

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

SciVerse ScienceDirect

journal homepage: [www.JournalofSurgicalResearch.com](http://www.JournalofSurgicalResearch.com)

## Association for Academic Surgery

# Negative pressure wound therapy in infants and children: a single-institution experience

Rebecca M. Rentea, MD,<sup>a</sup> Kimberly K. Somers, PAC,<sup>b</sup> Laura Cassidy, PhD,<sup>b</sup>  
Jessica Enters, BSN,<sup>b</sup> and Marjorie J. Arca, MD<sup>b,\*</sup>

<sup>a</sup> Department of Surgery, Medical College of Wisconsin, Milwaukee, Wisconsin

<sup>b</sup> Division of Pediatric Surgery, Department of Surgery, Children's Hospital of Wisconsin, Medical College of Wisconsin, Milwaukee, Wisconsin

### ARTICLE INFO

#### Article history:

Received 13 March 2013

Received in revised form  
22 April 2013

Accepted 10 May 2013

Available online 4 June 2013

#### Keywords:

Wound healing

Neonatal

Infants

Abdominal wounds

Negative pressure wound therapy

Surgery

### ABSTRACT

**Background:** Information regarding the use of negative pressure wound therapy (NPWT) in the pediatric population is limited. Because of adverse outcomes in adult patients, the Food and Drug Administration issued a warning in 2011 about the use of NPWT in infants and children. **Methods:** We performed an institutional review board–approved, single-institution, retrospective review of pediatric patients who had undergone NPWT from 2007–2011. We collected the types of wounds for which NPWT was initiated, the NPWT outcomes, and the complications encountered.

**Results:** The data from 290 consecutive patients were reviewed. Their average age was 9.3 y (range 12 d to 18 y), and their average weight was 46.5 kg (range 1.1–177). Of the wounds, 66% were classified as acute, 10% as chronic, and 24% as traumatic. The two most common indications were surgical wound dehiscence ( $n = 47$ ) and skin grafting ( $n = 41$ ). NPWT was used in 15 wounds containing surgical hardware, with 2 devices requiring eventual removal. NPWT was used for a median of 9 d per patient (two dressing changes). Complications occurred in 5 patients (1.7%). Documentation problems were noted in 44 patients. After NPWT, about one-third of the patients ( $n = 95$  patients) were able to undergo delayed primary closure.

**Conclusions:** NPWT is an effective adjunct in wound healing and closure in the pediatric population, with no mortality ascribed to NPWT. Also, the complication rates were low.

© 2013 Elsevier Inc. All rights reserved.

## 1. Introduction

Negative pressure wound therapy (NPWT) is a method of wound care developed to manage difficult wounds [1]. The Food and Drug Administration (FDA) approved NPWT in adults after several clinical trials that demonstrated successful treatment of acute and chronic wounds. NPWT has been

reported in infants and children in several retrospective reviews and descriptive series [2–19]. Despite this, the FDA issued a communication stating that the safety and effectiveness of NPWT in newborns, infants, and children have not been established [20]. In adults, 6 deaths and 77 complications were reported to be related to the use of NPWT. Most current indications and applications of NPWT for pediatric patients have

\* Corresponding author. Division of Pediatric Surgery, Department of Surgery, Children's Hospital of Wisconsin, 999 North 92nd Avenue, Suite 320, Milwaukee, WI 53226. Tel.: +1 414 266 6550; fax: +1 414 266 6579.

E-mail address: [marca@chw.org](mailto:marca@chw.org) (M.J. Arca).

0022-4804/\$ – see front matter © 2013 Elsevier Inc. All rights reserved.

<http://dx.doi.org/10.1016/j.jss.2013.05.056>

been extrapolated from the adult data. In a number of cases, NPWT has been used because no other alternatives exist. The FDA communication on the use of NPWT in the pediatric population prompted us to review our institutional experience to determine the outcomes and complications for NPWT.

## 2. Methods

An institutional review board–approved, retrospective chart review was conducted of 270 neonatal and pediatric patients, who had undergone 290 unique episodes of NPWT dressings from 2007–2011 at the Children’s Hospital of Wisconsin. The Children’s Hospital of Wisconsin is a tertiary children’s hospital with an average annual admission of 23,622 patients (inpatient admission 12,616) during the 5 y studied. The data fields were electronically populated into a Research Electronic Data Capture (REDCap) database [21]. The patient data were de-identified for analysis, complying with the Health Insurance Portability and Accountability Act regulations.

