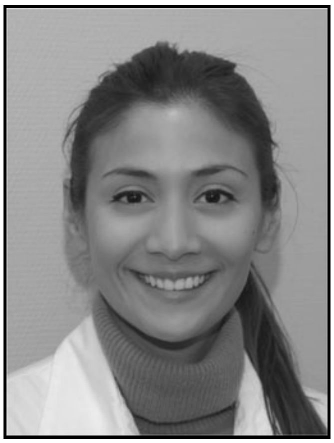
WHS Wound Healing Society

CRITICAL REVIEW

Negative Pressure Wound Therapy in Pediatric Burn Patients: A Systematic Review

Nadine Elisabeth Pedrazzi,[1,*] Surennaidoo Naiken,[1] and Giorgio La Scala[2]

[1]Department of Surgery, University of Geneva Hospitals, Geneva, Switzerland.
[2]Pediatric Plastic Surgery, Department of Pediatrics, University of Geneva Children's Hospitals, Geneva, Switzerland.



Nadine Elisabeth Pedrazzi, MMed

Submitted for publication March 4, 2020.
Accepted in revised form March 29, 2020.

*Correspondence: Department of Surgery, University of Geneva Hospitals, Rue Gabrielle-Perret-Gentil 4, Geneva 1205, Switzerland (e-mail: nadine.pedrazzi@hotmail.com).

Significance: Negative pressure wound therapy (NPWT) requires the placement of a dressing over a wound, covered with an adhesive film, and applying to these dressing a negative pressure in a controlled fashion. This therapy is a powerful complement to surgical care of wounds. Data are however poor on its use in pediatric burns.
Recent Advances: This systematic review, including a total of 466 patients, shows that NPWT as the initial treatment for burned children and after skin grafting has been shown to produce promising results. In the majority of studies, skin graft take rate is close to 100%. This therapy is particularly beneficial in the pediatric population because of less frequent dressing changes and early mobilization. NPWT devices accurately quantify burns water losses and allow tailoring liquid resuscitation.
Critical Issues: NPWT is not in the subject of controlled clinical trials in pediatric; most publications are case reports or retrospective reviews. The sporadic complications include bleeding, local infections, and mechanical device issues.
Future Directions: NPWT has been used in 2-month up to 18-year-old children with deep second- to third-degree burn of multiple etiologies, from a few days up to several months, on small to 40% total body surface area (%), and in difficult areas. Data gathered provide empirical guidelines on NPWT use in pediatric burns using continuous mode with a pressure of –50 to –75 mmHg for children younger than 2 years, and –75 to –125 mmHg in children over 2 years of age. Prospective randomized studies are needed to provide validated rules.

Keywords: negative pressure wound therapy, infant, child, adolescent, burns

SCOPE AND SIGNIFICANCE

Advances in burn care have improved children survival, however pediatric wound care represents a significant issue for care givers because of insufficient data in this vulnerable population.[1] There are many treatment options for pediatric wounds, among which is negative pressure wound therapy (NPWT), a technique that has continuously extended its clinical use. This comprehensive analysis aims to provide empirical guidelines for NPWT use in pediatric burns.

TRANSLATIONAL RELEVANCE

NPWT efficacy and safety are well known in adult patients. NPWT is not in the subject of controlled clinical trials in pediatrics; most publications are case reports or retrospective reviews. As there is no evidence-based use of this device in pediatrics, NPWT use relies on the clinical experience of

DOI: 10.1089/wound.2019.1089

the individual health provider. Nevertheless, the number of reports on NPWT is growing, describing new indications of this therapy in children, also for burns.[1,2]

CLINICAL RELEVANCE

Clear indications and standards for NPWT use for pediatric burns are essential because of the physiological differences between children and adults. For pediatric patients, multiple factors have to be considered such as age-appropriate negative pressure, treatment duration, frequency of dressing changes, and wound location.[2]

This article in an extensive review gives an outline of available studies on NPWT use for pediatric burn patients, with the aim to evaluate evidence supporting its use.

BACKGROUND/OVERVIEW

Burn care continues to improve with recent developments focusing on early balanced resuscitation, treatment of inhalation injury, nutritional support, and obviously wound care. NPWT is an adjunct to wound treatment, complementary to surgery.[1]

NPWT consists in placing a foam into the wound bed, covering the site with an adhesive film, and applying negative pressure in a controlled fashion through a tube connected to a suction pump. Once the wound is clean and well vascularized, NPWT can expedite healing of difficult wounds, reducing healing time.[3]

This therapy targets both the local micro- and macroenvironment of the wound bed. The macrostrain approaches the wound edges. The microstrain induces cell migration and proliferation, stimulates the production of growth factors, and promotes granulation tissue formation, which represent a milestone in the burn wound healing. NPWT creates a closed and moist wound healing environment and significantly reduces wound infection by removing contaminants. A major risk of burns is dehydration. Concerning fluid loss, NPWT improves vascular perfusion, removes excess fluid, and allows measuring fluid losses.[1,2] At the time of skin grafting, NPWT helps maintaining the graft on the wound in high-mobility areas and promotes skin graft adherence.[1]

However, some safety and effectiveness concerns have been raised. Adverse effects such as pain, skin necrosis, hemorrhage or hematoma, infection, delayed wound healing, and psychological difficulties in accepting NPWT have been subject of publications in adults.[2] Side effects from NPWT have been rarely reported in pediatric patients.[1]

Management of pediatric burns represent a significant issue for care givers because of insufficient data in this vulnerable population. Because of a higher surface/body ratio, children are predisposed to easier dehydration, heat loss with poorly tolerated hypothermia. Their fragile and immature skin make liable to sepsis because of rapid increase of bacteria in the wound. The complexity of pediatric cases includes noncompliance and high mobility. The child psychology and sensitivity to pain are crucial for wound management and often needs conscious sedation or general anesthesia for dressing changes.[1,2] NPWT efficacy and safety are well known in adult patients, in children, it has been employed in the treatment of wounds of multiple etiologies, including gastroschisis, omphaloceles, pilonidal sinuses, wound dehiscences, and pressure ulcers.[1]

Little has been published concerning NPWT use specifically for burned children and there is currently no consensus on its indication of this treatment in pediatric burns. The purpose of this study is to review the literature on NPWT use for burns in children to obtain data on its safety and identify age-specific NPWT treatment modalities.

