Negative pressure wound therapy is useful in pediatric burn patients, a retrospective review

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Boston University
NEGATIVE PRESSURE WOUND THERAPY IS USEFUL IN PEDIATRIC BURN PATIENTS, A RETROSPECTIVE REVIEW

by

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DEDICATION

I would like to dedicate this work to my mentor Dr. Sheridan
and my advisor Dr. Spencer.
ACKNOWLEDGMENTS

I would like to acknowledge the help from my research mentor Dr. Sheridan, my writing advisor Ms. Prelack, and my academic advisor Dr. Spencer.
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YANHAN REN

ABSTRACT

Introduction:

Negative pressure wound therapy (NPWT) has proved to be a powerful tool in facilitating the healing of difficult wounds of a variety of etiologies. The pediatric experience with NPWT has been limited because of concerns about vascular compression and pain associated with treatment.

Method:

A retrospective review (2004-2014) was conducted at Shriners Hospital for Children-Boston to evaluate the therapeutic effect of NPWT on children with difficult wounds due to burns or soft-tissue trauma. Information was collected on patient demographics, wound size and depth, burn injury etiology, length of hospital stay, number of operating room visits, and other treatment procedures. NPWT was instituted in the operating room under general anesthesia using a commercially available system. NPWT was not initiated until all necrotic material had been removed from the wounds. A negative pressure varying between -50 and -125 mmHg was applied to the wound as continuous suction, with younger children being prescribed the lower negative pressures. NPWT dressings were
changed every 5-7 days in the operating room. When wounds were clean and granulated, they were closed with split-thickness skin grafts.

**Results:**

Twenty-nine children with an average age of 9.43 +/- 1.95 years (range 2 months to 18 years) were treated with NPWT. The average total wound size was 24.8 +/- 8.9% (range 0%-95%) of the body surface in patients who had suffered burns and non-burn injuries. Injury mechanisms were categorized as hot liquid (2 children), contact with hot object (4 children), electricity (7 children), flame (9 children), and other non-burn injuries such as abrasion and degloving (7 children). Over 90% of the patients required central venous or bladder catheters. Perceived benefits of the treatment included reduced numbers of dressing changes and more rapid wound granulation. There were no episodes of bleeding associated with NPWT. All patients healed their wounds, were successfully grafted, and survived.

**Conclusion:**

NPWT has a useful role in the pediatric burn unit in facilitating wound healing and improving quality of life. A significant correlation between the size of third-degree burn wounds and the number of negative pressure therapiest suggests that NPWT may be more effective in treating complicated burn wounds. Overall, NPWT appears safe and effective when applied to well-debrided wounds, and the treatment does not seem to be associated with excessive bleeding or discomfort in children.
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LIST OF ABBREVIATIONS

CVC ................................................................. Central Venous Catheter
ICU ................................................................. Intensive Care Unit
NPWT ............................................................. Negative pressure wound therapy
OR ................................................................. Operation Room
VAC ............................................................... Vacuum Assisted Closure
INTRODUCTION

Burn Injury and Its Etiologies

Burn injury is a type of external trauma to skin and other tissues in which the layers of epidermis and dermis are destroyed because of high heat or abrasion. Burns have always been one of the most complicated trauma injuries in the United States as a result of various complications during post-burn care. In addition, the diverse etiologies of burns, such as conflagration, heat, electricity, chemicals, and other traumatic causes, make wound care even more complicated (Figure 1).

Studies have shown that the frequencies of burn injuries were proportional to the increased levels of industrial and domestic activities since the eighteenth century, when people started to live and work in close vicinity of open fires and unsafe warehouses. Children were also at high risk for burn injuries because they either lacked the methods to properly protect themselves from burns or were unaware of the presence of danger. However, since the implementation of prevention education and the installment of safe occupational environments in the late twentieth century, the number of burn incidences has been sufficiently reduced. Nevertheless, challenges still remain in treating the higher levels of burn injuries such as third- and fourth-degree burns, which are hard to maintain and difficult to heal.
Levels of Burn Injury

The severity of burn injury is based on the wound depth and the types of tissues affected (Figure 2). Burn injuries are classified into four different degrees based on the Emergency Medicine Study Guide.\(^5\)
**First-Degree Burn:** The causes of first-degree burn injury are mainly due to sunburns or hot-object contacts. Injury is only localized at the layer of epidermis. First-degree burn wounds are dry in appearance and are sometimes accompanied by skin rashes. The level of pain is tolerable for the individual, and the wound typically heals within a week.

**Second-Degree Burn (superficial partial thickness):** The causes for second-degree burn injury are mainly due to prolonged hot-object contacts, hot-liquid contacts, and conflagration. Injury at this degree often affects both the epidermis and the papillary dermis (upper layer of the dermis). Second-degree burn wounds with superficial partial thickness are moist and are often accompanied by blisters. Local infections sometimes occur, but the wound can heal within two weeks.

**Second-Degree Burn (deep partial thickness):** Injury at this degree affects deeper into the reticular dermis (lower layer of the dermis), leaving blistering and blanching on the wound surface. Often traditional wet wound therapy allows wound closure within a month; however, skin graft may be required if the area of the burn wound is high.