In our institution, we used the vacuum-assisted closure device (VAC; KCI, San Antonio, TX). Negative suction pressure was applied to the wound base through a porous sponge that was sealed to the wound by an adherent drape. In 2009, a group of experts in pediatric wound healing released a set of guidelines regarding the use of NPWT in newborns, infants, and children [22]. In brief, they recommended low pressures (–50 to –75 mm Hg) in newborns and children  $\leq$  2 y of age and pressures of –75 to –125 in patients  $>$ 12 y of age. In the 2–12-y range, the pressure recommendations varied depending on the location. Sternal wounds were recommended to have suction of –50 to –75 mm Hg for all ages. These recommendations were consistent with the use of NPWT at the Children’s Hospital of Wisconsin.

NPWT in neonates and infants was initiated using white reticulated open cell foam at a pressure of –50 to –75 mm Hg. In the beginning of our experience, we used –25 mm Hg. However, this low pressure cannot be achieved with the current setup. If the NPWT was placed on top of hollow viscera, a nonadherent petroleum-coated gauze was placed before applying the sponge and adhesive drape. The output from the NPWT device was closely monitored. Fluid replacements were administered if fluid loss from the wound was significant.

The patient characteristics collected included gender, age, comorbidities, and nutrition received at NPWT therapy. We classified the wounds according to the etiology (i.e., trauma, surgically created, congenital, burns, pressure ulcers, and skin grafts), age (acute versus chronic), and anatomic location. We also noted any unique characteristics of the treated site such as the presence of exposed bone, bowel, tendon, nerve, or vessel; joint involvement; the presence of exposed hardware; coverage of acutely placed skin grafts; and pre-existing wound infection. The details of treatment pertaining to the number of NPWT treatment days, frequency of dressing changes, and treatment outcome were abstracted. Because we were interested in pinpointing safety concerns, we also studied the documentation with each case. The complications associated with NPWT were entered into the electronic database.

A descriptive analysis was conducted using Statistical Analysis Systems, version 9.3 (SAS Institute, Inc, Cary, NC).

The clinical outcomes data were analyzed for the entire patient population and per etiology group. Categorical variables are expressed as frequencies and continuous data as the median and interquartile range.

## 3. Results

### 3.1. Patient characteristics

A total of 290 consecutive patients were treated using NPWT, who met the inclusion criteria. The patient demographic characteristics are listed in Table 1. The patients had an average age of 9.3 y (range 12 d to 18 y) and an average weight of 46.5 kg (range 1.1–177). Of the 290 patients, 174 were boys (60%) and 116 were girls (40.0%); 48 patients were  $<$  1 y, with a median weight of  $<$  3.6 kg (range 1.1–13.6). Comorbid disease was present in 147 patients (50.7%), with the highest percentage in the patients  $<$  1 y old (Fig.).

A total of 216 patients (74.5%) had an enteral diet during NPWT, 42 (14.5%) had a parenteral diet, and 32 (11.0%) had both an enteral and a parenteral diet. The length of NPWT was longest for the patients who received parenteral nutrition or both enteral and parenteral nutrition (Table 2). When present, the nutritional interventions in these patients included maximizing caloric and protein intake and supplementing vitamin A, zinc, and ascorbic acid.

### 3.2. Wound types

Of the 290 wounds, 192 were acute (66.2%), 30 were chronic (10.3%), and 68 were traumatic (23.5%). The wounds treated with NPWT were most commonly located in the lower extremities (42.1%) and the abdomen (24.5%). The wound locations are listed in Table 3.