DISCUSSION

Methods

We comprehensively searched PubMed, Cochrane, Web of Knowledge, Google Scholar and ResearchGate databases with the following keywords: (“negative pressure wound therapy” OR “negative pressure” OR “NPWT” OR “vacuum assisted closure” OR “VAC”) AND (“pediatric” OR “children”) AND “burn.” An initial search was performed in each database and articles meeting the search criteria were downloaded. Collected articles were read in abstract form to screen for inclusion and exclusion criteria (Table 1). Frostbite injury reports identified by these search criteria were also included in our analysis. Some of the excluded studies not meeting the inclusion criteria were referenced in the discussion if they introduced interesting concepts, but were not included in the summary table. We reviewed citations from the first group of articles selected and referenced articles containing search terms were also included if meeting inclusion criteria.

A literature summary table was drafted, including studies about NPWT in pediatric wounds with at least one case of burns. Studies about NPWT in burned patients, including adults and

Table 1. *Inclusion and Exclusion Criteria*

Inclusion	*Exclusion*
1. Articles in English, Italian, Spanish, or French	1. Articles in other languages
2. Human studies	2. Articles without abstracts
3. Retrospective single-center study	3. Experimental animal or bioengineering studies
4. Case reports	4. Studies on NPWT in pediatric wounds not involving cases of burn
5. Studies on NPWT in pediatric wounds involving at least one case of burn	5. Studies on NPWT in burn patients not involving pediatric cases
6. Studies about NPWT in burn patients involving at least one pediatric case	

NPWT, negative pressure wound therapy.

children but not allowing extraction of pediatric data, were referenced but not included in the summary table. Data items extracted from the clinical studies are summarized in Table 2.

After the publications' screening process was completed, we identified and included in this systematic review fourteen articles discussing NPWT use in pediatric burn patients: two reviews of the literature,[1,2] five retrospective single-center reviews,[4–9] and six case reports.[10–15] Excluding the reviews,[1,2] twelve articles were included in the summary table (Tables 3 and 4).

Table 2. *Data Extraction from Clinical Studies*

Data point
Author
Journal
Year
Study
Study type
Study period
Data source
Number of cases
Demographics
Age
Gender
Type of injury
Burn
Etiology
Percentage of TBSA
Degree
Anatomical
NPWT
Time between admission and NPWT
Type of NPWT dressing used
Negative pressure and mode
Duration
Number of dressing changes
Other treatments
Local treatment
Antibiotic use
Results
Number of operating rooms
Days of hospitalization
Graft survival
Other results
Complications

TBSA, total body surface area (%).

Statistical methods of the selected articles were not analyzed. Our literature review confirms that articles describing NPWT use for burns in pediatrics are sparse. Most studies are either retrospective, reporting a single-center experience or small case series. As the articles presented data in very different ways and focused on different aspects of NPWT, a quantitative metanalysis is not possible. This study is the first descriptive metanalysis of studies published to date on NPWT use in the burned child.

The Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) flow diagram summarizes the study selection processes (Fig. 1). This review is compliant with the PRISMA protocol guidelines. This protocol is registered with the Center for Reviews and Dissemination, University of York (CRD42018089874).

Population

In the twelve articles selected, 466 patients were treated by NPWT, of which 121 children were treated for burns.

The geographical origin of publications on NPWT for pediatric burns varies, with the majority of publications from the United States ($n=8$), but also from Austria ($n=3$), Turkey ($n=1$), Romania ($n=1$), and China ($n=1$). The dates of publications range from 2005 to 2017.

In the summarized studies, ten are pediatric-specific articles[5–12,14,15] and two articles include adults and children.[4,13] Sahin reports on 4 patients, including a 15-year-old boy; data concerning the pediatric case was easily extracted.[13] Hoeller studied patients from 3 months to 24 years of age. We contacted one of the authors who provided the data concerning the only nonpediatric case, a 24-year-old woman.[4] After this case selection, our report strictly focuses on pediatric cases. Patients' age ranges between 2 months and 18 years. In almost all the publications there was a majority of male patients. There was no specification about gender in one article.[10]

Etiology and wound characteristics

Eight articles focused specifically on burns,[4–6,11–15] whereas four others included other types of pediatric

