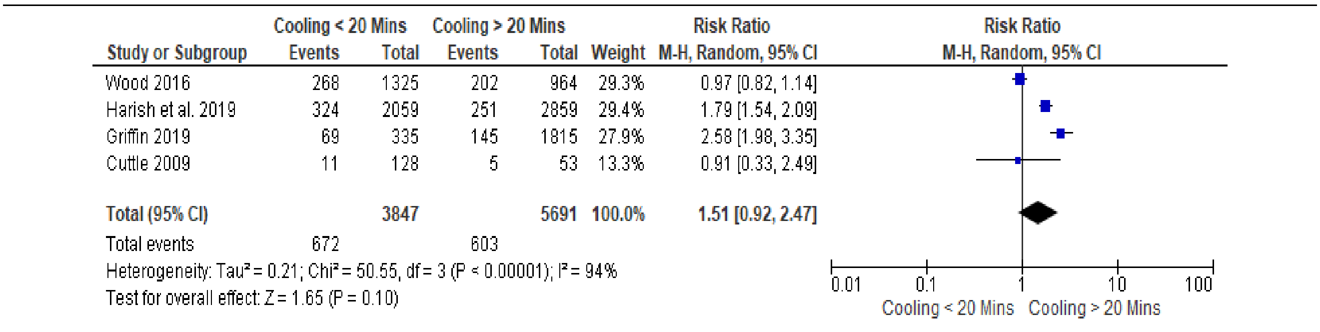


**Figure 7.** Forest plot of comparison of the Requirements for Skin Grafting

*4.8. Skin Grafting*

We assessed three studies that examined adverse outcomes such as skin grafting (15, 16, 18). Skin grafting is a surgical operation involving transplanting skins from healthy regions to infected regions. We examined the pool random effects model of skin grafting and found no statistically significant differences in the requirements of skin grafting for children whose burns were cooled for at most 20 min compared to those whose burns were cooled for more than 20 min (RR = 1.51, 95% CI, 0.92 – 2.47). In our sensitivity analysis, no significant changes was found in the requirements for skin grafting in children whose duration of exposure to cooling was 5 min, 10 mins, 15 min, and 20 min (see Figure 7). Furthermore, we found a statistically significant heterogeneity in the subgroup analysis.

*4.9. Analysis of Pain and Hypothermia as Secondary Outcomes*

A study by Harish et al. (21) on 117 children aged 5 years and below showed that a subgroup analysis of 24 children received analgesics, paracetamol, and morphine. We assessed pain as the requirement for the administration of pain relievers. These pain relievers were administered through unknown routes by paramedics, where children whose burns were cooled for at least 20 min received 57% analgesics, paracetamol, and morphine. However, children whose burns were cooled for less than 20 min received 59% analgesics, morphine, or paracetamol.

Hypothermia was an adverse outcome associated with increased TBSA and age. Hypothermia increases mortality due to dysregulation of body temperature. A study conducted by Fein et al. (17) showed that of 117 children aged 4 years subjected to water cooling after thermal burns, 25% of them had tympanic temperatures and 4% developed hypothermia.

## 5. Discussion

Our systematic review and meta-analysis revealed that cooling thermal burns with ice cubes, running water or cold wet compress techniques had effects on tissue healing, size, and depth of burn wounds. Our findings propose that the size of thermal burns is an essential primary outcome in the administration and management of first aid of thermal burns in children. Our subgroup analysis revealed that cooling of burns for 5 min, 10 min, 15 min, and 20 min with water cooling, ice cubes or wet compress techniques significantly affected the size of burns. Moreover, these cooling techniques reduced destruction of tissues and mitigated cell damage.

Our findings were consistent with Sutton and Wright (6), who proposed that cool running water was effective in reducing the destruction of cells and tissues. We propose that the action of cool running water reduces tissue damage by lowering the temperature and inflammation, transferring heat, and reducing pain. Thermal burns increase the temperature of the skin and surrounding tissues which leads to cell death, denaturation of skin proteins, and inflammatory responses. Lowering the skin temperature with cool water or ice can prevent or slow down the cell death, limiting tissue damage and promoting healing. It can also prevent protein denaturation, reduce inflammation triggered by the burn, and further reduce tissue damage. Furthermore, cooling the burn can also help to alleviate pain and discomfort because the cool water can help to numb the affected area and provide a soothing sensation.