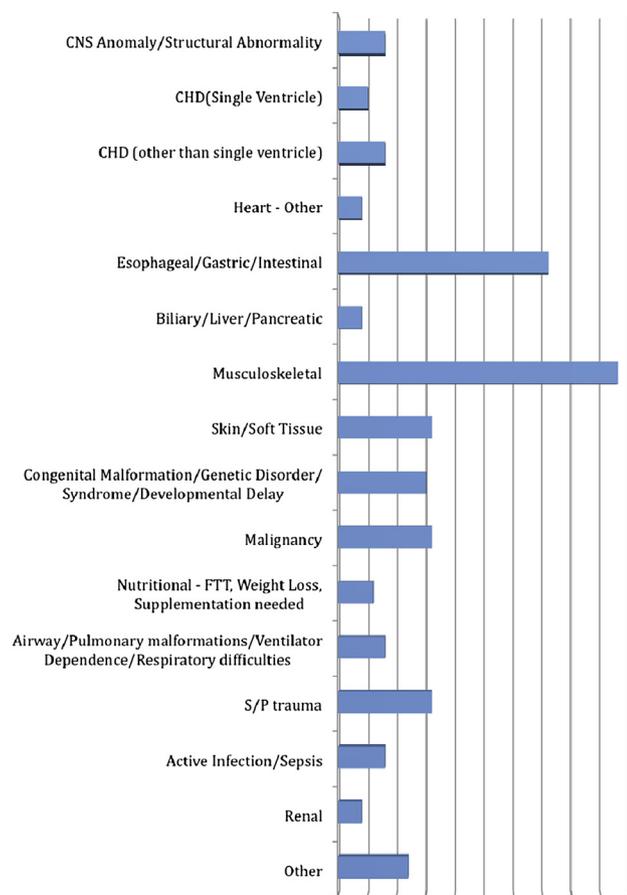
The most common indication for NPWT was as an adjunct for wound dehiscence ( $n = 47$ ) and as a primary dressing for a skin graft ( $n = 41$ ). Other indications for NPWT included planned temporary closure after a surgical procedure ( $n = 15$ ), pressure ulcer dressing ( $n = 9$ ), flap coverage ( $n = 8$ ), and acute burn dressing ( $n = 6$ ). The following structures were exposed in the wound bed at placement of NPWT: bone ( $n = 51$ ), hollow viscera ( $n = 7$ ), tendon ( $n = 5$ ), joint ( $n = 3$ ), and solid organ ( $n = 1$ ). Three patients had NPWT started to help local control of multiple enterocutaneous fistulas.

NPWT was used in infected wounds ( $n = 93$ ) and osteomyelitis ( $n = 16$ ). Surgical hardware was exposed in 12 cases.

**Table 1 – Demographics stratified by age and weight.**

Age	Patients (n)	Weight (kg) Median	Interquartile range
<1 mo	3 (1.0)	3	2.98–3.56
1 mo to 1 y	45 (14.8)	3.7	3.14–7.20
2–11 y	104 (34.2)	29.9	18.7–40.0
12–18 y	138 (45.4)	64.8	55.9–81.8
Total	290 (100)	—	—

Data in parentheses are percentages.



**Fig. – Comorbidities and number of study patients with each comorbidity. CHD = congenital heart disease; CNS = central nervous system; FTT = failure to thrive; S/P = status post. (Color version of figure is available online.)**

These included a vertical expandable prosthetic titanium rib ( $n = 2$ ), spine rods ( $n = 7$ ), pectus excavatum sternal strut or “Nuss bar” ( $n = 2$ ), and upper extremity hardware ( $n = 1$ ).

Eleven patients with malignancy received NPWT as a part of complex staged closure for primary resection wounds ( $n = 2$ ) or for salvage dressing therapy for necrotic, dehisced, or infected wounds ( $n = 11$ ). The two primary resections were for osteosarcoma, in which full resection of the malignant lesions had been performed but coverage required a muscle flap. NPWT was used to cover a part of the muscle flap. One patient with active acute lymphoblastic leukemia had a soft tissue infection for which NPWT was used. The remaining patients

had wound dehiscence or infection of the primary wound or the source of the flap that had occurred days after the resection or remotely after the patient had undergone chemotherapy. All but one of these patients had osteosarcoma.

### 3.3. Details of NPWT dressing changes

Of the 290 patients, 288 had NPWT initiated in the inpatient setting. Of these, 246 patients transitioned to outpatient care, with 139 patients returning to the operating room on an outpatient basis for dressing changes and nine undergoing dressing changes in a clinic setting. No NPWT changes occurred at home. The average duration of NPWT was 19 d (median 9, range 2–318). The NPWT duration at the extreme end of the range was for critically ill neonates and adolescents (cardiac transplantation, complex abdominal wall defects in newborns, intra-abdominal catastrophe with multiple enterocutaneous fistulas). The median interval to a dressing change was 2 d (median 2, range 0–8), with 50% of the dressing changes occurring in the operating suite. All NPWT dressing changes were performed by either a surgeon or an advanced practice provider. The dressing changes occurred an average of two times weekly (median 2.5, range 0–7). Infants underwent dressing changes more frequently at the bedside in the pediatric or neonatal intensive care unit. Older children most often underwent dressing changes in the operating room under general anesthesia or procedural sedation.