**Third-Degree Burn:** Third degree is the most common type of severe burn injuries. The entire dermis and epidermis are destroyed from the trauma, leaving yellow or black blanching on the wound surface. Because all peripheral neurons are damaged from the injury, patients are not able to sense pain. This makes treatment difficult as wound
infections can occur unnoticed by the patients. Patients with third-degree burns are treated with conventional moist wound wrappings and antibiotic dressings. If the wound is deep and wide, advanced therapy such as negative pressure wound therapy is prescribed to improve wound healing.

_Fourth-Degree Burn:_ Fourth degree is the most severe form of burn injuries. The burn penetrates deep into the adipose, muscle, or bone tissues. The surface of the wound is charred, and all peripheral neurons are completely destroyed. Amputations of the burned extremities are often required to avoid sepsis and tissue necrosis.
Statistics of Burns and the Burden on Patients

It is estimated that each year in the United States at least 500,000 patients visit medical centers through emergency departments for burn wound care. The etiologies of burns vary across different age groups. According to the National Burn Repository, flame burns and scalding injuries account for 80% of burns, which mainly occur in domestic environments. Children under the age of 5 are at increased risk of scalding injuries, because of limited mobility and limited understanding of safety measures appropriate around flames and hot liquids.

The physiological and psychological trauma and the financial burden resulting from burn injuries are tremendous. Patients with burn injuries become immunocompromised because of their wounds and systemic changes, which can elevate the risk for developing various complications such as sepsis, respiration failures, shock, and death. Children and adults recovering from serious burns are facilitated by prompt wound closure with supportive intensive care and nutritional assistance. However, burn care is expensive.
In 2014, for patients who were hospitalized for burn care, 96.7% of those who survived had average hospital costs of $86,146 per patient. For the 3.3% of patients who were severely injured and died despite treatment, the average cost per patient was $285,225.

**Negative Pressure Wound Therapy versus Conventional Moist Dressing**

Negative pressure wound therapy (NPWT) is a noninvasive therapy that promotes wound closing and controls infections. Since its first application in 1995, NPWT has been shown to sufficiently improve wound closure by establishing a vacuum through a sterilized occlusive dressing over the wound sites (Figure 3). The negative pressure is usually maintained between -75 and -125 mmHg based on the condition of the wounds. The vacuum created by a vacuum pump helps to maintain a pressure gradient that increases blood flow and immune cell recruitment. Antibiotics and saline are applied together with the therapy to hydrate the wounds.

Negative pressure wound therapy is an innovative approach in healing chronic ulcers. Traditionally, chronic wounds are maintained by moist wound therapies which contain hydrogels, silver ions, and alginates. Compared with this conventional counterpart, negative pressure therapy demonstrates a higher rate of wound closure and a lower risk of bacterial infection.
Traditionally, chronic wounds such as diabetic ulcers, venous ulcers, and burn wounds are treated with moist dressing. These types of wound wraps often contain gauze, foams, or hydrogels. In addition, silver ions or antibiotics are infused into the dressings to prevent infections. Although the conventional wound wraps can be purchased over the counter and are relatively inexpensive, they present increased risks of anaerobic bacteria growth as the dressing may not be able to cover deep wounds. Moreover, the moist wound wraps must be constantly changed over a lengthy period to allow physicians to cleanse the dead tissue.
Therapeutic Values of Negative Pressure Wound Therapy in Open Abdominal Wound Care

Figure 3. The V.A.C. Ulta™ Negative Pressure Wound Therapy System. This commercial device is produced by KCI (Kinetic Concepts, Inc., San Antonio, Texas, USA). The pump provides a vacuum environment that increases the flow of blood to the wound sites. The vacuum pump is connected to the wound site through occlusive foam dressings. V.A.C. = Vacuum-Assisted Closure.
The current commercialized form of negative pressure wound therapy is vacuum-assisted closure (VAC) therapy, which has been increasingly used in managing the open abdominal cavity.\textsuperscript{14, 15} Patients with open abdominal wounds present problems with wound closure. The difficulties in wound closure are mostly related to high intra-abdominal pressure generated by acute coronary syndrome and intra-abdominal bleeding. When the contents inside the abdominal cavity increase in volume, the pressure inside the cavity rises, causing skin dehiscence and hernia, which extend wound closing time.

Negative pressure therapy was first implemented in the field of abdominal surgeries in the late 1990s. Since then, NPWT has shown useful applications in controlling sepsis and tissue necrosis after laparotomy.\textsuperscript{18, 19} Studies have indicated that patients recovering from abdominal surgery demonstrated decreased risks of intestinal fistula and intestinal failure.\textsuperscript{18} Comparative studies and meta-analysis also revealed that patients who were recovering from primary abdominal wall reconstruction surgery exhibited decreased risk of skin dehiscence, hernia, and other common post-surgical complications when treated with incisional negative pressure wound therapy.\textsuperscript{23} In addition, NPWT was used in managing an open abdomen cavity between surgical procedures. Other research in this field indicated that the negative pressure environment significantly decreased the risk for wound infections and the chance of tissue necrosis.\textsuperscript{23}
The success of negative pressure therapies in patients recovering from open-abdominal surgery encouraged physicians to implement this advanced treatment procedure on patients with chronic open wounds such as diabetic ulcer and burns. 29, 30

Therapeutic Values of Negative Pressure Wound Therapy in Extremities Wound Care

Tissue ischemia and infections are the major concerns for patients presenting diabetic ulcers. These wounds are usually located in the extremities. 32 The implementation of NPWT to diabetic ulcers and chronic ulcers creates a negative pressure environment that promotes blood flow and recruitment of immune cells to increase the prognosis of chronic wound healing.