Our study suggests that ice cooling effectively reduces the size of burn wounds because ice cooling regulates the depth and severity of the burns and limits the spread of burns to surrounding tissues. We found that the action of ice cooling is based on vasoconstriction, lowering metabolism and inflammations. Ice application on a burn can constrict blood vessels, reduce blood flow, and prevent further tissue damage (26). It can also slow the metabolic rate of cells and decrease the rate of oxygen and nutrient consumption, limiting tissue damage and reducing the wound size. Additionally, ice can reduce inflammation, which minimizes swelling and further limits the spread of the burn.

We established that cold wet compress limits the size of burn wounds by preventing the spread of burns to surrounding tissues and reducing tissue damage. Cold wet compress technique increases the cooling effect and moisture content and lowers inflammation (27). A cold compress reduces tissue damage and the spread of a burn by lowering the skin temperature, causing vasoconstriction and reducing inflammation. Vasoconstriction narrows blood vessels, reducing blood flow to the affected area and limiting further tissue damage. The compress can also minimize swelling, which can contribute to the size of the burn, thereby reducing the wound size.

Our study suggests that in reducing the size of burn wounds as a proportion of TBSA, cool water should be performed as soon as possible after the burn occurs for 10-20 min. Ice cooling should be used with caution. It is important to wrap ice in a protective covering and apply it for short periods to prevent tissue damage and other complications. The wet compress should be applied carefully and intermittently for short periods to prevent cold injury to the skin and avoid restricting blood flow.

A study by Wood (16) proposed that water cooling was an effective first aid in the management of burn wounds with smaller to medium TBSA. However, children with medium TBSA were often administered to intensive care units ($P<0.001$). Moreover, they found that burns of a greater TBSA resulted in longer hospital stays for tissue and wound healing ($P<0.001$). We found that this effect was attributed to the exclusion of children who died while receiving treatment from the analysis. Our study suggests that the cooling effect of water, wet compress or ice cubes increased the survival and length of stay in hospitals compared to those who did not receive the first aid treatment and died within a short time. Another possible explanation is that the cooling effect generated adverse outcomes such as hypothermia that increased the duration of patients stay in the intensive care units. We suggest that cooling effect is effective in burn wounds of smaller TBSA that are recommended for graft surgeries.

According to our primary outcomes, previous studies (22-24) have suggested that it is difficult to determine the size of thermal burns despite being essential in the management of burns. We included studies that assessed the size of burn wounds using qualified professionals in the hospitals or burn centers. However, all the included studies did not provide an assessment method before and after administering the first aid treatment. Therefore, there exists a possibility that first aiders could have excessively cooled the burns for longer durations than the recommended duration. We proposed that stratifying our analyses would be significant in the analytical comparisons of the size and depth of burn wounds based on the duration of exposure. It is impossible to ascertain that the depth or size of the burn wounds could be estimated before first aid and then used to calculate the rate of cooling because first aid is designed to save lives and increase the chances of survival.

In all the included studies, we observed that most patients had smaller burn areas (less than 10% TBSA), with 70% of the burns being superficial in depth. No relationship was observed between improved outcomes and longer durations of cooling with water, ice or wet compress techniques. These effects can be explained by a skewed population of the included studies, which mainly focused on children. We observed that larger burns (greater than 25% of TBSA) required longer cooling durations due to increased pain and burning sensation. Furthermore, we proposed that no relationship was seen between duration of cooling and requirements for skin grafting. One possible explanation is that skin grafting was preserved for specific parts of the body. Therefore, smaller burns situated within the functional or specified body areas were grafted compared to burns that did not occur in functional body areas. In this regard, our study was limited by inaccessibility to raw data on the anatomical locations of thermal burns so that we could conduct a subgroup analysis.