### 3.4. Outcomes for NPWT

A total of 269 patients (92.8%) underwent successful NPWT. Delayed primary closure was achieved in 102 patients (35.1%). Most of these patients had had NPWT initiated as a primary dressing after four-compartment fasciotomy had developed in the lower extremity after traumatic injury. Five patients had delayed sternal closure. Two patients had delayed abdominal closure after trauma or large tumor resection. Thirty-six patients had a form of delayed closure using skin grafts ( $n = 21$ ), flaps ( $n = 9$ ), tissue reconstruction ( $n = 4$ ), or formal amputation of an extremity that had been traumatically mangled ( $n = 2$ ). In 51 patients (17.6%), NPWT was discontinued when the wound was too small or shallow to warrant this type of dressing. At that point, nonadherent dressings and skin grafts were placed.

One infant had multiple enterocutaneous fistulas. When NPWT was discontinued, a large stoma bag was used to control the egress of the enteral contents.

Twenty-one patients (7.2%) had NPWT discontinued before the therapeutic endpoint. Three patients had uncontrollable pain. Three patients developed a deeper infection within the wound. Two patients had excoriation of the surrounding tissue. One patient developed an enteroatmospheric fistula; this patient was immunosuppressed after a solid organ transplant. Five patients died during the course of NPWT of causes not related to the NPWT. Five patients showed no progression of their wounds over time. One patient had sustained a gunshot wound to the foot and had had a free flap placed; however, the vessel thrombosed, resulting in graft loss. One patient with pilonidal disease had the treatment discontinued because of an inability to maintain a sealed dressing over a wound that was close to the anal opening.

**Table 2 – Nutritional source.**

Nutritional source	NPWT duration (d)	NPWT changes (n)
Parenteral	42 (3–193)	3 (1–7)
Enteral	7 (2–318)	2 (1–6)
Both	16 (3–242)	2 (1–6)

Data are presented as median (range).  
The patient's nutritional source correlated with the duration of NPWT use and number of NPWT dressing changes.

**Table 3 – Wound types classified by etiology and age group.**

Etiology	Age (n)					Total (n)
	<1 mo	1 mo to 1 y	2–11 y	12–18 y	>18 y	
Surgical (staged)	1 (33.3)	35 (77.8)	52 (50)	86 (62.3)	10 (71.4)	184 (60.5)
Congenital	0 (0.0)	3 (6.7)	1 (1)	1 (0.72)	—	5 (1.6)
Dehisced wound	2 (66.7)	13 (28.9)	13 (12.5)	19 (13.8)	3 (21.4)	50 (16.4)
Partial thickness burn	—	1 (2.2)	5 (4.8)	—	—	6 (2.0)
Ulcer pressure	—	1 (2.2)	3 (2.9)	5 (3.6)	3 (21.4)	12 (3.9)
Flap	—	—	3 (2.9)	5 (3.6)	1 (7.1)	9 (3.0)
Skin graft	—	2 (4.4)	20 (19.2)	19 (13.8)	1 (7.1)	42 (13.8)

### 3.5. Complications

Complications occurred in five patients (1.7%). These included enteroatmospheric fistula formation ( $n = 1$ ), skin breakdown from the NPWT adhesive ( $n = 2$ ), a retained sponge ( $n = 1$ ), and new-onset infection deep in the wound ( $n = 1$ ). No complications were specific to an age-subset of the patients. The retained foreign body was noted approximately 48 days after discharge to a long-term care facility. The patient presented during routine follow-up with wound discharge, leading to discovery of the retained sponge.

### 3.6. Special populations

#### 3.6.1. Neonatal and infant wounds

Table 4 lists the types of wounds for which NPWT was used in neonatal and infant patients. The average length of therapy for patients < 1 y of age was 43.9 d (< 6 mo old, 40.6 d; 6 mo to 1 y, 49.1 d). In the infant population, the singular complication was one patient in whom the dressing was not able to hold suction.

Of the 290 patients, 48 were < 1 y old, including a number of infants who required NPWT dressings for an open abdomen after exploration for an “abdominal catastrophe,” complicated gastroschisis, or ruptured giant omphaloceles. Three of our patients had pre-existing enterocutaneous fistulas or enteroatmospheric fistulas, and the NPWT system was used to attain local control of the enteric contents. These infants all required surgery to repair the fistulas.