Patients with diabetic foot ulcer who underwent four months of active VAC showed a significant increase in wound healing rate and a reduced need for lower-extremity amputation. 33, 16 When compared with patients who underwent moist wound therapies, patients who received negative pressure therapy exhibited a greater chance of complete diabetic wound healing with much shorter healing episodes. 23 Furthermore, VAC was able to decrease the volume and the depth of diabetic ulcers beyond that of traditional
moist gauze dressings and consequently lower the risk of bacterial and fungal infections in these wound sites.\textsuperscript{17}

Recently, the efficacy of NPWT in controlling acute-phase infections and improving skin regeneration was also proved among patients with blunt traumas and lower extremity fractures.\textsuperscript{19} Overall, literature research indicates that negative pressure wound therapy has been increasingly studied and discussed in the last five years and has demonstrated tremendous therapeutic values in promoting various post-operative recoveries.

**Problems and Concerns Related to NPWT**

Although NPWT has proved to be an advantageous tool in closing various wounds, there are still concerns about the negative side effects. There have been reports of high levels of pain associated with NPWT.\textsuperscript{31} When the baseline for negative pressure is too high, usually above -125 mmHg, patients experience unnecessary pain.\textsuperscript{20} Because of reports of ischemia in patients after receiving NPWT, physicians have been cautious when applying negative pressure in pediatric patients.\textsuperscript{20} Their concerns are mainly due to the fact that children are more sensitive than adults in sensing pain.\textsuperscript{21} Children are also more prone to vascular compression when presented with an external source of pressure. This condition causes insufficient blood flow and loss of sensation in local wound sites.\textsuperscript{22} Moreover,
literature research does not reveal any significant studies on the efficacy of NPWT in promoting burn wound repair post-operatively.

**Aims of Study**

Previous researchers have shown that when applying NPWT to patients with chronic ulcers, the rate of tissue granulation greatly increased while the risk of tissue necrosis declined.\(^{14}\) The efficacies of negative pressure therapies are mostly observed in the treatment of diabetic ulcer and the management of open abdominal wounds.\(^{16,23}\) However, limited NPWT research has been conducted among patients with burn wounds, specifically pediatric patients.

Shriners Hospital for Children in Boston is responsible for treating complicated burned pediatric patients around the world. Children who are admitted to the hospital can present with deep and wide wounds because of burns or soft-tissue trauma. As traditional wet dressing therapy is often ineffective at closing these difficult wounds, negative pressure wound therapy was instituted in the operating room with general anesthesia control. This therapy, now in place at Shriners Hospitals for Children for over a decade, has shown promising healing outcomes in its population of children. Children who underwent the negative pressure therapy had reduced length of stay in the hospital and lowered risk of sepsis and other burn complications.
The purpose of this study is to complete a retrospective review evaluating the therapeutic effect of negative pressure wound therapy on pediatric patients with difficult burns. The aims of this review are to test the hypotheses that:

1. The application of negative pressure wound therapy grants efficient and safe recoveries to burned pediatric patients.
2. The faster healing process of negative pressure wound therapy helps these children rejoin society and school after discharge from the hospital.
3. Understand the most important factor in determining the prescription of negative pressure wound therapy to children.
METHODS

Data Collection

A retrospective review was performed to evaluate the therapeutic effect of NPWT on children with difficult wounds due to burns or soft-tissue trauma. Patient charts from the years between 2004 and 2014 at Shriners Hospital for Children in Boston were examined and selected for use in the review. Data were collected on patient demographics, wound size and depth, burn injury etiology, length of hospital stay, number of operating room visits, and number of ventilation days, intensive care unit days, central venous catheter days, and Foley catheter days.

NPWT was instituted in the operating room under general anesthesia using a commercially available system. The vacuum pump used in this study was the KCI V.A.C.Ultra™ Negative Pressure Wound Therapy System (Figure 3). NPWT was not initiated until all necrotic material had been removed from the wounds by surgical excision. The V.A.C.® Simplace™ Dressing, a foam dressing, was applied to selected deep wound sites and connected to the vacuum pump (Figures 4 and 5). The applied negative pressure ranged from -50 to -125 mmHg continuous suction, with younger children being empirically prescribed the lower negative pressures to potentially reduce discomfort. NPWT dressings were changed every 5-7 days in the operating room. When wounds were clean and had granulated, they were closed with split-thickness skin grafts.
Figure 4. Application of negative pressure wound therapy on burn wounds located at extremities. The occlusive dressing is wrapped over the wound area while connected to the vacuum pump. The vacuum pump is connected to the lower wound site, allowing gravity to facilitate fluid drainage (Shriners Hospital for Children in Boston, patients’ photo archive).
Figure 5. Application of negative pressure wound therapy on burn wounds located at the head and neck region. The occlusive dressing is wrapped over the wound area while connected to the vacuum pump. The vacuum pump is connected to the lower wound site, allowing gravity to facilitate fluid drainage. Patients also receive respiratory ventilation and anesthetics during the procedure to provide (Shriners Hospital for Children in Boston, patients’ photo archive) sedation.