Table 3. *Detailed Report*

				Demographics			Burn			
Author	*Study type*	*Study period data, source*	*No. of cases*	*Age*	*Gender*	*Type of injury*	*Etiology*	*TBSA (%)*	*Degree*	*Anatomical*
Hoeller *et al.*[4]	Retrospective single-center study	December 2003 to April 2012, Medical University of Graz, Austria	53 Pt, 52 of which pediatric (60 wounds)	8 ± 6 y	60% males 40% females	Thermal or any kind of burn like	Fire (n=20), hot fluid (n=25), chemical burns (n=2), hot airstream (n=1), revision of burn scar/contractures (n=12)	4.5% (3.0–12.0%), dPTB and FTB: 4.0% (2.0–6.0%). TBSA treated 3.5%.	PTB and FTB	Head/face and neck; upper limbs and trunk; genital/gluteal region; and thighs, lower legs, and feet
Kasukurthi and Borschel[10]	Case reports	Division of Plastic and Reconstructive Surgery, Washington University School of Medicine, USA	7	14 m–12 y	NR	Burns (n=5), epidermolysis bullosa (n=1), go-kart degloving injury (n=1)	Severe contact burn from flat iron, wood stove, boiling oil, or other	<1–11%	NR	Hand(s), unilateral or bilateral
Koehler *et al.*[5]	Retrospective single-center study	January 2009 to January 2011, Kapi'olani Medical Center for Women and Children, Department of Plastic Surgery, Honolulu, USA	22	3.4 ± 2.5 y (8 m to 10 y)	13 males (59%), 9 females (41%)	Burns	73% (n=16) scald, 23% (n=5) flame, 5% (n=1) chemical	3–18%, PTB 9.1% ± 4.7%, FTB 7.0% ± 4.0%.	72.7% (n=16) PTB, 27.2% (n=6) FTB	NR
Poulakidas *et al.*[6]	Retrospective single-center study	March 1999 to March 2014, Sumner L. Koch Burn Center, Hospital of Cook Country, Chicago, USA	3	23 m (16 m, 22 m, 31 m)	2 males 1 female	Frostbite	30–60 min exposure at temperatures from −12.6° to −18.1°C	NR	NR	Hand(s), unilateral or bilateral
Psoinos *et al.*[11]	Case report	University of Massachusetts Emergency Department, USA	1	8 m	Female	Burns	Scald burns with 76°C water during bath	6% (225 cm^2)	PTB and FTB	Lower back and bilateral buttocks, well demarcated. Spared gluteal cleft and anus.
Ren *et al.*[7]	Retrospective single-center study	Between 2004 and 2014, Shriners Hospital for Children, Boston, USA	29	9.34 ± 1.95 y (2 m to 18 y)	12 females 17 males	Burns (n=22) and nonburn injuries (abrasion and Stevens–Johnson syndrome) (n=7)	Hot fluids (n=2), hot object (n=4), electricity (n=7), flame (n=3), ignition of clothing (n=6)	27.62% ± 9.83% (range 1–95%)	20.27% ± 7.58% FTB	NR
Rentea *et al.*[8]	Retrospective single-center study	2007–2011, Children's Hospital of Wisconsin, USA	290 Pt who had undergone 270 episodes of NPWT dressing	9.3 y (range 12 d to 18 y)	174 (60%) males, 116 (40%) females	192 acute, 30 chronic, 68 traumatic wounds. After surgery (n=184), dehiscence (n=50), skin graft (n=42), pressure ulcer (n=12), flap coverage (n=9), PTB (n=6), congenital (n=5).	Burns	NR	PTB	42.1% lower extremities, 24.5% abdomen
Schintler *et al.*[12]	Case report	Dates NR, Children's Burns Unit, Graz, Austria	1	6 y	Male	Burns	Flame burns	40%: 7% R arm, 30% thorax, 3% neck	FTB	R arm, trunk, and neck.
Sahin *et al.*[13]	Case report	2007–2009, Gulhane Military Medical Academy Burn Center, Ankara, Turkey	4 Pt, one of which pediatric	15 y	Male	Electrical burn	High-voltage electrical injury	60%	FTB	L lower extremity, with exposure of the tibia and circumferential burn of the calf
Tevanov *et al.*[14]	Case report	November 2011, Emergency Hospital for Children, Bucharest, Romania	1	17 y	Male	Burn	High-voltage electrical burns	60%	FTB	Both arms, forearms, ant thorax, distal extremity of the R leg, and external and internal malleoli
Trop *et al.*[15]	Case report	Dates NR, Children's Burns Unit, Graz, Austria	2	a) 17 y b) 15 y	Males	Burns	a) Scald b) Flame	a) 40% b) 30%	a) SB and mainly dPTB b) dPTB and FTB	a) Trunk, both arms and legs, head and neck b) Ant and post trunk, bilateral forearms, hands, thighs, and distal lower legs and feet
Yuan *et al.*[9]	Retrospective single-center study	January 2010 to December 2012, Children's Hospital of Chongqing Medical University, Department of Burns and Plastic Surgery, China	53 Pt 20 controls	Cases: 5.5 ± 3.2 y, Controls: 6.2 ± 2.8 y	Cases: 35 males 18 females Controls: 11 males 9 females	Contusions and tears by traffic accidents (n=46 cases, n=18 controls), scalds (n=5 cases, n=2 controls), soft tissues infection (n=2 cases)	Scalds/burns			Limbs (n=48 cases, n=17 controls), trunk (n=5 cases, n=3 controls)

d, days; FTB, full-thickness burn; m, months; NR, not reported; PTB, partial-thickness burn; y, years.