Of the 48 neonatal patients, 21 required initial dressing changes in the operating room. As the wounds matured, the dressing changes were done at the bedside. The median

frequency of dressing changes was three times weekly. No changes were performed at home or in the clinic. Successful therapy was demonstrated in 87.5%. We discontinued therapy in one patient because of an inability to maintain suction. Four patients died of their underlying systemic disease during the course of NPWT.

#### 3.6.2. Hidradenitis suppurativa and pilonidal disease

NPWT was used as an adjunct for wounds secondary to hidradenitis suppurativa and pilonidal disease in 30 patients (10.3%). Their average age was 16 y (range 13–18). One-third of the NPWT dressings were initiated in the operating room as a plan for staged closure. Greater than one-third was initiated in the inpatient unit, as therapy for infected or inflamed wound beds. Three patients transitioned from operating room to clinic dressing changes. No dressing changes occurred at home. Two patients had no information available for the dressing change location. The average number of NPWT dressing changes was two (range zero to seven); 86.7% of the patients had successful outcomes with NPWT. Four patients had NPWT discontinued prematurely because of pain, tissue excoriation, infection, and a failure to maintain suction.

#### 3.6.3. Hardware and infected fields

NPWT was used as an adjunct in 12 patients whose wounds dehisced or became infected over surgical hardware or became infected. Wounds with spinal hardware (vertical expandable prosthetic titanium rib,  $n = 2$ ; spinal hardware,  $n = 7$ ) and chest (pectus carinatum bars,  $n = 2$ ) and upper extremity (plates or pins,  $n = 1$ ). Some soft tissue coverage occurred of the hardware in 3 patients but was completely exposed in 9 patients. Ten of the patients also had concomitant infection: four grew methicillin-resistant *Staphylococcus aureus*; three had methicillin-sensitive *S aureus*; and 3 showed nothing on final culture but had purulent material in the wound. Eventually, nine patients were able to undergo delayed primary closure and one required flap coverage. Four patients only had NPWT before definitive closure. Six patients underwent 2.5 NPWT dressing changes weekly on average (range 1–4 changes/wk) before definitive closure. Overall, 83% of patients had their hardware salvaged (10 of the 12 patients).

### 3.7. Documentation

A total of 44 documentation and safety deficiencies (15.2%) were noted. The documentation issues consisted of a lack of

**Table 4 – Wound types in newborns and infants (age < 1 y).**

Wound type	Patients (n)
Open abdomen	15
Soft tissue infection	14
Soft tissue defect	13
Open chest	7
Wound dehiscence	5
Nonhealing wound	3
Pressure ulcer	1
Burns	1
Gastrocutaneous fistula tract	1
Total	48

**Table 5 – Literature review on the use of NPWT in pediatric patients (studies with  $\geq 10$  patients).**

Investigator	Patients (n)	Age (if available)	Wound type (patients [n])
Baharestani [2]	24	14 d–18 y	Soft tissue (7), mediastinal (4), abdominal (7), orthopedic (6)
Butter et al. [3]	16	1 mo–18 y	Soft tissue (10), abdominal (3), mediastinal (3)
Canavese et al. [4]	14	3–9 y	Orthopedic (14)
Caniano et al. [5]	51	Neonates to 20 y	Soft tissue (50), abdominal (1)
Dedmond et al. [6]	15	2–7 y	Soft tissue (15)
Gabriel et al. [7]	58	10 d–16 y	Soft tissue (58)
Halvorson et al. [8]	28	2–17 y	Orthopedic (28)
Hassan et al. [9]	15	Neonates	Abdominal or gastroschisis (15)
Horn et al. [10]	11	7–19 y	Orthopedic
Katz et al. [11]	13		Soft tissue (13)
McCord et al. [12]	68	7 d–18 y	Soft tissue (31), abdominal (28), mediastinal (10)
Mooney et al. [13]	27	3 d–18 y	Soft tissue (27)
Petkar et al. [14]	21		Burn (30)
Stiefel et al. [16]	18		Soft tissue (18)—Integra fixation
Stoffan et al. [17]	18	Neonate	Abdominal (18)
Shilt et al. [15]	16		Soft tissue (16)
Ugaki et al. [18]	20	3 wk–5 y	Mediastinal (20)
Vicchio et al. [19]	12	Neonates and infants	Mediastinal (12)

operative or procedure note ( $n = 20$ ), failure to document the date of NPWT initiation or discontinuation ( $n = 9$ ), inconsistent documentation in the medical record ( $n = 6$ ), and a lack of home follow-up care documentation ( $n = 9$ ). The size and depth of the wounds were also documented inconsistently. The procedure notes for outpatient dressing changes were missing or incomplete in approximately 50% of the review population.