**Study Limitations**

There were several limitations during the recruitment process. The children who were recruited in this study were already presenting slow wound recoveries and various complications when admitted to the hospital. In order to avoid further deterioration of the wound, negative pressure wound therapy was prescribed to these patients rather than the conventional moist wound dressing. Consequently, there was no control group in the study because all recruited patients received negative pressure wound therapy.

The number of patients in this study was also limited. The complicated character of the wound and the size of the wound were relatively rare among pediatric patients. Patients who were recruited in this study had either large total burn size or complicated third-degree burn wounds.

**Statistical Analyses**

Patient data were collected throughout the treatments to evaluate the effectiveness of the negative pressure therapy. One-way analysis of variance (ANOVA), Welch’s two-sample t-test, and linear regression were used to analyze the data. The software programs R version 3.2.2 (R Core Team, Vienna, Austria) and Microsoft Excel 2010 (Microsoft
Corporation, Redmond, Washington, USA) were used for data collection and statistical analysis.
RESULTS

Patients’ General Demographics

A total of 29 children, 12 females and 17 males, with an average age of 9.43 years (range 2 months to 18 years), were treated with negative pressure wound therapy (Figure 6). The average total burn size was 27.62 +/- 9.83% (range 1%-95%) of the body surface, and the average third-degree burn size was 20.27 +/- 7.58% (range 1%-72%) of the body surface (Table 1). Perceived benefits of the treatment included a reduced number of dressing changes and more rapid wound granulation. There were no episodes of bleeding associated with NPWT.

Table 1 show patient demographics, injury levels, and the types of treatments received by the pediatric patients. The use of NPWT increased during the time interval of the study, and this was presumably due to the staff becoming more comfortable with the safety and efficacy of the therapy in children. The most common age range was 10-15 years, and the most common mechanism was electrical or mechanical soft tissue injury. All patients granulated their wounds, were successfully grafted, and survived (Figure 8A).
According to Figure 6A, male patients were more prone to burn injury. Figure 6B demonstrated that teenage children (10-15) are the population that is most at risk for burn injuries. These results matched our expectations as male children around this age were
highly active at exploring the surroundings and might not be able to protect themselves from the danger of burn.

Figure 7 A&B. Number of patients in each burn injury etiologies and number of patients with inhalation burn injury. Figure 7A described the number of recruited patients in each burn injury etiology. Figure 7B described the number of pediatric patients with inhalation burn injury (5 yes and 24 no).
According to Figure 7A and Figure 7B, the acronym representation for burn etiologies are: conflagrate: flame conflagration; contact: hot object contact; electrical: electrical burns; Ignition: Ignition of clothing; Liquids: hot liquids contact; Non-Burn: Other abrasion injuries).

Based on the information presented in Figure 7A, the distribution of burn cases in each etiologies were not evenly distributed. Electrical burns and cloth ignition accounted for the most frequent burn etiologies. Therefore, it could possible that the types of burn injuries might play important role in determining the frequency negative pressure wound therapy treatments.

According to Figure 7B, about 83% of the patient did not have inhalation injury. Inhalation injury represents a rare form of burn injury, which often happen during injury to the head to neck region. With less than 20% of patients presenting the symptom of inhalation injury, the possiblity of it being the determing prscription factor is unlikely.
Figure 8 A&B. Pediatric patients discharge locations and number of patients admitted from 2004 to 2014. Figure 8A histogram described where patients were discharged to after hospitalization. Figure 8B described the number of patients admitted between 2004 and 2014.
Based on information presented in Figure 8A and Figure 8B, more than 90% of patients were able to fully recover without the need for additional home-health. The rest of the 10% patients either need home-health care or after care at a primary care facility. As the therapy began to show positive prognosis, more and more patients started to receive NPWT to treat complicated wounds. Based on Figure 8B, the number of patients receiving negative pressure wound therapy steadily increased since 2006 and reached plateau in 2010. These results are encouraging as more and more patients will benefit from this advanced procedure at Shriners Hospital for Children in Boston in the future.

**Figure 9. Burn Size.** Figure 9 box plot demonstrates the percent of third degree burns (dark line in the middle of the box: median 20%) and the percent of total burn areas (median 28%).
It is possible that either total burn size area or the third degree burn size plays the decisive role in determining the frequency of negative pressure wound therapy. Based on the information presented in Figure 9, the area of total burn size and third degree burn size is relatively high among our patients. The mean for third degree burn size and total degree burn size are 20.27 and 27.62 respectively (Table 1).

In addition, the ranges for the burn size areas are broad. The interquartile ranges for third degree burn size and total degree burn size are 18 and 27.88 (Table 1) respectively. This could mean that the pattern of negative pressure therapy prescription could match to the pattern of burn size area distribution.
### Table 1. Summary of Negative Pressure Therapy

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<td>% Total Burn size</td>
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<td>27.62 +/- 9.83</td>
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<td>% 3rd degree Size</td>
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<td>14.37 +/- 6.34</td>
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<td>Foley Catheter Days</td>
<td>26</td>
<td>8.77 +/- 5.50</td>
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**Table 1. Summary of Negative Pressure Therapy.** Table 1 shows the general information on burn wound sizes, number of operating room visits, and other treatments received by the patients.
Based on the boxplots from Figure 10A and Figure 10B, we were able to see that burn sizes and injury etiologies are independent because boxplots overlap with one another across each category.
Figure 11 A&B. Average intensive care unit days and average length of stays in hospitals in different burn etiologies. Figure 11A described mean number of intensive care unit days received by patients in each injury category. Figure 11B measured the mean length of hospital stays per patients in each injury category.