Table 4. *Detailed Report*

		NPWT				Others treatments		Results				
Ref	Time between admission and treatment	Type of dressing	Negative pressure (mmHg) Mode	NPWT Duration	No. of dressing changes	Local	Antibiotics use	No. of OR	Days of hospitalization	Graft survival	Others results	Complications
4	8±5 d	Perforated silicone-coated sheets or perforated polyethylene sheet between graft and polyurethane foam.	70–125 depending on Pt age Continuous	5–6 d	NR	Wounds were cleaned, debrided, and covered with silver dressing. Burn excision or epifascial excision followed by immediate skin grafting. STSG (10 cases meshed, 50 nonmeshed) secured by NPWT.	NR	NR	NR	Take rate 96% (70–100%)	No difference on the take rate between meshes 1:2 or 1:4 or between meshed and nonmeshed STSG. No significant correlation between take rate and: TBSA treated with NPWT, time of admission to surgery, duration of the NPWT, etiology, involved body region. Correlation between grafted TBSA and take rate: the smaller the grafted TBSA, the better the take rate.	2 Extended bleedings; 1 large graft loss; 6 small hematomas in wound bed; 7 necrosis of graft's edges; 1 minor dehiscence; 1 minor dislocation of the graft; 1 mild local infection, 1 NPWT system contamination with stools.
10	Case 1: 3 w postinjury	Triangular pieces of GranuFoam®, in each web space to keep the fingers in abduction. A larger piece of foam covered the graft on the volar aspect of the hand. Adhesive drape applied to the level of the wrist.	75 Continuous	7 d for five Pt, 6 d for one Pt, 3 d for one Pt	NR	In one case, NPWT in preparation for free latissimus dorsi flap coverage of wound with skin graft.	Antibiotic ointment	NR	NR	Take rate between 90% and 100%	Conscious sedation used for final removal of the NPWT mitten. NPWT reduces pain and discomfort and increases safety by reducing the need for conscious sedation and its associated risks. Appropriate Pt can be discharged home with ambulatory NPWT, usually with equivalent results.	None
5	Hospital d 1 or d 2.	Black sponge directly on the burn ($n=8$), Mepitel® and Acticoat® ($n=10$), Mepitel or Acticoat ($n=5$) interface.	120–125 continuous ($n=19$), 120 intermittent ($n=1$), 70–75 continuous ($n=2$)	6.7±3.0 d. NWPT initiated on hospital d 1 or 2 and completed either the day before or the day of discharge.	Changed every 2–4 d. 3.5±1.1 d. PTB: 3.5±1.2; FTB: 3.3±1.0.	Debridement and NPWT placement in OR. One third was subsequently grafted and they had an NPWT placed over the newly grafted area for additional time.	One Pt received prophylactic antibiotics at debridement. 15 Pt treated with Silvadene or antibiotic ointment before NPWT.	NR	9.7±4.9 d, PTB: 9.1±4.9 d, FTB 11.3±4.7 d	NR	Burn degree was not significantly associated with Pt age, injury location, or TBSA. Boys had significantly more PTB than FTB. Narcotic use, duration of NPWT, and length of stay were not significantly different between PTB or FTB. Scald injuries were less likely to require skin grafting.	3 Pts had wound infections successfully treated with antibiotics, not requiring NPWT removal.
6	24 h	Silver-contact layer Acticoat	NR	5–6 d	NR	Debridement before NPWT. Silver sulfadiazine cream for 2–3 w.	NR	NR	9 d	NA	None requires amputation. Reepithelialization within 2 w postdischarge.	None
11	7 d	Single-layer Acticoat interface.	80 Continuous	5 d	None	Initially treated conservatively, then tangential excision, debridement, and STSG to buttocks with NPWT to the burn sites and the graft.	None	2 times	13 d	100% take	Successful use of NPWT in a difficult location (perianal area and buttocks), despite very young age.	None
7	NR	NR	50–125 Continuous pressure adapted according to Pt age	NR	Changed every 5–7 d, in the OR	Surgical excision, then NPWT. When wounds were clean and granulating, covered with STSG.	NR	Between 2 and 10 times, according to etiology	Between 5.5 and 67 d, related to etiology	% NR, all Pt granulated their wounds, and were successfully grafted	NPWT use is more related to burn depth rather than the burn size: NPWT is needed more frequently for higher area of FTB. Wound etiology does not influence choice of NPWT.	None
8	288 initiated in the hospital admission	Nonadherent petroleum-coated gauze was placed under (white reticulated open cell foam) and adhesive drape.	50–75 for newborns and children ≤2 y; 75–125 for ≥12 y of age; 50–75 for 2–12 y depending on the location: sternal	19 d (range 2–318). For Pt <1 y of age: 43.9 d	Usual dressing change interval: 2 d (range 0–8). Dressing changes occurred 2 times w (range 0–7).	NR	NR	NR	NR	NR	269 Pts (93%) had a successful NPWT. 102 Pts (35%) achieved delayed primary closure. 51 Pts (18%) NPWT discontinued when wound was too small or shallow. 21 Pts (7%) NPWT discontinued before therapeutic endpoint.	Skin breakdown from adhesive ($n=2$), retained sponge ($n=1$), deep wound infection ($n=1$)

(*continued*)

Table 4. (*Continued*)

		NPWT				Others treatments		Results				
Ref	*Time between admission and treatment*	*Type of dressing*	*Negative pressure (mmHg) Mode*	*NPWT Duration*	*No. of dressing changes*	*Local*	*Antibiotics use*	*No. of OR*	*Days of hospitalization*	*Graft survival*	*Others results*	*Complications*
12	38 h after injury	STSG with Mepitel interface with sponge.	125 Continuous	5 d	NR	Silver sulfadiazine dressing. Escharotomies. Acticoat. STSG 1:2 meshed. NPWT over all burned areas.	Intravenous antibiotic therapy	NR	NR	Almost 100%	Excellent recovery with early wound excision and NPWT. NPWT considered as promising for the treatment of extensive burns following debridement in children. NPWT did not interfere with mechanical ventilation. Management of tissue fluid loss was easier and measurable. Pt did not present symptoms of SIRS, possibly because of the removal of interstitial fluid.	2 leaks in the dressing, successfully sealed. *K. pneumoniae* in the interstitial fluid removed, without systemic consequences. Delayed donor sites healing *Staphylococcus aurueus* infection.
13	NR	NR	NR	30 d	Twice a w	NPWT after trepanation of the outer table of the tibia, to stimulate granulation. STSG after 30 d.	None	NR	NR	Complete take	Wound closure in 50 d. None of the Pts required other surgeries. No loss of function. Immobilization only for 5 d after STSG, then all Pts continued their physical therapy exercises throughout their treatment. In appropriate cases, a Pt may be followed as outpatients and admitted only for the skin graft.	One graft take failure due to infection, regrafted 10 d later and resulted in complete take.
14	NR	Silver and/or silicone dressing as interface between foam and wound bed. Hydrocolloid dressing to protect the skin between the defects.	Continuous pressure, then intermittent: 115 for 2 min, followed by 50 for 4 min	6 w	Twice a week, 11 dressing changes	After 6 w of NPWT, STSG covered with damp dressing	Colistin and Gentamicin intravenous	NR	>6 w	Wound closed 3 m after STSG	d 6: wound edges contraction, d 10: local extension of the granulation tissue, w 6: wounds ready for skin grafting. With NPWT it was possible to cover major chronic soft tissue defects, avoiding amputation. The Pt had acceptable limb function.	Bleeding on the bone area at the beginning of NPWT. Swab cultures positive for *Pseudomonas aeruginosa*, before and after NPWT without clinical signs of infection.
15	Pt a) d 7 postinjury Pt b) d 3 post-injury	Pt a) and Pt b) Mepitel interface between wound and open cell foam Pt b) NPWT on donor sites and the grafted area	Pt a) 125 initially, then temporarily reduced to 75 Continuous Pt b) 125 Continuous	NR	NR	Pt a) Acticoat wound dressing. Tangential excision to the trunk. STSG, meshed 1:4 and NPWT. Pt b) After wound lavage, Acticoat dressing. d 3: necrosectomy, and autologous 1:2 meshed STSG.	NR	NR	Pt a) 5 w Pt b) 26 d	Pt a) Excellent Pt b) 100% graft take, uneventful healing of donor sites	Massive hemorrhage from grafted and donor sites. In both Pts NPWT had to be discontinued: Pt a) Caused by widely meshed and expanded grafts. Pt b) Caused by large donor sites and graft, before sufficient hemostasis wound bed. In both cases, blood in the NPWT device appeared late (7–10 h after application) in the NPWT device. The black foam did not show any red discoloration for many hours. Monitor Pt on NPWT very closely for bleeding.	Pt a) Diffuse bleeding: when the foam was removed, it was found to be saturated with blood clots. Pt b) Foam completely soaked with blood, partly coagulated, partly fresh.
9	NR	NR	50–150	7–10 d of NPWT, repeated if wound surface had necrosis, infection, or inadequate granulation tissue.	7 cases receiving a single NPWT (7–10 d), the majority received more than one treated with NPWT.	Cases: debridement, NPWT. PELNAC® (artificial dermis), on granulation tissue after debridement and thin STSG. Controls: graft on the wound surface after debridement.	Penicillin and cephalosporins routinely used, while other antibiotics were chosen according to cultures.	NR	NR	NR	NPWT 100% successful. Good granulation tissue obtained for all cases within 14–21 d. The sequential therapy: "NPWT—artificial dermis—thin STSG" reduces discomfort, the grafted skin was smoother, more elastic, and lighter. The improvement in the final scar is also attributed to the use of the artificial dermis.	No necrosis or hematoma or seroma. Infections caused loss of artificial dermis in 3 Pts. Successful grafting was achieved after repeated NPWT and dressing.