Our findings were consistent with the recommendation of the WHO, European Burns Association (EBA), and the Australian & New Zealand Burn Association (ANZBA) on the duration of cooling of burns for at least 20 min (28, 29). However, in the UK and Red Cross, the duration of cooling is recommended for 10 min. In our study, we established in reducing the size of burn wounds and depth of burn wounds, the duration of cooling was critical, with at least 20 min being essential for mitigating adverse outcomes. However, regarding the requirements for skin grafting and tissue healing, there were no differences in the duration of cooling. According to Cuttle et al. (25), there is a beneficial impact of cooling burns for at least 20 min compared to 10 min, 30 min, or 60 min. It is because at 20 min, the rate of wound and tissue healing increases and reduces the length of stay in hospitals or burn centres. Furthermore, they suggested that immediate cooling of burns for at least 5-10 min is beneficial compared to no-cooling (25).

Our study lacked high quality randomized human or cohort studies that have established the optimum duration of cooling of thermal burns in children. We obtained a higher heterogeneity in the subgroup analysis, suggesting that the combined studies are not similar enough to produce a meaningful summary effect size. This can be due to differences in study design, population, intervention, or outcome measures. Higher heterogeneity can reduce the precision and accuracy of the summary effect size, making it more difficult to draw conclusions about the overall effect of cooling burn wounds. In addition, it may suggest that there are important moderators influencing the effect of cooling in the subgroups. Identifying these moderators can be useful for developing more targeted interventions and understanding the underlying mechanisms of cooling effect.

We suggest that future high-quality studies involving prospective or cohort analysis in children should be incorporated in meta-analysis to ensure a consistent definition of the duration of exposure of cooling with ice, water or wet compress techniques in the treatment of burn wounds. Future studies should adopt a uniform and consistent definition of eligible burns, recommended window period of applying coolant from the time of injury and a consistency in measuring the duration of cooling outcomes. The heterogenous methods of included studies made it difficult for us to synthesize and analyse data, for example, there was insufficient information on whether the cooling effect was administered by bystanders (likely administration of early cooling) or first-aid professionals (likely administration of late cooling) or medical professionals (probably early administration of cooling) or emergency burn centres (likely administration of late cooling). The administration of the cooling effect could be a significant factor in determining the optimal duration of cooling burns and how it affects tissue healing and safety.

Future studies should examine the adverse effects of secondary outcomes such as hypothermia and inform efficient pain management techniques to reduce mortality. We suggest that more data on hypothermia should be incorporated to capture children whose temperatures increased significantly after suffering burn injuries.

### *5.1. Limitations*

Our study was limited by the following factors:

1.) No prospective or randomized interventional studies was found that focused on our research question. Moreover, most of the identified studies focused on water cooling techniques compared to ice cubes and wet compress techniques.

2.) In all the included studies, the exposure outcome of cooling duration was a subjective measure of the time-taken to administer first aid after burn injuries rather than an objective measure of the time-taken from suffering burn injuries to the administration of first aid. Therefore, there were different classifications of children in various categories. Moreover, no study reported whether the duration of cooling was an average of several attempts using various cooling techniques or it was a single measure. Lastly, we found no details on the temperature of ice cubes or water used.

3.) The inclusion of studies from burn centres suggest that children who suffered from small and superficial burns were excluded. Moreover, most studies were from a similar geographical area of Australia and New Zealand, which could lead to biased findings. We suggest that studies from other regions, such as Asia and Africa should be incorporated for more comparisons. However, we excluded studies that used cooling techniques, such as milk or toothpaste (24, 30, 31).

4.) We observed a higher heterogeneity in the methodology of the included studies, making it impossible to carry out meta-analysis of all outcomes.

## 6. Conclusion

Our findings are conclusive that the application of water cooling, ice cubes, and wet compress procedures are effective in the management of burn wounds by increasing the rate of tissue healing and recovery. However, we found inconclusive evidence on the specific duration by which these techniques should be applied for optimum tissue and wound healing. We suggest that adoption of national and international guidelines in the administration of first aid burns could improve consistency in the duration of cooling and lower mortality rates.

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## Footnotes

**Conflicts of Interest:**
**Author Contribution:**
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