Figure 11A and Figure 11B discribed the number of days patients spent in the intesnive care unit and number of days patients stayed in the hospital (length of stay). With the
help from negative pressure wound therapy, site infections and tissue necrosis rates were significantly reduced, expediting the rate of wound recovery. Therefore, fewer days were required for intensive care. The improved prognosis allowed patients to spend fewer days in the hospital. This advancement allowed the pediatric patients to rejoin the society quicker, reducing their anxiety during hospitalization.

**Figure 12 A&B.** Average days patients on central venous catheter and Foley Catheter in different burn etiologies. Figure 12A described mean number of days patients received central venous catheter in each injury category. Figure 12B mean number of days patients received Foley catheter in each injury category.
Figure 12A and Figure 12B described the frequency of central venous catheter and Foley catheter received by patients during their stay. Central venous catheter was placed for patients to allow flexible delivery of medicine, nutrients, and saline, which can avoid frequent syringe injections as many children were needle-phobic. In addition, Foley catheter are inserted into the urethra of the patients to allow sanitized urine outflow to prevent infections wound areas.
Based on information presented in Figure 13, many of the boxplots representing each burn etiologies did not overlap with each other. This could indicate that different sources of burn would play the determining role in negative pressure wound therapy prescription. To further test this hypothesis, T-test and ANOVA were performed.

**Figure 13. Average Number of Negative Pressure Wound Therapy Received by Patients in Each Etiologies.** Because negative pressure wound therapy is conducted in the operation room, the number of operation room visits indicate the dosage of NPWT prescribed to patients.
Burn Injury Etiology as the determination factor in prescribing negative pressure wound therapy

Table 2. Negative Pressure Therapy and Other Treatments Based on Injury Etiologies

<table>
<thead>
<tr>
<th>Injury Etiologies</th>
<th>Conflagrate</th>
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<th>Hot Objects</th>
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<td>7</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Mean % Total Burn size</td>
<td>41.33</td>
<td>29.64</td>
<td>30.25</td>
<td>2.44</td>
<td>35.17</td>
<td>26.38</td>
</tr>
<tr>
<td>Mean % 3rd degree Size</td>
<td>34.67</td>
<td>23.00</td>
<td>29.25</td>
<td>2.44</td>
<td>27.5</td>
<td>2.83</td>
</tr>
<tr>
<td>Mean Length of Stay</td>
<td>64.00</td>
<td>56.57</td>
<td>46.00</td>
<td>5.50</td>
<td>67.17</td>
<td>32.43</td>
</tr>
<tr>
<td>Mean OR Visits for NPWT</td>
<td>8.67</td>
<td>9.86</td>
<td>5.00</td>
<td>2.00</td>
<td>10.00</td>
<td>6.43</td>
</tr>
<tr>
<td>Mean Ventilation Days</td>
<td>0.00</td>
<td>8.83</td>
<td>0.00</td>
<td>0.00</td>
<td>13.60</td>
<td>0.29</td>
</tr>
<tr>
<td>Mean ICU Days</td>
<td>9.33</td>
<td>27.00</td>
<td>9.00</td>
<td>0.00</td>
<td>25.00</td>
<td>7.86</td>
</tr>
<tr>
<td>Mean Central Venous Catheter Days</td>
<td>27.00</td>
<td>27.17</td>
<td>9.00</td>
<td>0.00</td>
<td>25.00</td>
<td>13.33</td>
</tr>
<tr>
<td>Mean Foley Catheter Days</td>
<td>3.00</td>
<td>18.00</td>
<td>0.00</td>
<td>0.00</td>
<td>18.60</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Table 2. Negative Pressure Therapy and Other Treatments Based on Injury Etiologies. Table 2 shows the statistics of injury levels and amounts of treatments received based on different etiologies.
As shown in Table 2, burns etiologies included flame (3 children), electrical (7 children), hot liquids (2 children), contact (4 children), electrical with secondary clothing ignition (6 children), and other non-burn mechanical soft-tissue injuries such as abrasions and degloving trauma (7 children).

Because of the limitations at the recruitment phase, a control group was not established in which patients received conventional moist dressings. Nevertheless, we were able to compare within groups to test which variable, the etiologies of burns or the size of burns, would be the most determining factor in prescribing the dosage of negative pressure wound therapy.

To understand if the amounts of negative pressure therapies received were different across each burn injury mechanism groups, Welch’s 2-sample \( t \)-test was performed by comparing the amounts of negative pressure therapy received across all subgroups. A significant in-group variance was noticed within the percentage of total burn size and percentage of third-degree burn size. Therefore, one-way analysis of variance (ANOVA) was conducted across all subgroups’ total burn size and third-degree burn size to certify that the statistical differences were significant.

The two-sample \( t \)-tests measuring the amount of negative pressure wound therapy received revealed significant statistical differences between the group of hot objects
contact burns, flame conflagration, electrical burns, and material ignition burns (p < 0.01).

