V.A.C.® Therapy in the management of paediatric wounds: clinical review and experience


ABSTRACT

Usage of negative pressure wound therapy (NPWT) in the management of acute and chronic wounds has grown exponentially in the past decade. Hundreds of studies have been published regarding outcomes and methods of therapy used for adult wounds. This treatment is increasingly being used to manage difficult-to-treat paediatric wounds arising from congenital defects, trauma, infection, tumour, burns, pressure ulceration and postsurgical complications in children, although relatively few studies have been aimed at this population. Given the anatomical and physiological differences between adults and children, a multidisciplinary expert advisory panel was convened to determine appropriate use of NPWT with reticulated open cell foam (NPWT/ROCF) as delivered by Vacuum Assisted Closure® (V.A.C.® Therapy, KCI Licensing, Inc., San Antonio, TX) for the treatment of paediatric wounds.

The primary objectives of the expert advisory panel were to exchange state-of-practice information on paediatric wound care, review the published data regarding the use of NPWT/ROCF in paediatric wounds, evaluate the strength of the existing data and establish guidelines on best practices with NPWT/ROCF for the paediatric population. The proposed paediatrics-specific clinical practice guidelines are meant to provide practitioners an evidence base from which decisions could be made regarding the safe and efficacious selection of pressure settings, foam type, dressing change frequency and use of interposing contact layer selections. The guidelines reflect the state of knowledge on effective and appropriate wound care at the time of publication. They are the result of consensus reached by expert advisory panel members based on their individual clinical and published experiences related to the use of NPWT/ROCF in treating paediatric wounds. Best practices are described herein for novice and advanced users of NPWT/ROCF. Recommendations by the expert panel may not be appropriate for use in all circumstances. Decisions to adopt any particular recommendation must be made by the collaborating medical team, including the surgeon and wound care specialist based on available resources, individual patient circumstances and experience with the V.A.C.® Therapy System.

Key words: Negative pressure wound therapy • NPWT • V.A.C. Therapy • Vacuum-assisted closure • Paediatric wound care • Abdominal compartment syndrome • astroschisis
INTRODUCTION

Although advances in medical technology have enhanced patient survival in the paediatric population during the past 20 years, management of acute and chronic paediatric wounds of various aetiologies often remains a healthcare challenge because of a lack of knowledge and research upon which to guide clinical practice in this population (1). Epidemiological studies and empirical evidence suggest that the most commonly encountered wound types among hospitalised neonates and children include epidermal stripping, extravasation injuries, surgical wounds, incontinence-associated dermatitis, chemical and thermal injuries, wounds secondary to congenital abnormalities and pressure ulcers (2,3). Major tissue loss or oedema often precludes immediate closure and when the normally rapid wound healing response of paediatric patients is delayed, it can result in increased mortality and morbidity and compounded anxiety levels for patients, families and clinicians (4). Specific challenges of the paediatric population, including age appropriate communication styles, pain management, fluid volume maintenance, poor nutrition, early mobility, psychological assessment and product safety, contribute to the complexity of these cases.

There are many therapies available to physicians for treating paediatric wounds. One such therapy is Vacuum Assisted Closure® (V.A.C.® Therapy, KCI Licensing Inc., San Antonio, TX), an integrated wound therapy system that applies controlled, negative pressure to acute and chronic wounds via an open cell, reticulated polyurethane foam or polyvinyl alcohol (PVA) foam dressing. The system prepares the wound bed for closure by removing excessive interstitial fluid and infectious materials, decreasing oedema and promoting perfusion and granulation tissue formation (5).

The methods and clinical effectiveness of negative pressure wound therapy with reticulated open cell foam (NPWT/ROCF) are well documented in adult wounds through published randomised controlled clinical trials. Although NPWT/ROCF has not yet been formally evaluated in paediatric wounds in controlled clinical trials, there is a small but growing number of peer-reviewed case series reflecting its safety and efficacy (4,6–17). More recently, Contractor et al. have provided an overview summarising the results of a comprehensive review of the literature on the use of NPWT/ROCF exclusively in paediatric patients (18). To date, adjunctive use of the therapy has been reported in 27 paediatric-focused studies to treat a wide variety of wounds and conditions including abdominal compartment syndrome (ACS), pilonidal disease, sternal and other dehiscences, giant omphalocele, gastroschisis, burns and extremity wounds in paediatric patients of all ages.

Therapy advantages reported in the paediatric NPWT/ROCF literature mirror those reported in adult studies, which include facilitating wound closure (4,9,13,19), decreasing the need for muscle flaps (12), improving wound bed preparation and graft take (14,15), helping in controlling inflammatory response (20), and reducing costs (6). Aspects of the therapy most often noted in the literature as particularly beneficial to the paediatric population include less frequent dressing changes, reduced need for pain medication, accountability for fluid loss across the wound, protection of intact and periwound skin, and a decreased hospital stay, which allows for earlier return of function.

Publication of paediatrics-specific literature has not kept pace with the growing usage of NPWT/ROCF in paediatric wounds; thus, clinicians have been forced to extrapolate application information from adult studies and adapt it. This dilemma is compounded further by the ethical and litigious issues involved in carrying out research on this vulnerable population, leaving clinicians with less of an evidence base from which to render care (2). In an effort to bridge this gap, an expert advisory panel was commenced to facilitate a knowledge transfer of adult and paediatric NPWT/ROCF-treatment experience into comprehensive paediatric NPWT/ROCF-treatment guidelines. The objectives of the expert advisory panel were to (i) exchange state-of-practice information on paediatric wound care, (ii) review the published data regarding the use of NPWT/ROCF in paediatric wounds, (iii) evaluate the strength of the existing data and (iv) establish guidelines on best practices with NPWT/ROCF for paediatric wounds.
Table 1 Paediatric subgroups and ages

<table>
<thead>
<tr>
<th>Paediatric subgroup</th>
<th>Approximate age range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn (neonate)</td>
<td>Birth to 1 month of age</td>
</tr>
<tr>
<td>Infant</td>
<td>Greater than 1 month, but 2 years or less</td>
</tr>
<tr>
<td>Child</td>
<td>Greater than 2 years, but 12 years or less</td>
</tr>
<tr>
<td>Adolescent</td>
<td>Greater than 12 years, but less than 21 years</td>
</tr>
</tbody>
</table>

BACKGROUND

Paediatric age group definitions
Considering the rapid changes in integumentary, physiologic, communicative and psychological development from birth through adolescence, it is important to define the subgroups within the paediatric population. The newborn period includes the day of birth to 30 days postnatal, and infancy is defined as 30 days to 2 years of life. Childhood starts at 2 years and extends until age 12. The adolescent period is from 12 to 21 years. These are the paediatric subgroup age ranges as defined by the US Food and Drug Administration listed in Table 1 (5).

Paediatric population characteristics
Wounds in children typically follow the same wound-healing trajectory as adults, but exhibit faster closure rates (18,21). This expectation of faster closure and innate integumentary resiliency based on age, however, can result in a lack of wound-care knowledge transfer to the paediatric population (3). The paediatric element of wound care requires special expertise, precise management and a clear understanding of the diverse developmental characteristics of each age segment (22).

Wound healing in children can be compromised by protein-calorie malnutrition, hypotension requiring inotropic therapy, impaired perfusion, oedema, infection and physiological instability that prevents safe redistribution of pressure (18,23–25). Distinct intricacies of the neonatal and paediatric populations, such as integumentary immaturity, a high body surface to volume ratio, sensitivity to pain, increased potential for toxic percutaneous absorption and an immature immune system create additional complexity in treating these age groups (2,3).