OR, operating room; SIRS, systemic inflammatory response syndrome; STSG, split thickness skin graft; w, weeks.

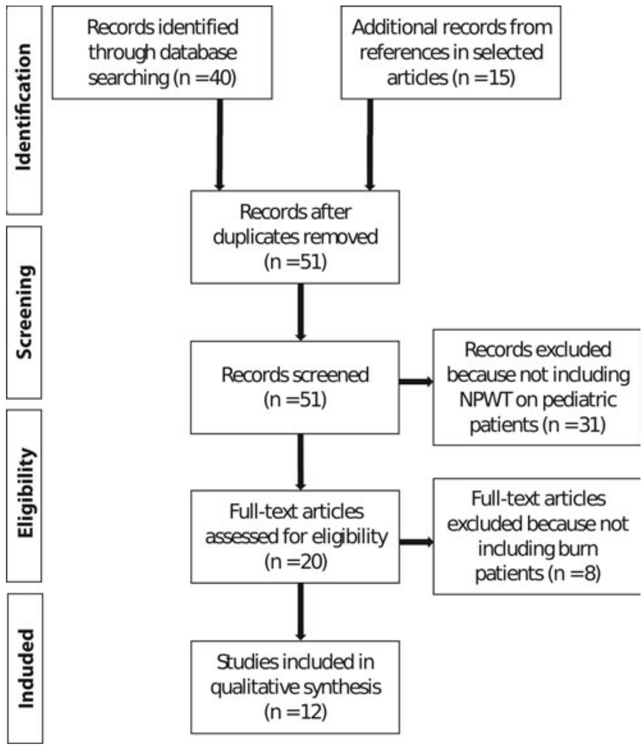


Figure 1. The PRISMA flow diagram summarizes the study selection processes. We included in this review 14 articles discussing NPWT use in pediatric burn patients: 2 reviews of the literature,[1,2] 6 retrospective single-center review,[4–9] and 6 case reports.[10–15] NPWT, negative pressure wound therapy; PRISMA, Preferred Reporting Items for Systematic Review and Meta-Analysis.

wounds.[1,2,7–10] The burn etiology is primary thermal, in 95 of the 121 (78.5%) burned children treated with NPWT. The main thermal causes are scald, contact with hot objects, and flame burns. Also reported electrical burns for 9 cases (7.4%),[7,13,14] chemical burns for 3 cases (2.5%),[4,5] and frostbite for 3 cases (2.5%).[6] In the remaining 11 cases (9.1%) NPWT was applied after burn scar revision.

NPWT has been applied in children with second- to third-degree burns. The reported pediatric patients had burns in all regions of the body: head and neck, hands and feet, upper and lower limbs, trunk, genital, and gluteal regions. There was one case of circumferential burn of the calf.[13] Negative pressure dressings were applied in all these regions.

Burn etiology does not appear to be a decisive factor for NPWT use. Wound healing was satisfactory for all burn types. Frostbite in pediatric patients presents a challenging condition not only for skin care, but also because of the risk of injury to open epiphyseal growth plates in the affected extremities, with bone shortening. Poulakidas found satisfying results with NPWT in three children with frostbite on the hand, both on re-epithelialization and growth plate preservation.[6] In high-voltage electrical burns, it is difficult to recognize the limit between viable and necrotic tissue. In Sahin's opinion, NPWT may help to promote angiogenesis and increase the viability of the borderline tissues.[13]

NPWT use seems to be proportional to grade and extension of burn injuries: NPWT is applied more frequently for pediatric patients with larger areas of third-degree burn wounds.[7] The majority of the authors in the identified studies applied NPWT to deep second- to third-degree burns. Rentea, Sahin, and Tevanov used NPWT also in burns involving muscle or bone that they qualified as fourth-degree burns.[8,13,14] Rentea applied the NPWT to exposed bone, to encourage granulation, and preparation for tissue coverage.[8]

Burned total body surface area (%) can be an important element in the choice of the dressing. Hoeller stated that there is an inverse correlation between the extent of grafted TBSA and the percentage of skin graft take rate, with higher percentage of skin graft take with smaller grafted areas under NPWT.[4] Schindler applied NPWT on a 40% TBSA burn; in this case the young patient remained immobilized for the duration of treatment (5 days).[12] It is important to note that extended burns in child could be a challenge, because of difficulties in securing the dressing, as well as for mobilization problems. Once clear guidelines for use in the pediatric population have been established, targeted research should aim at development of age-adapted devices.