On the other hand, the amounts of therapies received by other subgroups, hot liquid burns and non-other burns, were not significantly different with each other (p > 0.05). Moreover, one way analysis of variance (ANOVA) showed high levels of within-group errors when comparing the percentages of total burn size and the percentages of third degree burn size across all subgroups. These indicated burn sizes could play a more important indicator than burn injury etiologies in prescribing NPWT.

**Burn size area as the determination factor in prescribing negative pressure wound therapy**

Previous test indicated that wound etiologies may not be the decisive factors in prescribing negative pressure therapy. Therefore, we decided to examine the possibility of burn size as the determining factor in NPWT administration.

Linear regression analysis was performed to better understand whether total burn size or third-degree burn size correlates with the amounts of negative pressure therapy received.
Figure 14 A & B Linear correlation between total burn size area to number of NPWT and third-degree burn size to number of NPWT. Based on figure 14A and figure 14B, a stronger linear correlation relation was observed between the third degree burn size and the number of negative pressure wound therapy received.
Linear regression tests from figure 14A and 14B demonstrated positive correlation between the numbers of NPWT received and total burn size areas as well as third-degree burn size areas. However, a stronger correlation was observed between the amounts NPWT and third degree burn size ($r^2=0.41$) than total burn size ($r^2=0.25$). These findings indicate that usage of negative pressure therapy might be more related to level of burn injuries severity rather than the burn wound sizes in general.

To further understand the relationship between third-degree burn size and the prescription pattern of NPWT, patients were separated into two groups: third-degree burn size below 20% and third-degree burn size of 20% and above. Welch’s two-sample $t$-test was performed on the two groups, and the results are shown in Table 3. Significant statistical differences were observed between the two groups except for the number of Foley catheter days. This latter result was expected since 90% of all the pediatric patients received Foley catheter treatments to prevent urinary tract infections.
Table 3. Negative Pressure Therapy and Other Treatments Based on Third-Degree Burn Size

<table>
<thead>
<tr>
<th></th>
<th>3rd Degree Burn Size Below 20%</th>
<th>3rd Degree Burn Size 20% and Above</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Patients</td>
<td>11</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

**Welch Two Sample t-test**

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean % Total Burn size</td>
<td>7.39</td>
<td>38.71</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean % 3rd degree Size</td>
<td>5.34</td>
<td>32</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean Length of Stay</td>
<td>23.36</td>
<td>64.57</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean OR Visits for NPWT</td>
<td>5.00</td>
<td>9.57</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean Ventilation Days</td>
<td>0</td>
<td>10.08</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean ICU Days</td>
<td>5.55</td>
<td>23.17</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean Central Venous Catheter Days</td>
<td>5.55</td>
<td>27.67</td>
<td>P&lt;0.01</td>
</tr>
<tr>
<td>Mean Foley Catheter Days</td>
<td>3.18</td>
<td>14.58</td>
<td>P=0.05</td>
</tr>
</tbody>
</table>

**Further t-tests from table 4 demonstrated that third-degree burn size is more indicative than total burn size in determining the amounts of NPWT. Patients who received 10 or**
higher applications of NPWT presented with significantly higher third-degree burn size than patients who received 5 NPWTs or lower. Patients who received between 5 and 10 NPWTs also presented with significantly higher third-degree burn size than those who had 5 or less NPWTs. These findings indicated that more frequent negative pressure therapies are needed for pediatric patients with higher areas of third-degree burn wounds.
Table 4. Average Percentage of Third-Degree Burn Size and Number of NPWT Received

<table>
<thead>
<tr>
<th>Number of Patients</th>
<th>Group 1 OR Visits 5 and Below</th>
<th>Group 2 OR Visits &lt;10</th>
<th>Group 3 OR Visits 10 and Above</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>12</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Welch Two Sample t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean % Total Burn size</td>
</tr>
<tr>
<td>8.82</td>
</tr>
<tr>
<td>Mean % 3rd degree Size</td>
</tr>
<tr>
<td>5.68</td>
</tr>
</tbody>
</table>

Table 4. Average Percentage of Third-Degree Burn Size and Number of NPWT Received. As seen in Table 4, the mean third-degree burn size showed stronger influence in determining the dosage of negative pressure therapy.
DISCUSSION

Role of Negative Pressure Wound Therapy in Post-Discharge Recovery

With today’s medical advancements, the length of hospital stays and the mortality rates for burn injuries have gradually decreased over the past decades. Nevertheless, challenges still remain in helping patients to rejoin society as well as improve their quality of life after discharge. The disfiguration from burns can cause depression, inferiority feelings, and other emotional traumas. This situation is especially critical in pediatric burn patients who are in a crucial period of psychological and cognitive development. The long-term hospitalization creates an isolation environment for the burned pediatric patients, and these children require the help from social workers and healthcare workers to reestablish hope and global self-worth. Therefore, an efficient treatment procedure for wound healing will undoubtedly facilitate the recovery and the improvement in the quality of life for burned children.

This study demonstrated that negative pressure wound therapy can be safely conducted on burned pediatric patients under careful anesthesia administration. All 29 pediatric patients who underwent NPWT survived the treatments. Over 90 percent of the children were able to reach complete wound healing and were discharged to home without the need for additional home healthcare. The expedited healing process of NPWT can help
these children rejoin society quickly and relieve the burden of physical and emotional traumas.