Possessing minimal to no antigen exposure and an immature skin barrier, neonates are at especially high risk for life-threatening sepsis secondary to bacterial proliferation and overgrowth within the wound bed (3). Decreased epidermal-to-dermal cohesion places neonates and infants at increased risk for epidermal stripping. Children’s relatively large surface-area-to-volume ratio can lead to increased, difficult-to-measure transepidermal water loss with resultant heat loss (2,4,26,27). Pain management is paramount to patient and family compliance and can require sedation or anaesthesia prior to dressing changes.

Parent/patient education
The family/paediatric patient component in the treatment of paediatric patients is unique and more intricate than the family/adult patient component. Paediatric care centres have become more like family care centres, where the approach to wound care involves discussions of the comprehensive treatment plan with the patient and the family. It is important to convey to the patient/family that the interview is a form of consent and provides information on the treatment process and the benefits and risks of treatment.

NPWT/ROCF (V.A.C.® THERAPY)
NPWT/ROCF was developed at Wake Forest University School of Medicine, Winston-Salem, NC, by Louis Argenta, MD, and Michael Morykwas, PhD, in 1995 (23,28,29). Since its introduction over a decade ago, use of the therapy has grown exponentially to treat wounds in a wide variety of patients, including paediatrics (29). Nearly 600 studies, 16 of which are randomised, controlled clinical trials, have been published regarding its efficacy in adult wounds.

The unique mechanisms of action for NPWT/ROCF contribute greatly to successful wound healing. NPWT/ROCF’s ability to provide a moist, closed wound healing environment, draw wound edges together, remove infectious materials, reduce oedema and promote tissue perfusion and granulation tissue formation helps to prepare the wound bed for delayed primary or secondary closure (Figure 1) (23,29–31). These actions specifically target both the macro- and micro-environment of the wound bed. NPWT/ROCF produces...
V.A.C.® Therapy in the management of paediatric wounds

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Figure 1. NPWT/ROCF Mechanism of Action.

macrostrains that draw the tissue against the foam, causing the wound margins to contract and drawing the wound edges together for better approximation (32). Additionally, the negative pressure through the ROCF induces microstrains that cause cellular microdeformations, which promote cellular migration and proliferation, and produce positive growth factors that are important for wound healing (33,34).

Indications
The US Food and Drug Administration has cleared the V.A.C.® Therapy System as a negative pressure device that creates an environment for promoting wound healing by secondary or tertiary intention, preparing the wound bed for closure, reducing oedema, promoting granulation tissue formation and perfusion, and removing exudate and infectious material. It is intended as an adjunctive wound treatment. NPWT/ROCF is indicated for chronic, acute, traumatic, subacute and dehisced wounds, partial-thickness burns, diabetic ulcers, pressure ulcers, flaps and grafts.

It has been used to treat wounds of different aetiologies including gastrochisis, giant omphalocele, pilonidal sinus excision, abdominal, sternal and other dehiscences, pressure ulcers, burns and extremity wounds.

V.A.C.® THERAPY
RECOMMENDATIONS FOR TREATING PAEDIATRIC WOUNDS

Patient size and weight
The size and weight of the patient must be considered when prescribing NPWT/ROCF. Children of all ages, particularly neonates, should be closely monitored for fluid loss and dehydration. Patients with highly exudating wounds or large wounds in relation to the patient size and weight should be in a closely monitored environment such as a neonatal intensive care unit (NICU) or paediatric intensive care unit (PICU), as they have an increased risk of excessive fluid loss and dehydration. Extracellular water content decreases from 45% at term gestational birth to 20–25% consistent with adult levels by 1 year of age (35). Children with moderate dehydration (6–10% loss) have histories of fluid losses plus physical findings (dry mucous membranes, skin tenting, weight loss, sunken eyes and fontanel, and/or slight lethargic mental status changes). Most patients with severe dehydration (11–15% loss) have cardiovascular and neurological instability (skin mottling, tachycardia, hypotension, irritability and/or coma). Patient care is directed to replace fluid volume losses and provide maintenance fluid to sustain cardiovascular and neurological stability (35).

Monitoring should include close tracking and replacement of input and output fluids.
Table 2  Recommended guidelines for NPWT/ROCF foam use for paediatric wounds

<table>
<thead>
<tr>
<th>Wound type/condition</th>
<th>Black (polyurethane) foam</th>
<th>White (polyvinyl alcohol) foam</th>
<th>Silver (polyurethane) foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sternal</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Omphalocele/gastroschisis</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enterocutaneous fistula</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal compartment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spinal</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pilonidal disease</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pressure ulcer</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Extremity wounds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasciotomy wounds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burns</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Postgraft placement</td>
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</tr>
</tbody>
</table>

When monitoring fluid output, consider the volume of fluid in both the tubing and canister. The total tubing volume is 26.7 or 0.09 cc/linear cm from the T.R.A.C.™ Pad to the canister. To prevent excessive fluid loss for high risk patients, it is recommended that the 300 cc canister should be prefilled with sterile water or saline to accommodate for safe fluid output.

Foam use and pressure settings
There are three different foam types to consider for paediatric use. Table 2 lists the recommended foam usage for specific paediatric wounds.

Pressure settings should ensure the best perfusion, oedema resolution, cellular deformation, bioburden reduction and exudate removal to facilitate enhanced tissue growth. Historically, NPWT/ROCF pressure settings for adult patients were based on swine studies by Morykwas et al. (36). However, the recommended pressure settings (Table 3) for paediatric patients are suggestions based on literature and panel expert opinion. Optimal levels are age dependent and depend on wound type and size, wound location, comorbidities, perfusion, sensitivity of the skin area and pain tolerance. Pressure increases should be gradual and only as tolerated, because of patient size, weight and response to therapy.

Complications and precautions
Adverse events from NPWT/ROCF have been reported infrequently in the paediatric population and have not differed from those reported in adult literature. Table 4 lists the major and minor complications reported in the paediatric literature. There are also certain precautions that need to be considered when using NPWT/ROCF for paediatric wounds (Table 5).

Wound types
For ease of guideline usage, wound types have been classified into anterior trunk, posterior trunk and extremity wound groups, and subdivided as follows:

- Anterior trunk wounds
  - Thoracic wounds
  - Abdominal wounds
  - Enterocutaneous fistulae (ECF)

- Posterior trunk wounds
  - Spinal wounds
  - Pilonidal disease wound repair
  - Pressure ulcers

- Extremities
  - Extremity wounds
  - Fasciotomy wounds
  - Burns
  - Postgraft wounds

Table 6 lists references that have focused on NPWT/ROCF use in paediatric wounds.

Anterior trunk wounds
Depth of defect is an important consideration in the management of anterior trunk wounds. For simplicity within these guidelines, wounds in the thoracic area are considered deep when the sternum is not intact. Acquired abdominal wounds (postsurgical dehiscence, open
Table 3 Recommended guidelines of NPWT/ROCF pressure settings for paediatric wounds/conditions