#### 4. Discussion

NPWT is a wound therapy system that promotes healing by secondary or tertiary intention. NPWT prepares the wound bed for closure by reducing edema, promoting granulation tissue formation, increasing perfusion, and removing exudates and infectious material [1]. However, in 2009 and 2011, the FDA issued a warning regarding the use of NPWT in infants and children that might have been based in part [20] on the adverse outcomes associated with NPWT in adults: 6 deaths from bleeding and 77 complications, with the most common a retained sponge in the wound. Our use of NPWT in the infant and pediatric population preceded the FDA communication. The decision to use NPWT was carefully evaluated by the treating team on an individual basis; in each case, the team believed that NPWT was the best option, given the circumstances of the wound and the patient. Other dressing options were less favorable in terms of needing multiple dressing changes (causing pain and anxiety), wound desiccation, slow granulation tissue development, and an inability to protect intact skin. Although the FDA has not endorsed the use of NPWT in pediatric patients, the American Association of Pediatrics “Pediatric Medical Device Safety and Improvement Act” recognizes that sometimes medical and surgical devices are not immediately available to the pediatric population. In their document, the American Association of Pediatrics stated that the off-label use of medical and surgical devices should be “done in good faith, in the best interest of the patient, and without fraudulent intent” [23].

The published data are replete with experience with NPWT in the pediatric population (Table 5). Table 5 is a list of the English language reports on NPWT and “vacuum-assisted closure” use in pediatric patients (aged 0–18 y) with  $> 10$  patients. NPWT has not been associated with any reported fatalities in the published data. Our report represents the largest to date of the use of NPWT in infants and children.

We encountered few complications in our patient population. The most serious complication encountered was the development of an enteroatmospheric fistula in one immunosuppressed patient receiving abdominal NPWT. This complication has been reported in at least six other patients, mostly newborns, who had received abdominal NPWT dressings over intestinal anastomoses [17,24]; however, it is not unique to the pediatric population [20]. Another complication encountered was skin breakdown along the wound edges. The prevention of skin breakdown needs to be individualized to the patient and clinical situation. Measures that can be taken include skin barrier therapy such as 3M Cavilon No Sting Barrier (3M, Minneapolis, MN), Mepilex products (Mölnlycke Health Care US, Norcross, GA), and even the adhesive drape packaged with the NPWT dressing. The complication of a retained sponge is most likely to occur when the wound is large and complex [5]. The risk factors for a retained sponge include wounds requiring several pieces of the sponge, several providers performing sequential dressing changes, and dressing changes performed in different phases of patient care. Documentation of the number of sponges left in the wound would decrease this adverse occurrence.

The results of the present review suggest that NPWT is an effective method for preparing the wound bed for closure. The published data have also suggested that NPWT is able to incorporate different dermal substitutes for reconstruction, including Integra (Integra Life Sciences, Plainsboro, NJ) [16], Alloderm (LifeCell, Bridgewater, NJ) [25], and Surgisys (Cook Surgical, Bloomington, IN) [7]. Even exposed bone, such as that encountered in degloving injuries can be covered with NPWT to encourage growth of granulation tissue in preparation for tissue coverage [26,27].

We obtained an 83% salvage rate for infected wounds with surgical hardware, a finding consistent with previously reported data [10]. The ability to save indwelling surgical hardware is one of the more dramatic advantages of NPWT in this population. Those patients in whom surgical hardware remained intact did not have evidence of long-term local or systemic infection once the wounds were closed.