**Advantage of Negative Pressure Wound Therapy in First Aid**

The ideology of negative pressure therapy is to increase blood flow to the wound site to support wound healing and prevent infections. The sooner this therapy is applied to the patient, the better the outcome of the treatment. Negative pressure therapy is an efficient and convenient treatment method. The model used in this study is portable and reusable, which proved to be a convenient healing tool for emergent burn wounds. Because Shriners Hospital for Children accepts pediatric burn patients from all countries in North and Central America, patients would be able to have continuous wound care if NPWT is deployed to medical transporters in the future.

**Related Studies Conducted on Pediatric Patients**

A literature review revealed limited NPWT studies conducted in the pediatric population because of major concerns for pain and stress in the children. However, in one particular study carried out in Austria, negative pressure wound therapy was performed on patients recovering from skin grafts. Pediatric patients in this study had a mean total burn size
of less than 4% and a third-degree burn size close to 0%. All therapies were conducted either at the bedside or on a portable device which could be carried when the children were moving. This study was valuable in that it suggests that operation room environments may not be necessary for children with smaller sizes of burn wounds.

**Limitations of Study**

This retrospective review study revealed promising results about the values of negative pressure therapy in burned pediatric patients. However, there are several limitations to these findings as a result of recruitment issues and concerns for negative side effects.

The pediatric patients who received the negative pressure therapy all presented with deep burn wounds and severe injury complications. After triage, physicians from Shriners Hospital for Children decided that all these patients must receive the progressive NPWT treatment to prevent further injuries. Therefore, children who presented with similar wound characteristics were not available for recruitment into a control group prescribing conventional moist dressing therapy. Children with low burn volumes and less severe degree of burns did not necessarily need negative pressure therapy and were able to fully recover from conventional wound care protocols.
Moreover, caution was used in prescribing NPWT to pediatric patients because of the negative side effects associated with it, including pain, vascular compression, and ischemia\textsuperscript{19}. Since children are more sensitive than adults in feeling and expressing pain, the procedure was hard to conduct without the aid of an anesthetic\textsuperscript{19}. As Shriners Hospital for Children at Boston is the first medical facility to experiment with the efficacy of NPWT on burned pediatric patients, previous knowledge is lacking about the appropriate amounts of narcotics to be applied to these pediatric patients. Therefore, more clinical trials are needed before a general protocol can be formulated for prescribing negative pressure wound therapy and the amounts of anesthetics for burned pediatric patients.

**Conclusions**

To conclude, this study demonstrated that negative pressure wound therapy is an effective procedure in healing burned pediatric patients. The frequency of using negative pressure wound therapy appears to be independent of burn wound etiology but more related to the area of the burn wound. The dosage of this treatment is more correlated with third-degree wound size than with total burn wound size, which could indicate that NPWT is more effective in healing third-degree or higher burn wounds.
REFERENCES

1. National Hospital Ambulatory Medical Care Survey: 2011 Emergency Department Summary Tables


CURRICULUM VITAE

Yanhan Ren. Year of Birth: 1992

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BOSTON UNIVERSITY MASTER IN MEDICAL SCIENCES

BOSTON UNIVERSITY BOSTON, MA

Master of Arts in Medical Sciences  Anticipating May 2016

• Cumulative Master Program GPA 3.62/4.0

• Courses in physiology, Histology, Biochemistry, Molecular and Cell Biology, Immunology, Pathology, and Biostatistics

• Activities: Vice Chair, Social Activity Committee, Master of Medical Science Program Representative, Graduate Medical Science Student Organization (GMSSO)

• Honors: Boston University School of Medicine Community Service Award

UNIVERSITY OF ROCHESTER BACHELOR OF SCIENCES

UNIVERSITY OF ROCHESTER  ROCHESTER, NY

Bachelor of Science in Molecular Genetics and Minor in Chemistry September 2010- May 2014

• Cumulative GPA 3.72/4.0; Major GPA: 3.70/4.0

• Courses in pre-medicine, genetics, biochemistry, public health, epidemiology, and
Activities: Active member, Undergraduate Society of Biology Students, Charles Drew Pre-Health Society, and Astronomy Club

Honors: Diploma Distinction in Research, Latin Honor Cum Laude, Rochester International Scholarship Recipient for Academic Excellence, Citation for Achievement in College Leadership, and Dean’s List 7 out of 8 Eligible Semesters

CLINICAL AND PATIENT CARE EXPERIENCE

MASSACHUSETTS GENERAL HOSPITAL, SHRINERS HOSPITAL FOR CHILDREN BOSTON, MA

Clinical Researcher and Clinical Observation

Fall 2015-Present

- Supervised by Dr. Robert L. Sheridan from Shriners Hospital for Children for clinical research, investigate negative pressure wound therapy’s efficacy in treating burned children via R Program, article currently under review by BURNS journal
- Supervised by Dr. Robert L. Sheridan and Dr. Derek Hursey from Shriners Hospital for Children for clinical research, Investigating liposomal exparel anesthetics’ efficacy in managing burned pediatrics patients’ donor sites pain
- Supervised by Dr. Jo-Anne Shepard from Massachusetts General to observe thoracic biopsy, read thoracic CT and radiography, and attend research seminars
JINGLING HOSPITAL NANJING, CHINA