<table>
<thead>
<tr>
<th>Wound type/condition</th>
<th>Newborn/infant (birth to 2 years)</th>
<th>Child (&gt;2 to 12 years)</th>
<th>Adolescent (&gt;12 to 21 years)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sternal</td>
<td>−50 to −75* continuous</td>
<td>−50 to −75* continuous</td>
<td>−50 to −75* continuous</td>
<td>• Baharestani (4)*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Agarwal et al. (26)*</td>
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<td></td>
<td>• Salazar et al. (37)*</td>
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<td></td>
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<td></td>
<td>• Kadohama et al. (38)*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• McCord et al. (39)*</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Bookout et al. (40)*</td>
</tr>
<tr>
<td>Omphalocele/</td>
<td>−50 to −75* continuous</td>
<td>−75 to −125* continuous</td>
<td>−75 continuous</td>
<td>• Gabriel and Gollin (8)*</td>
</tr>
<tr>
<td>gastroscisis</td>
<td></td>
<td></td>
<td></td>
<td>• Kilbride et al. (9)*</td>
</tr>
<tr>
<td>Enterocutaneous fistula</td>
<td>−50 to −75* continuous</td>
<td>−75 to −125* continuous</td>
<td>−75 continuous</td>
<td>• McCord et al. (39)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Caniano et al. (6)*</td>
</tr>
<tr>
<td>Abdominal compartment</td>
<td>−50 to −75* continuous</td>
<td>−50 to −125* continuous</td>
<td>−75 to −125* continuous</td>
<td>• Caniano et al. (6)*</td>
</tr>
<tr>
<td>syndrome</td>
<td></td>
<td></td>
<td></td>
<td>• Bookout et al. (40)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Gabriel et al. (19)*</td>
</tr>
<tr>
<td>Spinal</td>
<td>−50 to −75* continuous</td>
<td>−75 to −100* continuous</td>
<td>−75 to −125* continuous</td>
<td>• Canavese et al. (41)*</td>
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<td></td>
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<td></td>
<td>• Horn et al. (42)*</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Butter et al. (11)*</td>
</tr>
<tr>
<td>Pilonidal disease</td>
<td>−50 to −75* continuous</td>
<td>−50 to −125* continuous</td>
<td>−75 to −125* continuous</td>
<td>• Caniano et al. (6)*</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Butter et al. (11)*</td>
</tr>
<tr>
<td>Pressure ulcer</td>
<td>−50 to −75* continuous</td>
<td>−75 to −125* continuous</td>
<td>−75 to −125* continuous</td>
<td>• McCord et al. (39)*</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Caniano et al. (6)*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Gabriel et al. (19)*</td>
</tr>
<tr>
<td>Extremity wounds</td>
<td>−50 to −75* continuous</td>
<td>−75 to −100* continuous</td>
<td>−75 to −125* continuous</td>
<td>• McCord et al. (39)*</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Mooney et al. (13)*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Baharestani (4)*</td>
</tr>
<tr>
<td>Fasciotomy wounds</td>
<td>−50 to −75* continuous</td>
<td>−75 to −100* continuous</td>
<td>−75 to −125* continuous</td>
<td>• Baharestani (4)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Gabriel et al. (19)*</td>
</tr>
<tr>
<td>Burns</td>
<td>−50 to −75* continuous</td>
<td>−75 to −125* continuous</td>
<td>−75 to −125* continuous</td>
<td>• Schintler et al. (15)*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Trop et al. (43)*</td>
</tr>
<tr>
<td>Postgraft wounds</td>
<td>−50 to −75* continuous</td>
<td>−75 to −100* continuous</td>
<td>−75 to −125* Continuous</td>
<td>• Taub et al. (17)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Gabriel et al. (19)*</td>
</tr>
</tbody>
</table>

Note: Pressure settings based on panel expert opinion and/or literature. Symbols (+ † Ⅽ) identify reference(s) supporting stated pressure level for specified wound type/condition and age range.

Table 4 Complications associated with NPWT/ROCF in paediatric wounds

<table>
<thead>
<tr>
<th>Major complications</th>
<th>References</th>
<th>Minor complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterocutaneous fistula</td>
<td>Baharestani (4)</td>
<td>Dermatitis or skin maceration</td>
</tr>
<tr>
<td>Retained piece of foam in wound</td>
<td>Caniano et al. (6)</td>
<td>Minimal bleeding with dressing removal</td>
</tr>
<tr>
<td>Haemorrhage from graft</td>
<td>Trop et al. (43)</td>
<td>Pain with dressing changes</td>
</tr>
<tr>
<td>Haemorrhage from donor site</td>
<td>Trop et al. (43)</td>
<td>Device malfunction</td>
</tr>
</tbody>
</table>

abdomen compartment syndrome decompression, ECF, and traumatic wounds) are considered deep when they are below the level of the rectus fascia.

Thoracic wounds (poststernotomy/mediastinitis). NPWT/ROCF may be most effective in paediatric thoracic wound care when the goal of therapy is to reestablish sternal stability and permit sternal salvage, promote formation of granulation tissue and wound closure, decrease long-term mortality compared with conventional treatment options or manage
Table 5 Precautions when using NPWT/ROCF for paediatric wounds

<table>
<thead>
<tr>
<th>Precautions</th>
<th>Spinal cord injury</th>
<th>Bradycardia</th>
<th>Periwound tissue protection</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discontinue NPWT/ROCF to help minimise sensory stimulation</td>
<td>Do not place dressing in proximity to the vagus nerve</td>
<td>Protect fragile/friable periwound skin with additional drape, thin hydrocolloid or other transparent film</td>
<td>Repetitively applying and removing drapes may lead to stripping of periwound skin</td>
<td>Closely monitor and maintain temperature</td>
</tr>
</tbody>
</table>

Wound infection. Treatment should be on opt-out basis if deep infection is suspected or confirmed.

In paediatric cardiac surgery, median sternotomy is a routine approach for the correction of congenital anomalies (50–52). Postoperative deep sternal wound infection following median sternotomy is a serious and potentially life-threatening complication associated with significant morbidity and increased healthcare costs. The reported incidence rate is 0.4–5.0% in the paediatric population (24,53). While the reported incidence of deep sternal wound infections is relatively low in both adult (54,55) and paediatric (24,52) populations, mortality rates associated with postoperative mediastinitis using conventional therapy range from 5% to 46% in both populations (24,27,39,53,56,57). Dehisced sternal wounds typically require additional surgeries, including multiple debrideaments and complicated tissue transfer to cover the exposed sternum (39). A growing number of paediatric studies have shown that sternal wound closure can be achieved safely and within a relatively short period of time with NPWT/ROCF, which has been deemed a first-line therapy option for poststernotomy wound treatment at a number of institutions (25,39,48).

A literature search showed nine published paediatrics-specific case series or case studies reporting on adjunctive use of NPWT/ROCF to treat sternal wounds in a total of 28 patients. Additionally, Agarwal et al. reviewed 103 patients with open sternal wounds treated with NPWT/ROCF, 19 of whom were children from ages 3 months to 14 years (26). Patients were treated for an average of 11 days and all wounds subsequently closed – 68% by definitive surgical closure and 32% by secondary intention. In one of the largest paediatric series to date, McCord et al. showed a significant reduction in wound volume of 88 ± 14% in 12 days among 10 patients in the open sternal wound group. All wounds were aggressively debrided before initiation of NPWT/ROCF and healed completely by secondary intention without requiring definitive primary or muscle flap closure (39). The study also reported superior long-term aesthetic results, compared with wet-to-dry dressings or tissue transfer with grafting, and the sternal bone was preserved in all cases.

Fleck et al. also noted preservation of the sternal bone for secondary closure in three neonates with poststernotomy mediastinitis treated with NPWT/ROCF (48). Blood loss did not occur during debridement, NPWT/ROCF system application or secondary closure. None of the three patients required transfusions. Salazard et al. reported reduction of local infection, purulence and C-reactive protein levels within 72 hours of NPWT/ROCF in three children with mediastinitis (37).

There is consensus in the literature and between panel members that a lower, continuous pressure (50–75 mmHg) should be used for sternal wounds of infants and children (25,38,48). Kadohama et al. showed in two infants and one child that 50 mmHg negative pressure with ROCF dressings was safe and effective in managing poststernotomy mediastinitis (38). Fleck et al. showed that at 50 mmHg negative pressure, no haemodynamic changes, such as impaired ventricular compliance and filling, elevated pulmonary venous pressure and reduced cardiac output were experienced (48). The authors did not observe any changes in heart rate, blood pressure or respiration pattern, effects that could be an indication of pain during the therapy (48). Although thorough debridement prior to NPWT/ROCF initiation is recommended, Ramnarine et al. reported dramatic improvement following 24 hours of NPWT/ROCF in a 5-month-old with purulent mediastinitis who was too unstable for surgical debridement (7).