Our retrospective review of the present varied cohort of patients has characterized the quality and safety issues encountered daily in the use of NPWT. The vast majority of the review sample (288 of the 290 patients) had NPWT applied in the inpatient setting. Nursing education and the development of a standardized order set containing nursing instructions, call parameters, and pressure settings are necessary in caring for these patients. Planning ahead to order a home NPWT system will decrease the hospital length of stay. Communication with the outpatient clinic regarding the patient and details of the wound care is mandatory to deliver optimal care. In the present series, the patients who were discharged with NPWT were all adolescents whose dressings were on soft tissue defects, most commonly in the gluteal cleft (pilonidal disease). These patients did not have any of their dressing changes performed at home. We believed that an advanced practice provider (physician or physician assistant) was needed to examine the wound with each dressing change to ensure that progress was being made. This particular aspect of our patient care might have contributed to our low rate of complications.

We found a significant number of patients lacking sufficient documentation regarding NPWT, especially in the outpatient setting. We have developed a standard documentation set within patients' electronic health records that would capture the following data: the indications for NPWT, start date of NPWT, dates of dressing changes, pressure used on the wound, number of sponges in the wound, stop date for NPWT, and reason for NPWT discontinuation. To decrease the risk of retained sponges, we have designed a sticker to be placed over the dressing, denoting the number of sponges left in the wound.

Our study had limitations, most notably that the study was a single institutional review. Data were not consistently available on wound sizes. Compared with other centers, NPWT systems have been used extensively in our institution, and our results might be reflective of our experience level and high patient volume. The cost benefits associated with using NPWT in these patients go beyond a simple cost analysis. The retrospective nature of the review and overall study design did not allow for cost comparison between NPWT and other approaches of wound management. Several combinations of wound management therapies were used before and after NPWT, which would have confounded any cost comparisons. The cost data accrued after the data were collected could not be included owing to the study design. Finally, facilities charge differently for dressing supplies, making the applicability of our findings regarding cost limited in applicability, because several combinations of wound management therapies were used before and after NPWT.

The FDA has recommended against the use of NPWT in necrotic wounds with eschar, untreated osteomyelitis, non-enteric and unexplored fistulas, malignancy in the wound,

exposed vasculature, exposed nerves, exposed anastomotic site, and exposed organs. Our experience in pediatric patients suggests that NPWT can be used cautiously on unexplored enteric fistulas as a temporizing measure to allow for clinical stabilization before a patient undergoes a definitive surgical procedure. With regard to exposed organs, we had an infant who had liver exposed under NPWT, who had no adverse outcomes; precautionary measures of decreased pressure and a protective nonadherent membrane were used in this case. In patients at high risk of bleeding and hemorrhage, careful consideration should be given before implementing NPWT. Most of our cardiac patients for whom NPWT was used were receiving anticoagulation, but no bleeding complications were encountered. All these patients were in the intensive care unit setting during their NPWT course. Our review findings would concur with the FDA that wounds with necrotic tissue with eschar present, untreated osteomyelitis, or ongoing malignancy in the wound bed should not be considered for NPWT.

Our review is the latest among many reports describing the successful use of NPWT application in infants and children. Despite the warnings from the FDA about the use of this modality of wound care in this population, situations occur in which alternatives simply do not exist or are inferior to NPWT. We believe that the present review, along with the numerous published reports, argue for the safety and efficacy of NPWT in the pediatric population. We have demonstrated that the complication rate with NPWT can be low in infants and children if care and caution are exercised.

#### REFERENCES

- [1] Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. *Ann Plast Surg* 1997;38:563.
- [2] Baharestani M. Use of negative pressure wound therapy in the treatment of neonatal and pediatric wounds: a retrospective examination of clinical outcomes. *Ost Wound Manage* 2007;53:75.
- [3] Butter A, Emran M, Al\_Jazaeri A, Ouiment A. Vacuum-assisted closure for wound management in the pediatric population. *J Pediatr Surg* 2006;41:940.
- [4] Canavese F, Gupta S, Krajchich JI, Emara KM. Vacuum-assisted closure for deep infection after spinal instrumentation for scoliosis. *J Bone Joint Surg Ser B* 2008;90:377.
- [5] Caniano DA, Ruth B, Teich S. Wound management with vacuum-assisted closure: experience in 51 pediatric patients. *J Pediatr Surg* 2005;40:128.
- [6] Dedmond BT, Kortesis B, Punger K, et al. Subatmospheric pressure dressings in the temporary treatment of soft tissue injuries associated with type III open tibial shaft fractures in children. *J Pediatr Orthop* 2006;26:728.
- [7] Gabriel A, Gollin G. Management of complicated gastrochisis with porcine small intestinal submucosa and negative pressure wound therapy. *J Pediatr Surg* 2006;41:1836.
- [8] Halvorson J, Jinnah R, Kulp B, Frino J. Use of vacuum-assisted closure in pediatric open fractures with a focus on rate of infection. *Orthopedics* 2011;34:e256.
- [9] Hassan SF, Pimpalwar A. Primary suture-less closure of gastrochisis using negative pressure dressing (wound vacuum). *Eur J Pediatr Surg* 2011;21:287.
- [10] Horn PL, Beebe AC. Lawn mower injuries in pediatric patients. *J Trauma Nurs* 2009;16:136.