Clinical Shadowing and Volunteer 2009-Present

- Shadowed Physicians and Observed Surgery in Gastrointestinal Surgery Department, Hepatobiliary Surgery Department, Cardiovascular Surgery Department, Urology Department, Neurology Department, Pediatrics Department, and Pathology Department
- Retired Chair and senior consultant of Little Renal Friend, a volunteering society in Nanjing, China
- Volunteer four hours per week during summer and winter vacation starting at the year of 2006
- Goal is to bring happiness and to provide psychological comfort to the little patients who are fighting renal diseases
- Activities include storytelling, playing games, and assisting patients’ school studies

STRONG MEMORIAL HOSPITAL ROCHESTER, NY

Clinical Laboratory Medical Observer, Immunology Department

Fall 2011

- Shadowed Dr. Paul E. Bankey for six hours per week
- Prepared blood samples for cell counts and observed doctoral students in daily use of advanced medical equipment
BOSTON MEDICAL CENTRE BOSTON, MA

Volunteer/Intern, Diabetic Foot Chronic Wounds Department Summer 2010

- Supervised by Dr. Vickie R. Driver from Boston Medical Centers for clinical rotations and diabetic wound healing research
- Assisted physicians with removing stitches, wound cleaning, dressing changing, and escorting patients into examination rooms during emergency visits
- Observed surgeries including Tenotomy, Bunionectomy and acute trauma surgery
- Participated in the research project of searching a novel biomarker for diagnosing diabetic foot ulcer

TRANSLATIONAL RESEARCH EXPERIENCE

UNIVERSITY OF ROCHESTER ROCHESTER, NY

Independent Research Project, Department of Biology May 2013-May 2014

- Assisted Xin Bi, Ph.D. on research project investigating chromatin remodeler Fun30’s role in poly & mono ubiquitination of PCNA and heterochromatin formation.
- Lab technique include southern blot, western blot, PCR, gel-electrophoresis, DNA extraction, cell culture growth
- Participated in weekly literature readings and lab group discussions on current research progress
- Final Undergraduate Honorary Research Thesis written under the instruction of Dr. Bi.
MASSACHUSETTS GENERAL HOSPITAL, SHRINERS HOSPITAL FOR
CHILDREN BOSTON, MA

Summer Intern, Animal Laboratory, Burns Department Summer 2012

• Recipient of the 2012 Lemieux First Lady Summer Internship Award from Harvard
  University Medical School. Research project conducted under supervision of Yu Yong-
  Ming, M.D., Ph.D. and Dr. Ying Hui-Nan, M.D., Ph.D.

• Performed research methods including catheterization operation, insulin clamp, and
  taking blood glucose readings.

• Investigated the effectiveness of a Hyperinsulinemic euglycemic clamp used to
  suppress the insulin resistance symptoms commonly associated with burn injuries

PUBLICATIONS, POSTER PRESENTATIONS AND CONFERENCES

Publications:

• Yao, M., Attalla, K., Ren, Y., French, M. A., & Driver, V. R. (2013). Ease of Use,
  Safety, and Efficacy of Integra Bilayer Wound Matrix in the Treatment of Diabetic
  Foot Ulcers in an Outpatient Clinical Setting: A Prospective Pilot Study. Journal of the
  American Podiatric Medical Association, 103(4), 274-280.

• Yanhan, R., Guosheng, G., Min, Y., & Driver, V. R. (2014). Role of matrix
  metalloproteinases in chronic wound healing: diagnostic and therapeutic
  implications. Chinese medical journal, 127(8), 1572.
Research Presentations, Speeches, and Conferences:

- Northeastern Chinese Surgical Infection and Recovery Conference at Jilin University School of Medicine (December 2015)
- National Conference on Undergraduate Research at The University of Kentucky (April 2014)
- National Collegiate Research Conference at Harvard University (January 2014)
- Unite for Sight Global Health & Innovation Conference at Yale University (April 2013)
- University of Rochester Undergraduate Research Exposition poster session (April 2012, 2013, 2014)
- University of Rochester Undergraduate Program in Biology and Medicine Research Symposium (October 2012 & 2013)
- University of Rochester School of Medicine Undergraduate Research Day (October 2012 & 2013)

TEACHING EXPERIENCE

BOSTON UNIVERSITY BOSTON, MA

Teaching Internships and Mentorships Fall 2015-Present

- Teaching Assistant for Physiology and Immunology in the Medical School and Dental Medical School
- Personalized tutoring session for 9 to 10 students per semester
- Mentor for Boston public high school students on sciences and public health subjects
UNIVERSITY OF ROCHESTER  ROCHESTER, NY

Teaching Internships Fall 2011-Spring 2014

• Teaching internship in Calculus II for fall 2011

• Teaching Internship in Introductory Physics Mechanics laboratory and Introductory Physics Electromagnetics laboratory from fall 2011 to spring 2012, and fall 2013 to spring 2014.

• Completed Research Seminar in order to receive training on teaching methods, learning styles, leading workshops, etc.

• Responsibilities included leading labs, answering students’ questions, assisting with lab report questions

Study Group Leader/Note Taker Spring 2014

• Hired as Study Group Leader for Introductory Physics Electromagnetics through Center for Excellence in Teaching and Leadership

• Completed seminar on Study Group Leadership, examining various learning styles and teaching methods

• Took notes for students with disabilities who are unable to attend class