Thoracic wound management recommendations.

The most important aspects of managing
<table>
<thead>
<tr>
<th>Author/title</th>
<th>Patients (n) reported</th>
<th>Age category</th>
<th>Wound aetiologies</th>
<th>Average duration of NPWT/ROCF reported (days)</th>
<th>Type of study performed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arca et al. (16). Use of vacuum-assisted closure system in the management of complex wounds in the neonate</td>
<td>2</td>
<td>Premature infant (2)</td>
<td>Acute soft tissue wound of abdomen, and posterior torso</td>
<td>32</td>
<td>Case description</td>
</tr>
<tr>
<td>Archer et al. (10). Reconstruction of an acquired abdominal wall defect in a neonate using acellular human dermis</td>
<td>1</td>
<td>Neonate (1)</td>
<td>Necrotising soft tissue infection emanating from surgical incision in abdomen</td>
<td>56</td>
<td>Case description</td>
</tr>
<tr>
<td>Baharestani (4). Use of negative pressure wound therapy in the treatment of neonatal and pediatric wounds: a retrospective examination of clinical outcomes</td>
<td>24</td>
<td>8.5 years (range, 14 days–18 years)</td>
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deep mediastinal wound infections are adequate irrigation, thorough debridement, and treatment of the primary infection during the first operation. NPWT/ROCF is initiated after debridement of devitalised tissue and the sternum, when necessary and possible. Following debridement of all devitalised tissue, NPWT/ROCF can be initiated with a GranuFoam™ or GranuFoam Silver® dressing, starting at –50 mmHg negative pressure for neonates, infants and children, and –75 mmHg for adolescents. Continuous mode is mandatory for achieving thoracic cage stability, and it minimises movement.

The primary goal for the first stage of NPWT/ROCF is to close the sternum, usually at the first dressing change. While the sternum is open, the treating surgeon should perform the dressing change. Once the sternum is closed, it is recommended that an interposed layer be used between tissue and the foam dressing to help protect exposed underlying structures. Careful positioning of the non-adherent interposed layers and foam dressing is warranted to protect the heart and prevent adhesions and injury during therapy. Structures may shift with application of NPWT/ROCF, potentially causing contact between the heart and the sternal edges. Caution should be taken to gently place and not tightly pack the wound with ROCF and to ensure that the ROCF is not oversized as is commonly done in the adult population. Over packing might induce cardiac compression with the same symptoms as cardiac tamponade.

The clinician may choose not to close the wound completely and instead place approximating stitches and then apply NPWT/ROCF between the spaces in order to progressively decrease the size of the wound. Once the sternum is closed, NPWT/ROCF can be continued until the wound is ready for definitive closure.

Congenital abdominal defects. Congenital abdominal wall defects, such as gastrochisis and omphaloceles, occur in the USA at a rate of one case per 2000 births, translating to 2360 cases diagnosed per year (6). These relatively common congenital abdominal wall defects range from small defects to very large defects, wherein the entire abdominal viscera are exposed. Surgery for abdominal wall defects aims to return the abdominal organs back into the abdominal cavity, and to repair the defect, if possible (10).

Management of giant defects is challenging and often associated with complications (10). Gastrochisis is a congenital defect of the abdominal wall, which allows bowel to herniate outside the peritoneal cavity. The bowel in this setting can become very oedematous, matted and difficult to reduce. An omphalocele is a congenital herniation of the abdominal contents through the umbilical cord and is covered by a sac that protects the underlying viscera. In addition to bowel, the omphalocele sac often contains solid organs such as the liver. These organs developed in the sac, outside the abdominal cavity and as a consequence, the abdominal space is usually inadequate to allow immediate reduction of the viscera. If the omphalocele sac ruptures, the abdominal viscera are then exposed with no option for immediate repair. It may be challenging to close the facial defect in severe gastrochisis even after reduction of the protruding abdominal contents. With large omphaloceles, time may be needed for the final reduction into the abdominal cavity (10).

In neonates with gastrochisis, fascial closure is usually achieved primarily or after silo reduction (58,59). If fascial closure of a gastrochisis defect cannot be achieved after a silo has been in place for 7–10 days and visceral contents are not reduced to the level of the abdominal wall, several strategies are available (8,60–63). A prosthetic graft may be used to cover exposed bowel, but is unlikely to result in definitive closure unless skin coverage can be obtained. Alternatively, a biological dressing can be used to cover the abdominal wall defect to achieve a temporary or permanent closure. Recently, Gabriel et al. reported a novel approach of using porcine small-intestinal submucosa (SIS) augmented by NPWT/ROCF at –75 mmHg to treat complicated gastrochisis in three neonates who had previously failed in achieving fascial and skin closure. In each case, visceral coverage was achieved (8).

Management of an omphalocele differs. These patients have a large degree of viscera abdominal disproportion because of the underdevelopment of the abdominal cavity. Neither silo nor primary closure has been successful in treating all patients with a giant omphalocele. Kilbride et al. reported a temporising measure of managing complicated giant omphaloceles.
using NPWT/ROCF (9). This therapy allows for cleansing the wound, control of drainage, decreasing bacterial bioburden and gradual reduction of the viscera into the abdominal cavity while the abdominal cavity of the neonate grows. Patients in the study were treated at a negative pressure of –75 mmHg with the GranuFoam™ Dressing and a non adherent interposed layer.

In the rare situation in which fascial closure of gastrochisis or ruptured omphalocele cannot be achieved, the combination of SIS and NPWT/ROCF has been shown to provide a safe and effective means of visceral coverage and, in some cases, definitive abdominal wall closure (8).

Congenital abdominal wound management recommendations. Management of these wounds consists of covering the viscera with an interposed layer and positioning a GranuFoam™ Dressing over the layer. Recommended negative pressure is –75 mmHg. For gastrochisis patients, once the fascial closure is achieved by primary or a secondary synthetic agent, the therapy at –75 mmHg can continue until the wound has contracted and the granulation tissue has covered the entire wound cavity. At this time, the therapy can be switched to a routine moist dressing as the final dressing modality. In cases of complicated omphalocele, NPWT/ROCF can be continued until the cavity has enlarged enough to accommodate the protruding viscera, or complete coverage of the exposed viscera is established.

Abdominal compartment syndrome. Clinicians are seeing a rise in paediatric multi-trauma (64). An increasing number of children are being diagnosed with ACS requiring acute decompression (65,66). However, the improvement of anaesthesia, a better understanding of aseptic technique, blood banking and antibiotics have led to safer abdominal surgeries and improved survival rates in tertiary care settings. To facilitate re-access to the abdominal cavity, an open abdomen is maintained with a temporary abdominal closure (TAC) device. Patients with open abdomens require multiple trips to the operating room using staged abdominal explorations. An ideal TAC protects abdominal contents, prevents evisceration, preserves fascia, minimises desiccation and damage to the viscera, quantifies third space fluid losses, allows for selective tamponade, minimises the loss of domain, lowers bacterial counts, infection and inflammation, and keeps the abdomen dry and intact (67).

For definitive closure of some open abdominal defects, a temporary or permanent graft or patch may be used. The ideal material used to repair an abdominal fascial defect should be strong, biocompatible, and support growth of new tissue. Non-absorbable patches composed of material such as knitted polypropylene, polytetrafluoroethylene and polyester are strong, but have a tendency to form intra-abdominal adhesions (68). They offer little support for granulation tissue if skin coverage cannot be achieved, and must be removed in cases of infection (10). Absorbable meshes, such as Polyglactin 910 and polyglycolic acid mesh, are more biocompatible than non-absorbable materials, but increase the possible recurrence of hernia after the disappearance of the mesh (69).