Wound of irregular shape can be treated with NPWT. Sahin applied the NPWT to a circumferentially burned extremity.[13] Authors consider NPWT an interesting option to treat burns in difficult anatomical areas. NPWT seems to be helpful in regions of uneven contours, such as axilla, hands, feet, genital, and perianal regions.[6,10–12] Perianal area is a challenging location for all types of dressings, because of the movements in the area, sweating, and the risk of contamination. NPWT creates a barrier reducing the risk of infection in these areas in which wound soiling with feces can be hard to prevent; fecal drainage with a rectal tube and urinary catheterization can however still be necessary.[11] Split thickness skin grafts (STSGs) on mobile surfaces, such as the hands, can be successfully performed using NPWT for immobilization.[6,10]

Negative pressure wound therapy settings

Table 5 lists the mode and negative pressure settings used in pediatric cases. The majority of the

Table 5. *Negative Pressure Wound Therapy Use Summary*

Author ref	*Age*	*Mode*	*Pressure settings (mmHg)*	*Interface layer wound—foam*	*Treatment/STSG*
Hoeller *et al.*[4]	3 m to 24 y	Continuous	–75 to –125	Silicone-coated or polyethylene film	Immediate STSG, covered by NPWT
Kasukurthi and Borschel[10]	14 m to 12 y	Continuous	–75	None	Immediate STSG, covered by NPWT
Koehler *et al.*[5]	8 m to 10 y	Continuous or intermittent	–70 to –125	None (n=8)	2/3 NPWT only
				Mepitel and (n=10) /or (n=5) Acticoat	1/3 NPWT, then STSG covered by NPWT
Poulakidas *et al.*[6]	16 to 31 m	NR	NR	Silver-coated contact layer	NPWT only
Psoinos *et al.*[11]	8 m	Continuous	–80	Silver-coated contact layer	Immediate STSG, covered by NPWT
Ren *et al.*[7]	2 m to 18 y	Continuous	–50 to –125	NR	NPWT then delayed STSG
Rentea *et al.*[8]	12 m to 18 y	NR	–50 to –125	Petroleum-coated gauze	35% NPWT only
					18% NPWT then delayed STSG
Schintler *et al.*[12]	6 y	Continuous	–125	Silicone-coated layer (Mepitel)	Immediate STSG, covered by NPWT
Sahin *et al.*[13]	15 y	NR	NR	NR	NPWT then delayed STSG
Tevanov *et al.*[14]	17 y	Continuous and intermittent	–50 to –115	Silver and/or silicone-contact layer	Immediate STSG, covered by NPWT
Trop *et al.*[15]	15 and 17 y	Continuous	–75 to –125	Silicone-coated layer (Mepitel)	STSG, covered by NPWT
Yuan *et al.*[9]	2 to 8 y	NR	–50 to –150	NR	NPWT then delayed STSG

centers applied a continuous negative pressure, with the exception of Koehler who used a –120 mmHg intermittent suction in one of his 22 patients[5] and Tevanov who temporary switched to an intermittent suction to control blood loss.[14] Negative pressure varied between –70 mmHg and –150 mmHg. Hoeller, Ren and Rentea adapted the pressure to the ages of their patients.[4,7,8] There is currently no guideline concerning negative pressure settings for burned pediatric patients. In her retrospective chart review, Baharestani identified in the literature for NPWT pressure settings, guidelines for pediatric wounds (not specifically in burns). She suggested using –50 to –75 mmHg continuous suction for burned newborns and infants (birth to 2 years), and –75 to –125 mmHg continuous mode for burned children (>2 to 12 years) and adolescents (>12 to 21 years).[1] Contractor proposed to apply a continuous negative pressure of –50 to 75 mmHg in younger children and - 100–125 mmHg in older ones.[2] Negative pressure should be adapted to patient weight and comorbidities, wound type, size, and location.[1]

The majority of the authors placed an interface layer between the wound bed and the foam, such as silicone-coated layers[4,5,12,15] and/or silver-coated contact layers.[5,6,11,14]

Most centers applied the NPWT from 3 to 10 days.[4–6,9–12] Other authors considered this dressing a long-term wound care: Sahin treated a 15-year-old boy with NPWT for 30 days,[13] Tevanov extended the treatment duration to 6 weeks,[14] and Rentea treated wounds from 2 to 318 days according to patients' age.[8]

Dressing changes were performed from twice a week[5,8,13,14] to every 5–7 days.[7]

The length of hospital stay was variable, ranging between 5 and 67 days, depending on the severity of the injuries.

Skin graft and NPWT

Koehler and Poulakidas used NPWT with the purpose of promoting primary intention healing.[5,6] Other studies used NPWT as a complement to STSG. Five centers employed NPWT to prepare the wound bed before grafting.[5,7,13,15] Kasukurthi used NPWT before using a free latissimus dorsi flap to cover an electrical burn, then applied a STSG.[10] Six authors secured the STSG by covering it with NPWT.[4,5,10–12,14] NPWT is the preferred choice for graft fixation in burn centers such as the Children's Burn Unit at the Medical University of Graz[4] and the Center for Women and Children, Honolulu.[5] Results concerning the take rate of the STSG were very encouraging, approaching 100% in almost all studies.[4,7,9–15]

Poulakidas applied the NPWT system without skin grafting in patients with frostbite and avoided the need for amputation. Patient follow-up showed reepithelialization of the wounds within two weeks after discharge.[6]

Hoeller reported one case who lost most of the graft, and seven cases who had minors peripheral necrosis of the skin graft; this study reports also one case with a slight dehiscence of the wound and another with a minor graft displacement. Despite this, the overall skin graft take rate in Hoeller's study was 96%.[4]

Wounds involving <20% TBSA can usually be closed with unmeshed or low-ratio meshed STSG.[15] The question of using meshed or unmeshed graft is still the subject of discussion in the literature. The major disadvantage of meshing the skin graft is its appearance, as the patient will have a textured skin forever. When meshed grafts are used in exposed areas like face and hands, this concern is even more significant. Hoeller used 83% of nonmeshed and 17% of meshed STSG in their patients. Meshed STSG had a ratio of 1:2 in seven cases, 1:2 and 1:4 for two children, and 1:4 in one patient only because of extensive burns. There was no difference in take ratio between 1:2 and 1:4 meshed STSG, or between meshed and nonmeshed STSG.[4] Trop applied NPWT on 1:4 meshed STSG in a 17-year-old boy who had secondary bleeding from this area. The author stated that the cause of bleeding was the use of widely meshed skin graft.[15] All other authors did not report whether the STSG were meshed or unmeshed.