- [11] Katz MS, Finck CM, Schwartz MZ, et al. Vacuum-assisted closure in the treatment of extensive lymphangiomas in children. *J Pediatr Surg* 2012;47:367.
- [12] McCord SS, Naik-Mathuria BJ, Murphy KM, et al. Negative pressure therapy is effective to manage a variety of wounds in infants and children. *Wound Repair Regen* 2007;15:296.
- [13] Mooney JF III, Argenta LC, Marks MW, Morykwas MJ, DeFranzo AJ. Treatment of soft tissue defects in pediatric patients using the V.A.C. (TM) system. *Clin Orthop Relat Res* 2000;376:26.
- [14] Petkar KS, Dhanraj P, Kingsly PM, et al. A prospective randomized controlled trial comparing negative pressure dressing and conventional dressing methods on split-thickness skin grafts in burned patients. *Burns* 2011; 37:925.
- [15] Shilt JS, Yoder JS, Manuck TA, Jacks L, Rushing J, Paterosn SB. Role of vacuum-assisted closure in the treatment of pediatric lawnmower injuries. *J Pediatr Orthop* 2004;24:482.
- [16] Stiefel D, Schiestl CM, Meuli M. The positive effect of negative pressure: vacuum-assisted fixation of Integra artificial skin for reconstructive surgery. *J Pediatr Surg* 2009;44:575.
- [17] Stoffan AP, Ricca R, Lien C, Quigley S, Linden BC. Use of negative pressure wound therapy for abdominal wounds in neonates and infants. *J Pediatr Surg* 2012;47:1555.
- [18] Ugaki S, Kasahara S, Arai S, Takagaki M, Sano S. Combination of continuous irrigation and vacuum-assisted closure is effective for mediastinitis after cardiac surgery in small children. *Interact Cardiovasc Thorac Surg* 2010;11:247.
- [19] Vicchio M, De Feo M, Caianiello G, Cotrufo M. Vacuum for pediatric post-sternotomy mediastinitis: the role of laser Doppler velocimetry in the establishment of adequate subatmospheric pressure intensity. *Ann Thorac Surg* 2008; 86:1399.
- [20] FDA Safety Communication. Update on serious complications associated with negative pressure wound therapy systems, % 3ca href=http://www.fda.gov/MedicalDevices/Safety/AlertsandNotices/ucm244211.htm [accessed 08.04.2013].
- [21] Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research Electronic Data Capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009;42:377.
- [22] Baharestani M, Amjad I, Bookout K, et al. V.A.C.® therapy in the management of paediatric wounds: clinical review and experience. *Int Wound J* 2009;6(Suppl 1):1.
- [23] American Academy of Pediatrics. Uses of drugs not described in the package insert (off-label uses). Committee on Drugs, <https://www.premierinc.com/quality-safety/tools-services/safety/topics/pediatrics/downloads/AAP-Pediatric-Drugs-Devicespdf117:577> [accessed 08.04.2013].
- [24] Kilbride K, Cooney D, Custer M. Vacuum-assisted closure system: a new method of treating patients with giant omphalocele. *J Pediatr Surg* 2006;26:532.
- [25] Lee KN, Seo DM, Hong JP. The effect and safety after extended use of continuous negative pressure of 75 mmHg over mesh and allodermis graft on open sternal wound from oversized heart transplant in a 3-month-old infant. *Int Wound J* 2010;7:379.
- [26] Kelly TF, Banks SB, Miller LA. Straightforward management of a large pediatric scalp degloving injury in a combat zone. *J Oral Maxill Surg* 2010;68:1411.
- [27] Subotic U, Kluwe W, Oesch V. Community-associated methicillin-resistant *Staphylococcus aureus*-infected chronic scalp wound with exposed dura in a 10-year-old boy: vacuum-assisted closure is a feasible option: case report. *Neurosurgery* 2011;68:E1481.