Authors are now advocating an additional option of NPWT/ROCF for abdominal coverage after damage control laparotomy or ACS (70). Six small case series or studies report on the use of NPWT/ROCF to treat acute open abdominal wounds in a total of 17 paediatric patients. Successful closure was reported for all 17 patients (19). Gabriel reported a mean NPWT/ROCF-treatment time of 5 days to achieve 100% primary abdominal closure for six paediatric ACS patients (19). McCord et al. concluded that NPWT/ROCF helps manage fluid losses, reduce abdominal wall oedema, and in some cases, improve ventilation (39). Recently published articles also show effective management of congenital and acquired abdominal wall defects in the neonate using bioengineered tissues in conjunction with NPWT/ROCF (10,16).

ACS wound management recommendations. NPWT/ROCF can be used to close abdominal wounds with intact fascia, approximate the wound edges in preparation for delayed primary closure or to progress the wound until it can be managed with a less advanced, absorptive dressing, such as a hydrofiber. In cases of an open abdominal wound with exposed viscera, the V.A.C.® Abdominal Dressing System (ADS) should be used. The layers of non-adherent-covered foam are applied first under the fascia and over the omentum or exposed internal organs. The encapsulated foam within the non-adherent layer helps minimise dressing shift within the abdomen. Caution should
be used when placing the ADS on compromised bowel, even in the presence of a variant. A GranuFoam™ Dressing is placed over the non-adherent layer and sealed with a drape. The dressing changes should occur under sterile conditions and be performed by the treating surgeon, with no exceptions.

Following immediate decompression of the ACS, the use of NPWT/ROCF at lower negative pressures of –50 to –75 mmHg is recommended. Once the fascia is closed, the pressure can be incrementally increased to –125 mmHg or as tolerated. Early use of this therapy in adults has been found to enhance the chances of an early and less complex primary closure because of rapid reduction in oedema and protection of the intra-abdominal gutters from loss of domain. It is important to closely monitor the paediatric patient’s fluid status prior to fascial closure because of the high volume of third space fluid evacuation that occurs with the use of this therapy. In cases of intact fascia, GranuFoam™ is placed directly on the abdominal wound and a non-adherent interposed layer is recommended to decrease adherence and chance of bleeding. However, a non-adherent layer may be used to restrict ingrowth of granulation tissue into the foam if needed.

Enterocutaneous fistulae. ECF arise as complications in 0.8–2% of abdominal operations. Global mortality rates in adults have been reported to be between 5% and 37%, and exceeding 60% in cases of high-output fistulae and when sepsis and malnutrition are involved (71). The term fistula defines an abnormal communication between two epithelial surfaces. Intestinal fistulae can be internal and external (enterocutaneous). In addition to their anatomic classification, fistulae are defined according to their fluid output. In adults, a daily discharge of less than 200 ml is defined as low-output, 200–500 ml is moderate and greater than 500 ml is high-output (72–75). In chronic fistulae, the enterocutaneous fistula is segregated from the surrounding or adjacent abdominal wound and NPWT/ROCF is applied to the wound. The effluent from the fistula is diverted into another containment system. NPWT/ROCF is used in these chronic fistulae cases to allow conditioning of the wound and patient, providing for sufficient healing to occur to the point where a subsequent repair can be performed (80). Studies have noted its efficacy in controlling fistula effluent and promoting healing of excoriated skin (78,80).

Interestingly, Gunn et al. found in a study of 15 adult patients with ECF not amenable to surgical treatment that the presence or absence of visible intestinal mucosa is the single-most important clinical factor when considering the use of NPWT/ROCF to manage a patient with ECF. In 11 adult patients who had no visible intestinal mucosa on examination, the closure rate was 100%, and in 4 patients who did have grossly visible intestinal mucosa, no closure occurred (72).

Only two paediatric case series report on the use of NPWT/ROCF to treat wounds with a fistula in a total of four patients. Butter et al. reported use of NPWT/ROCF to treat one boy with a chronic perineal fistula post-abdominoperineal resection. NPWT/ROCF was initiated in the operating room (OR) following reexcision of the fistula (11). Cessation of the therapy occurred after 12 days when the fistula was only 1 cm deep. However, the area
never completely healed, necessitating reexcision and primary closure. Almost 1 year later, the perineum remained healed with no demonstrable fistula (80). McCord et al. reported on the use of NPWT/ROCF to treat three wounds with fistulae in patients under the age of 5. One wound with a high-output enterocutaneous fistula did not close, and the other two wounds with non-described fistulae closed without incident (39).

Several authors have described successful adjunctive use of NPWT/ROCF in managing high-output fistulae in adults (81–83) but use in this manner remains experimental. Fischer reported a higher mortality rate from subsequent fistula development following NPWT/ROCF treatment of gastrointestinal fistulae (84). The therapy is contraindicated for unexplored or non-enteric fistulae (72,73,78). Larger prospective studies regarding NPWT/ROCF use in treating abdominal wounds with fistulae in paediatric patients are needed.

Enterocutaneous fistula management recommendations. The panel recommends negative pressure of –50 to –75 mmHg for management of all explored ECF. It is the clinician’s discretion to use this therapy for high-output fistulae. Additional recommendations regarding NPWT/ROCF and fistula management only in adults are published in the V.A.C. Therapy Clinical Guidelines; all manufacturer guidelines should be followed.

Posterior trunk wounds

Posterior trunk wounds include spinal wounds, pressure ulcers and complicated pilonidal cyst wounds.

Spinal wounds. Advances in instrumentation and anaesthesia have made it possible to perform spinal deformity-correction surgery in children with severe spinal curves, many of whom also have neuromuscular diseases. Despite the use of prophylactic antibiotics, advances in surgical techniques and postoperative care, postoperative wound infection after spinal surgery is a serious problem that continues to exist. Unfortunately, the rate of infection is considerably higher in children with neuromuscular scoliosis such as cerebral palsy and myelomeningocele than in those with idiopathic scoliosis (85). This greater incidence may be as a result of greater resistance to antibiotic therapy or because of undetected bladder infections or incontinence that can contaminate the lower lumbar wound (86–88). The rate of overall spinal wound infection in the literature ranges from 0.4% to 20%, increasing with the complexity of the procedure, the most complex being fusion with instrumentation (86,89–99.) The majority of infections occur after posterior instrumentation (87,100,101).

Surgical wound infections compromise patient outcomes and result in significant morbidity. Costs are considerable in terms of prolonged hospital stay, pain, time away from school or work, repeated surgical procedures and risks for associated medical complications (102). Hardware removal, in the worst cases, can lead to a loss of correction, collapse and/or pseudoarthrosis (103).

Various methods have been described for managing infected spinal wounds. Some authors advocate a one-stage technique of opening the wound, radical debridement, irrigation, primary closure and antibiotic treatment (104,105). Successful use of antibiotic impregnated polymethyl methacrylate beads (101) or irrigation–suction systems (87,91,100) has also been reported. Recently, authors have shown in paediatric and adult patients that instrumentation salvage is possible with surgical debridement and wound temporisation with NPWT/ROCF until delayed primary closure is obtained (41,105–107). NPWT/ROCF has been advocated to reduce the dead space and help wound conditioning of deep subfascial infection after dorsal spine surgery (105). Authors of a paediatric case series suggest that the closed NPWT/ROCF system may keep the back area clean without leakage around the wound, thereby minimising incidence of infection (42). The study concludes that between surgical interventions and after the final debridement, NPWT/ROCF, combined with antibiotic therapy, is a better alternative than conventional gauze therapy. NPWT/ROCF acts as a continuous dressing, keeps the environment clean, wicks away debris and promotes granulation tissue formation (42).