Other reported advantages

As children are not small adults, several specific physiological and anatomical considerations should be considered with respect to using NPWT in pediatrics.[16,17] Younger patients may have increased skin fragility, for this reason close attention must be payed also to skin adjacent to burns. In children it is also crucial to avoid laying the foam over intact skin, as well as repeatedly applying and removing the adhesive tape to avoid stripping the periwound skin.[1] Furthermore, the periwound skin maceration should be prevented, especially in neonates, by applying barrier protectors on the skin or using an additional thin hydrocolloid or another transparent film before placement of the adhesive drape.[1,18] There are important age-related specificities in the physiology of electrolytes' and fluids' handling and differences in the various body proportions that predispose children of all ages, to a higher risk of severe and rapid loss of fluids and dehydration.[1,16] In the literature, one of the most often noted benefits of NPWT is the precise measurement of wound fluid losses.[1,11,12] Before using NPWT it is fundamental to evaluate child hydration considering the significant amount of third space fluid removal that may occur with NPWT.[1] Schindler quantified wound fluid losses in a 6-year-old child with 40% TBSA burn.[12] The maximal fluid loss occurs during the first 24–48 h due to the inflammatory increase in capillary permeability.[16] This was also observed in Schindler's patient, who lost 1270 mL through the wound in the first 48 h; the patient's care was without complications and management of tissue fluid losses easier as a result of using NPWT. Furthermore, the author suggests that the edema evacuation from extravascular space was beneficial to their patient, as it improves microcirculation, decompressing small vessels, and increasing local blood supply.[12]

Burns can have several psychological consequences in pediatric patients. Most of the child's and parents' anxiety are related to the painful dressing changes. In contrast with classic dressings that are usually changed on a daily basis, NPWT can be changed twice a week or even less frequently. This decreases patient's and parent's discomfort, medication required for pain control, dressing material use, and frees the burn team for other tasks.[2,5,6,10,11]

Another major advantage of NPWT in comparison to conventional dressings for pediatric patients is early mobilization. In younger children compliance difficulties are expected and a secure and stable fixation of STSG is essential to prevent graft displacement and to ensure a favorable outcome. Early high mobility is possible with portable NPWT, allowing children to play outside of their beds.[4,5] This advantage was also confirmed in Sahin publication, reporting a patient continuing physical therapy exercises during NPWT.[13]

This review showed that NPWT can be used in treating pediatric burn cases over a wide range of time spans. Appropriate patients may be followed on an outpatient basis while on NPWT and admitted only for dressing changes or skin grafting. This may decrease hospital stay and costs and allow an earlier return of function.[1,8,10,13]

Complications

Bleeding and hematoma were the main NPWT complications noted.[4,14,15] Tevanov reported only one complication, bleeding on the bone at the initiation of NPWT; this was managed by switching to intermittent suction, with the hemorrhage stopping over 24 h. NPWT was continued, and after STSG with NPWT, the whole area was successfully covered.[14] Trop reported two hemorrhages, one from the grafted area and the other from the donor site, both under NPWT. In the first patient, the suspected reason for the bleeding was the widely meshed grafts. For the second patient, the donor site was large and probably hemostasis was not completed before NPWT application. In both cases, NPWT was discontinued. Despite the bleeding, the skin graft take was complete and the healing of the donor sites uneventful.[15]

Another adverse effect was mild local infection,[4,5,8,9,12–14] with cultures growing *Klebsiella pneumoniae*[12] or *Pseudomonas*.[14] Sahin lost a skin graft because of infection. The patient was regrafted 10 days later with complete STSG take.[13] No systemic infections were observed. In Koehler's report three patients developed wound infections but did not require NPWT removal and they were successfully treated by antibiotics.[5] Some centers used NPWT with antimicrobial prophylaxis such as silver dressings[4–6,11,12,14] or intravenous antibiotics.[5,9,12,14]

Rentea reported two skin breakdowns under the NPWT adhesive; in his large series, <2% of their patients had adverse events.[8]

Other rare complications included device problems, such as leaks in the NPWT system,[12] retained foam in the wound,[8] and malfunction of the NPWT because of a contamination with stool.[4] With extensive and deep wounds, there is a higher risk of leaving sponge fragments in the wound.[8]

Four studies in this review did not report complications, for a total of 40 patients.[6,7,10,11] Complications seem rare in pediatric population and they did not appear to have any long-term consequence on burn wound healing.

Study limitations

Publications on NPWT may suffer of reporting bias, publishing only favorable outcomes. In the majority of the publications there was no control group. Most of the included studies were retrospective single-institution reviews, with results reflecting only local experience and patient volume. Studies reported data differently allowing only a descriptive and not a quantitative metanalysis.

SUMMARY

The data collected provides empirical guidelines on NPWT use in pediatric burns. This versatile technique has been used in children from 2 months to 18 years presenting deep second- to fourth-degree burns of different etiologies (thermal, chemical, electrical, and frostbite). NPWT can be applied for a few days or up to several months, on small to large surfaces (up to 40% TBSA), and in problematic locations such as hands and perianal region.

NPWT can be used to promote primary intention burn healing or as a complement to STSG. In the operative management of burns, NPWT can be applied before the graft, to prepare the wound bed and/or over a STSG, covering the newly grafted area and securing it. NPWT wound immobilization and protection may allow easier and faster patient mobilization.

There is still no indication on whether grafts should be meshed or not for NPWT application. The majority of the centers apply an interface layer between the wound bed and the foam. Safe NPWT settings appear to be a continuous mode with a negative pressure of –50 to –75 mmHg for burned patients younger than 2 years, and –75 to –125 mmHg for children over 2 years of age.

Some adverse effects from NPWT have been reported but seem still uncommon in pediatric patients and were not different from those reported in publications on adults. Bleeding, local infections, and mechanical device issues were the most common problems noted. These complications highlight the importance of having clean wounds and proper hemostasis before applying NPWT.