NPWT/ROCF management of deep wound infection following instrumented spinal fusion in paediatric scoliosis has been described in three small retrospective case series (41,42,49). In a prospective pilot study of six paediatric neuromuscular scoliosis patients, van Rhee et al. reported that with adjunctive NPWT,
wound closure averaged 3 months, infection parameters were normalised within 6 weeks and removal of instrumentation was not necessary in any patient (49). Horn et al. reported similar results in a retrospective chart review of 11 paediatric patients who developed an infection postspinal fusion and were treated with NPWT/ROCF (42). All 11 patients had comorbid conditions including myelomeningocele, cerebral palsy and scoliosis after paraplegia. In 10 of the 11 cases, NPWT/ROCF was used until the wound healed to a superficial level. Some of the patients required minimal or total instrumentation removal because of breakage, looseness or because it was no longer necessary. However, all patients who developed an infection within the first year of their fusion had total instrumentation retention.

Canavese et al. concluded in a retrospective review of 14 patients with early deep spinal infection that adjunctive use of NPWT/ROCF is a reliable and simple temporising measure that allows for retention of the instrumentation, maintenance of spinal correction and enhanced success with fusion (41). Wound closure was achieved in all cases, but the authors noted an increased number of repeat procedures and longer healing time required for children, versus adults with spinal wound infection. This is likely attributable to the high rate of neuromuscular disorders among the children. The study also showed a reduction in C-reactive protein and white blood cell count following the application of NPWT/ROCF in patients with infected spinal wounds.

**Spinal wound management recommendations.** Irrigation and debridement remain as primary importance. On the basis of both paediatric and adult literature, the panel recommends management of these wounds with V.A.C.® WhiteFoam and GranuFoam™, or GranuFoam Silver®. WhiteFoam can be used in the deep abscesses of the wound and directly over bone and exposed hardware. GranuFoam™ can be placed over the WhiteFoam if needed, or over tissue (42). An interposed layer is recommended with the regular GranuFoam™ to prevent rapid up-growth of granulation tissue into the foam. All exposed vital structures, including nerves, must be completely covered and protected prior to placement of the NPWT/ROCF dressing. Coverage with a muscle flap or other thick layer of natural tissue provides the most effective protection. If not available many clinicians have used non-adherent fine-meshed layer or bioengineered tissue. The higher density WhiteFoam requires a minimum pressure setting of –125 mmHg. With GranuFoam™ or GranuFoam Silver®, negative pressure should be started at –50 to –75 mmHg for all paediatric patients with deep or superficial infection. If needed, the pressure can be gradually adjusted to a maximum of –125 mmHg, based on age, size, weight and response to therapy and clinician expertise.

Myelomeningocele patients who are insensitive with no pain can have their dressings changed in their room with or without anti-anxiety medication as needed. It is recommended that patients who experience pain receive dressing changes in the PICU under conscious sedation to decrease pain and psychological trauma (42).

**Pilonidal disease.** A pilonidal cyst, a cyst near or over the coccyx, affects approximately 26 per 100,000 people. In adults, pilonidal disease is far more prevalent in males than in females (108,109). In children, however, the ratio is the opposite – occurring in four females for each male affected. It is usually seen in adolescence with a peak incidence between ages 16 and 20 years. Pilonidal disease is a result of hair and cellular debris finding a portal of entry into the skin and hair follicles (108,109). The ingrown hair causes an inflammatory reaction and oedema. The oedema causes occlusion of the skin opening increasing the hair follicle size. This results in an eventual spread of purulent material into the subcutaneous tissue causing a foreign body reaction (110). Definitive treatment requires wide excision of all involved tissue followed by secondary intention healing or reconstructive surgery. An aggressive approach is warranted for recurrent pilonidal sinus disease, which results in a persistent, midline, non-healing wound. Methods to repair the soft tissue defect have been reported but regardless of the procedure used, a more definitive treatment is often required because of a high recurrence rate of around 50% (110).

McGuinness et al. reported the first adult case of a complex pilonidal sinus that was managed with excision and NPWT/ROCF (110). The authors reported that the therapy shortened the length of hospital stay, the need for further surgery and provided a cosmetically acceptable result (110). Additional reports
have emerged highlighting the successful use of NPWT/ROCF in the management of this disease (111,112).

To date, three publications have reported on NPWT/ROCF management of the defect in postsurgical treatment of both acute and recurrent pilonidal disease in children. In the largest series of 21 patients, Caniano et al. reported healing in all six patients with primary disease at an average of 37 days (30 days in lean patients and 45 days in obese patients). In patients with recurrent disease, 12 healed in an average of 48 days (38 days in lean patients and 62 days in obese patients) and 3 developed recurrent sinuses. By the third postoperative day, 87% of these patients had returned to school and were managed on a thrice weekly dressing change schedule at home (6). Butter et al. reported slightly longer healing times and a higher recurrence rate (100%) in patients with recurrent pilonidal disease (11). An additional pilot series reported on five NPWT/ROCF-treated patients with complex pilonidal disease, four of whom were under age 21. NPWT/ROCF was used for an average of 6 weeks and all patients were managed at home (113).

**Pilonidal disease wound management recommendations.** As previously emphasised, the key to successful wound management is surgical débridement of all devitalised or infected tissue. NPWT/ROCF with GranuFoam Silver® or GranuFoam Silver® may then be initiated at a negative pressure of −125 mmHg in continuous mode for adolescents and −50 to −75 mmHg in continuous mode for children 12 years old and younger. If the wound is closed with a skin graft, the management should be just like the management of any skin substitute or skin graft placement, which is to maintain NPWT/ROCF at a negative pressure of −75 mmHg in continuous mode over the graft for 3–5 days. The continuous therapy is used to provide a constant bolster. When the therapy is discontinued, a conventional dressing is initiated for a limited time.

**Pressure ulcers.** Pressure ulcers are a serious health issue, leading to clinical, financial and emotional challenges. One of the earliest studies addressing pressure ulcer development in children was reported by Okamoto et al. (114). The authors studied 227 patients with myelomeningocele who developed pressure ulcers over a 20-year time frame. A prospective, matched case study in a 14-bed PICU also showed a 26% pressure ulcer incidence rate (115). Waterlow et al. conducted a multicentre study of 300 children and identified that plaster casts as well as friction from the pull of the traction are two additional major causative factors of pressure ulcers in children (116). During a 4-year period, another study confirmed that paediatric patients with spina bifida and spinal cord injuries were at a high risk for development of pressure ulcers (117).

Pressure ulcer prevalence rates as high as 27% have been reported among patients in PICU and 23% in NICU with most ulcers occurring within 2 days of admission (117–119). Among non-critical hospitalised paediatric patients, prevalence rates of 0.47–13% and incidence rates of 0.29–6% have been reported (117–121). Several studies have showed the effectiveness of NPWT/ROCF for pressure ulcer treatment in adults (122–130). In addition, three case series reports on NPWT/ROCF treatment of paediatric pressure ulcers have been published, showing safe and effective use in this population (6,19,39). Caniano et al. reported on nine patients with myelomeningocele-related sacral and extremity ulcers treated with NPWT/ROCF before definitive skin grafting and/or flap closure. Following débridement, NPWT/ROCF was initiated for an average of 8 days with successful skin grafting and flap closure in eight of the nine children. Skin graft failure in one child was managed with flap closure and an additional application of NPWT/ROCF (6). McCord et al. reported that the mean duration of NPWT/ROCF for 13 pressure ulcer patients was 40 days with a 68 ± 23% average wound volume reduction. The authors noted that an advantage of NPWT/ROCF in children is that the system provides a secure, occlusive dressing that is not easily dislodged with movement, or cannot be easily pulled off (39). Gabriel et al. reported complete closure in two of five paediatric pressure ulcer patients. Closure was not attempted on the other three wounds because of poor nutritional and overall health status of the patients (19).

**Pressure ulcer management recommendations.** Management of pressure ulcers is complex in both adult and paediatric populations, because of the chronic nature of the wounds combined with patient comorbidities. The
generally accepted staging system for pressure ulcers was updated by the National Pressure Ulcer Advisory Panel (NPUAP) in 2007 (131). NPWT/ROCF is recommended for treatment of full-thickness Stage III and IV pressure ulcers only. NPWT/ROCF can be used either as a definitive treatment or to optimise the wound bed prior to surgical closure. Gupta et al. developed an algorithm to assist clinicians in making decisions about appropriate use of NPWT/ROCF in pressure ulcer management with subsequent consensus guidelines being published later that are applicable to paediatric pressure ulcer care (132,133).

Stage III and IV pressure ulcers may be managed with NPWT/ROCF after appropriate debridement and in cases of underlying treated osteomyelitis. The patient should be started first on systemic antibiotics, and then NPWT/ROCF can be initiated after the wound is adequately debrided of necrotic tissue, pressure is offloaded, the host is maximised and the patient’s nutritional indices are addressed. GranuFoam™ or GranuFoam Silver® dressing is placed directly onto the wound base and NPWT/ROCF pressure is set to –50 to –75 mmHg of pressure at a continuous setting for younger children or –125 mmHg in adolescents.

When using NPWT/ROCF for paediatric pressure ulcers, there is a risk of producing another pressure ulcer caused by pressure from the tubing system. Care must be taken to prevent further trauma and/or pressure when placing NPWT/ROCF tubing, particularly over bony prominences. Another complication can be the lack of a good seal at the ulcer site, which may be resolved by using swabs, drapes or adhesive paste to coagulate areas to be sealed. Additional detailed information regarding the complete management of these complex wounds can be obtained from published pressure ulcer algorithms for adults (132,133).

Extremities wounds. Soft tissue defects in the paediatric population can lead to multiple surgeries, which have significant aesthetic and functional consequences. Severe extremity injuries are frequently associated with significant complications, including infection, delayed union or nonunion, compartment syndrome and long-term function deficits (134). Early bony stabilisation and soft tissue treatment are crucial in establishing limb salvage and limiting complications (12).

NPWT/ROCF’s combined effects of oedema reduction with improved granulation tissue generation, increased vascularity and wound contraction have resulted in the ‘downstaging’ of the reconstructive efforts so that wounds previously requiring free tissue transfer may now be covered by a local flap, skin substitute and/or skin graft (135–137). The aggressive oedema reduction from this therapy appears to result in better tissue mobility and tension-free closure. Downstaged procedures have multiple benefits for the paediatric population, including decreased donor site morbidity and anaesthesia time, a reduction in later revisions because of bulky tissue transfer coverage, as well as potentially faster restoration of function (13).

Temporary treatment of traumatic soft tissue extremity wounds is the widest reported indication for NPWT/ROCF use in paediatric wounds. Eight studies have reported on the use of the therapy in a total of 102 paediatric patients with extremity soft tissue deficit wounds. Dedmond et al. showed that temporary NPWT/ROCF treatment of paediatric type III open tibial shaft fractures in 15 patients reduced the need for major soft tissue coverage procedures by 50% compared with what would have been predicted based on injury type. The need for follow-up procedures, hospital stay and recovery time were also reduced (12). A subsequent study by Dedmond et al. reported in a series of adult and paediatric patients that infection and non-union rates of NPWT/ROCF-treated grade/type III open tibial shaft fractures were similar to those of historical controls (136).

Shilt et al. showed a trend towards a decrease in revision amputations and improvement in function after NPWT/ROCF treatment in a 16-patient case series. The authors concluded that NPWT/ROCF was a safe and effective method of treating soft tissue injuries resulting
from lawnmower accidents in children (14). In a series of nine paediatric patients who sustained significant soft tissue loss in the extremities from blunt trauma, gunshot injury and intravenous extravasation, wound healing with NPWT/ROCF occurred without the need for skin grafting at an average of 10 days and with acceptable limb function (6).

**Extremity wound management recommendations.** Paediatric extremity wounds are largely similar to adult extremity wounds in terms of indications and complications, and are generally treated in the same manner. Following appropriate operative debridement, GranuFoam™ or GranuFoam Silver® dressing can be placed directly over fracture sites with or without exposed bone and/or hardware. The panel recommends if there is exposed hardware or bone, the wound will benefit from the GranuFoam™ Dressing with a non-adherent interposed dressing. If tendons, ligaments and nerves are exposed, a non adherent layer is recommended to avoid direct contact with the foam dressings. Negative pressure should be initiated at –50 to –75 mmHg and increased to a maximum of –125 mmHg depending on the age and size of the child. In the presence of a skin substitute or skin graft, the pressure should be maintained at a continuous setting at –50 to –75 mmHg for infants, –75 to –100 mmHg for children and –100 to –125 mmHg for adolescents.

**Fasciotomy wounds.** Compartment syndrome (CS) is a limb- and life-threatening condition observed when the pressure within a closed anatomic space exceeds the perfusion pressure of the tissue within that space. In most cases, paediatric patients develop CS in the setting of a fracture. Although long bone fractures are a common cause of CS, vascular injury is also a known antecedent to CS (138).

Pain out of proportion with the injury is the most important early symptom. Severe pain is experienced with passive stretching of the muscles in the involved compartment or on palpation of the involved muscles. The diagnosis can be confirmed by measuring the pressure in the compartment. In adults, when the compartment pressure is greater than 45 mmHg or when the pressure is within 30 mmHg of the diastolic blood pressure, then the diagnosis is made. An urgent fasciotomy is indicated to maintain normal limb function. Because of the difficulty with cooperation in physical examination of children with pain, early recognition of CS in children can be more difficult. Unfortunately, the inability to make a prompt and accurate diagnosis can lead to tissue necrosis, permanent functional impairment, and if severe, renal failure and death.

Studies have evaluated the efficacy of NPWT/ROCF for treatment of fasciotomy wounds for traumatic CS with positive outcomes both in the adult and paediatric populations (19,25,139). In a retrospective review of adults, Yang et al. found an average time to closure of 6.7 days for NPWT/ROCF-treated fasciotomy wounds following CS of the leg, versus 16.1 days (P < .05) to closure for similar wounds in the non NPWT group (139). Both Baharestani and Gabriel et al. reported on very small subsets of paediatric patients with CS as part of larger populated case series. Full closure was reported for all paediatric fasciotomy wounds with a mean time to closure of 5 days (range, 5–10 days) for three of them (19,25).

**Fasciotomy wound management recommendations.** NPWT/ROCF can be initiated intraoperatively as a wound dressing, following a two-incision fasciotomy to release all four compartments. Tarkin et al. recommend applying gentle tension to the wound margins to prevent skin retraction in fasciotomy wounds amenable to delayed primary closure (140). In these cases, a GranuFoam™ or WhiteFoam® Dressing is cut and placed within the wound cavity. Crossed rubber bands, or other skin stretching material, are then stapled to the skin edge over the foam. The sealing drape is then applied over the bands and dressing. Following complete oedema reduction, delayed primary closure may be achieved.

Fasciotomy sites that will require coverage with a split-thickness skin graft can be prepared using NPWT/ROCF (see PostGraft placement section of these guidelines). The subatmospheric pressure assists in coating the muscular tissues with a thin layer of vascular granulation tissue to enhance graft take (141).