NPWT seems to be beneficial in the pediatric burn population, both physically and psychologically. Prospective randomized trials are required to develop guidelines for a safe and efficient use of NPWT in pediatrics burn patients.

ACKNOWLEDGMENTS AND FUNDING SOURCES

This work was supported by the Division of Pediatric Surgery, University of Geneva Children's Hospitals, Switzerland. The authors would like to thank PD Dr. Pfurtscheller from the University Hospital Graz, Austria, for sharing the data of his study.

Earlier versions of this work were presented in November 2018 at the 6th Meeting—International Society of Pediatric Wound Care and March 2019

TAKE-HOME MESSAGES

- NPWT has been used from the age of 2 months in patients with deep second- or third-degree burns of multiple etiologies (thermal, chemical, electrical, and frostbite).
- For burned children younger than 2 years –50 to –75 mmHg continuous negative pressure appears safe.
- For children over 2 years of age –75 to –125 mmHg continuous negative pressure appears safe.
- NPWT measurement of fluid losses allows tailored rehydration.
- NPWT facilitates earlier mobility and return of function.
- NPWT requires less frequently painful dressing changes.
- Prospective randomized trials are needed to stipulate evidence-based guidelines for a safe and efficient use of NPWT in pediatric burn patients.

at the 54th Congress of the European society for surgical research.

AUTHOR DISCLOSURE AND GHOSTWRITING

No competing financial interests exist. The content of this article was expressly written by the authors listed. No ghostwriters were used to write this article.

ABOUT THE AUTHORS

Nadine Pedrazzi, MMed, is a resident in Surgery at the University of Geneva Hospital (Switzerland) with the goal of becoming a plastic surgeon with a special interest in burns and wound care.

Surrenaidoo Naiken, MD, is an attending surgeon in General Surgery at the University of Geneva Hospital.

Giorgio La Scala, MD, PD, is a senior lecturer and an attending surgeon at the University of Geneva Children Hospital, responsible for Pediatric Plastic Surgery, including wound care, burns, and vascular anomalies. He is currently Secretary General of the International Society for Pediatric Wound Care.

REFERENCES

1. 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 1:1–26.
2. Contractor D, Amling J, Brandoli C, Tosi LL. Negative pressure wound therapy with reticulated open cell foam in children: an overview. J Orthop Trauma 2008;22:S167.
3. Anghel EL, Kim PJ. Negative-pressure wound therapy: a comprehensive review of the evidence. Plast Reconstr Surg 2016;138:129S–137S.
4. Hoeller M, Schintler MV, Pfurtscheller K, Kamolz L-P, Tripolt N, Trop M. A retrospective analysis of securing autologous split-thickness skin grafts with negative pressure wound therapy in paediatric burn patients. Burns 2014;40:1116–1120.
5. Koehler S, Jinbo A, Johnson S, Puapong D, de Los Reyes C, Woo R. Negative pressure dressing assisted healing in pediatric burn patients. J Pediatr Surg 2014;49:1142–1145.
6. Poulakidas SJ, Kowal-Vern A, Atty C. Pediatric frostbite treated by negative pressure wound therapy. J Burn Care Res 2016;37:e489–e492.
7. Ren Y, Chang P, Sheridan RL. Negative wound pressure therapy is safe and useful in pediatric burn patients. Int J Burns Trauma 2017;7:12–16.
8. Rentea RM, Somers KK, Cassidy L, Enters J, Arca MJ. Negative pressure wound therapy in infants and children: a single-institution experience. J Surg Res 2013;184:658–664.
9. Yuan X-G, Zhang X, Fu Y-X, et al. Sequential therapy with "vacuum sealing drainage-artificial dermis implantation-thin partial thickness skin grafting" for deep and infected wound surfaces in children. Orthop Traumatol Surg Res 2016;102: 369–373.
10. Kasukurthi R, Borschel GH. Simplified negative pressure wound therapy in pediatric hand wounds. Hand (N Y) 2010;5:95–98.
11. Psoinos CM, Ignotz RA, Lalikos JF, Fudem G, Savoie P, Dunn RM. Use of gauze-based negative pressure wound therapy in a pediatric burn patient. J Pediatr Surg 2009;44:e23–e26.
12. Schintler M, Marschitz I, Trop M. The use of topical negative pressure in a paediatric patient with extensive burns. Burns 2005;31:1050–1053.
13. Sahin I, Eski M, Acikel C, Kapaj R, Alhan D, Isik S. The role of negative pressure wound therapy in the treatment of fourth-degree burns. Trends and new horizons. Ann Burns Fire Disasters 2012;25: 92–97.
14. Tevanov I, Enescu DM, Bălănescu R, Sterian G, Ulici A. Negative pressure wound therapy (NPWT) to treat complex defect of the leg after electrical burn. Chirurgia (Buchar) 2016;111:175–179.
15. Trop M, Schintler M, Urban E, Roedl S, Stockenhuber A. Are 1:4 mesh and donor site contraindications for vacuum-assisted closure device? J Trauma 2006;61:1267–1270.
16. Sharma RK, Parashar A. Special considerations in paediatric burn patients. Indian J Plast Surg 2010; 43:S43–S50.
17. Santosa KB, Keller M, Olsen MA, Keane AM, Sears ED, Snyder-Warwick AK. Negative-pressure wound therapy in infants and children: a population-based study. J Surg Res 2019;235: 560–568.
18. de Jesus LE, Martins AB, Oliveira PB, Gomes F, Leve T, Dekermacher S. Negative pressure wound therapy in pediatric surgery: how and when to use. J Pediatr Surg 2018;53:585–591.

Abbreviations and Acronyms

Ant = anterior
dPTB = deep partial-thickness burn
FTB = full-thickness burn
NA = not analyzed
NPWT = negative pressure wound therapy
NR = not reported
OR = operating room
Post = posterior
Pt = patient(s)
PTB = partial-thickness burn
SB = superficial burn
sPTB = superficial partial-thickness burn
STSG = split-thickness skin graft
TBSA = total body surface area (%)