**Partial-thickness burns.** Over the last 50 years, the evolution of burn treatment has led to a major decrease in mortality. Current survival rates have improved to such an extent that the survival rate in children with burns involving 100% total body surface area (TBSA) is 50% (142). Major advances have been made in early resuscitation, respiratory care, treatment
of inhalation injury, control of infection, modulation of the hypermetabolic response and nutritional support. The greatest impact on survival, however, has been the change in the approach to burn wound treatment. Prior to 1970, burn wounds were allowed to separate by means of human and bacterial collagenases. Today, early tangential or fascial excision and grafting by various techniques makes it possible to quickly remove all dead tissues and close the wound. By changing the natural course of the burn injury, the incidence of invasive wound infection and sepsis is minimised in paediatric burn patients (20).

Several case series have described the use of NPWT/ROCF in adult burn patients with improvement in skin graft take and donor site healing without complications (15,143–146). Unfortunately, little has been published regarding NPWT/ROCF-treatment of paediatric burn wounds. In 2005, Schintler et al. presented the first case report of NPWT/ROCF use in securing skin grafts in a paediatric patient with a 40% body surface area full-thickness burn. NPWT/ROCF did not interfere with mechanical ventilation of the 6-year-old child, who was extubated successfully without discontinuation of NPWT/ROCF. The authors reported an approximate 100% graft take rate and no sign of systemic or local infection. They also reported simplified patient care and easy and measurable management of tissue fluid loss using NPWT/ROCF (15).

Recently, a report described complications of NPWT/ROCF in 17-year-old (40% TBSA) and 15-year-old (10% TBSA) burn patients (43). Extensive bleeding occurred within the grafted site in the 17 year old and the donor site in the 15 year old, requiring transfusions. The authors, who are experienced users of NPWT/ROCF in children, theorised that the 17 year old’s bleeding was a result of the widely meshed and expanded grafts, and the 15 year old’s bleeding was a result of haemostasis not being achieved prior to beginning treatment with the NPWT/ROCF. NPWT/ROCF was discontinued in both cases after unsuccessful attempts to achieve haemostasis, and the patients ultimately healed. These two cases highlight the potential for complications in compromised, large TBSA burn patients, and the importance of achieving haemostasis prior to and during NPWT/ROCF. Complication rates with NPWT/ROCF reported in the literature are low; this is the first report where a massive haemorrhage from the grafted area and donor site, respectively, has occurred in young patients with burns.

**Burn wound management recommendations.** Successful use of NPWT/ROCF has occurred over grafts in cases of fascial-level excision in children (15). The therapy can be especially useful on uneven mobile surfaces and to secure dermal substitutes. According to Schintler et al., the therapy is well tolerated by burned children, and is generally painless (15). The application technique and recommended pressures listed in the PostGraft placement. Recommendations section should be followed for post-graft application of NPWT/ROCF in children. On the basis of known risks of uncontrolled bleeding following large tangential excision (147), NPWT/ROCF is not recommended over major burn areas in these instances.

**Postgraft placement.** Perioperative management of grafts in active young patients is crucial to graft survival. The graft requires a well-vascularised wound bed, stabilisation with staples, sutures or fibrin glue and prevention of postoperative shearing. The use of NPWT/ROCF as a dynamic bolster to better secure a meshed skin graft has been reported in the literature (15,148,149). The dressing conforms to the wound surface with application of negative pressure and promotes skin graft adherence while removing exudate and oedema from surrounding tissues. Adjunctive use of NPWT/ROCF can be especially efficacious in cases of irregularly contoured wounds or wounds with high levels of exudate. Importantly, in treating children, the conformity of the foam dressing acts as a firm stabiliser that prevents graft shearing and removal. Immobilisation of skin grafts on uneven or mobile surfaces such as nuchal area, axilla, web spaces and perineal area has been reported with NPWT/ROCF use in adult patients (150).

Scherer et al. reported that NPWT/ROCF is an excellent alternative for securing skin grafts to the wound bed and achieving better graft outcomes in adults (151). Moisidis et al. also showed that use of NPWT/ROCF on split-thickness skin grafts significantly improved the quality of the skin graft’s appearance postoperatively in adults (152). Besides the case study
described by Schintler et al., there are currently no paediatric case series focused specifically on postgraft application of NPWT/ROCF. However, general references are made to its postgraft usage in children in larger paediatric studies (6,19).

Postgraft placement recommendations. The GranuFoam™ or GranuFoam Silver® dressing can be used with skin grafts and skin substitutes in paediatric patients. A non-adherent surface must be placed as an interface between the skin graft and foam dressing to prevent peeling the graft off when removing the foam. On day five, the wound should be inspected for adequate graft take. Once adequate graft take is achieved, NPWT/ROCF should be discontinued and the patient switched to a moist wound management alternative for 1–2 weeks.

CONCLUSION
Paediatric surgery for congenital and non-congenital conditions having the potential to create large complex wounds is increasing in frequency. Achieving wound closure in these cases can be difficult because many of these wounds require bioengineered tissues and multiple surgeries to approximate the gross deficits. To provide more timely closure, decreased morbidity and mortality, and improved quality of life, physicians/surgeons or wound care specialists are becoming more innovative with early intervention and treatment. Bioengineered tissues are more plentiful but are not always readily incorporated. NPWT/ROCF can increase the rate of incorporation of many bioengineered tissues and facilitate the approximation of the gross deficits while maintaining a moist, closed wound environment that promotes wound healing, protects otherwise exposed organs and reduces insensible fluid and temperature loss.

Aggressive intervention to prevent wound-related complications can be lifesaving in this population, with long-term implications in quality of life and functional capabilities. It was the consensus of the panel that NPWT/ROCF has emerged as an optimal adjunctive therapy in situations where no prior options have been available. NPWT/ROCF has been used effectively and with minimal side effects in a variety of wound types from neonates to age 21 with positive outcomes.

NPWT/ROCF does not replace standard medical care for this severely at risk population. Continuing to monitor vital signs, weight, fluid volume status, nutritional status, volume of wound exudate while paying particular attention to cosmetic and functional outcomes based upon age-specific requirements should remain standard practice to ensure safe and effective outcomes.

Relatively few randomised controlled trials (RCTs) have been completed to evaluate the clinical effectiveness and safety of many medical devices in the paediatric population as compared with the adult population. However, US governmental regulatory bodies are more strongly encouraging the completion of clinical trials to ensure the safe and effective use of medical therapies in the paediatric age group. We recommend the continued emphasis upon establishing the clinical efficacy and safety development of this innovative surgical adjunct. As the science behind NPWT/ROCF becomes more understood, better and innovative protocols will be developed to improve patient satisfaction and outcomes.

DISCLAIMER
This is a practical guide for the use of Vacuum-Assisted Closure for the treatment of wounds in paediatric patients. Negative pressure wound therapy using reticulated open cell foam (NPWT/ROCF) is delivered to the wound by way of the Vacuum Assisted Closure® Therapy System (KCI Licensing, Inc., San Antonio, TX) in all instances and within supporting evidence included in the article. All Negative Pressure Wound Therapy (NPWT) systems do not perform in the same manner, and recommendations or outcomes using other systems may not be similar.

The information in this guide was formulated by an expert panel with representation from the fields of cardiothoracic surgery, plastic and reconstructive surgery, vascular surgery, general surgery, paediatric surgery, neonatology and advanced practice nursing with wound care certification. Additional input was received from specialists who were unable to attend the consensus group meeting. These recommendations are not intended as a guarantee of results, outcomes or performance of the V.A.C.® Therapy System. They are recommendations to help clinicians establish paediatrics-specific treatment protocols for the use of the system in acute, extended or home care. As with any application, follow all appropriate instructions and reference guides for product use and operation. Please note that use of V.A.C.® Therapy treatment does not preclude the use of other surgical techniques to manage wounds. Always consult the relevant section of this
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