The American Journal of Surgery 217 (2019) 1065–1071

Contents lists available at ScienceDirect

The American Journal of Surgery

journal homepage: www.americanjournalofsurgery.com

Equivalent outcomes with once versus thrice weekly dressing changes in midline laparotomy wounds treated with negative pressure wound therapy

Omar E. Beidas [a], Tabitha Garwe [b, c], Ryan F. Wicks [b], Aditi Jalla [b], Cressilee Bryant [b], Zoona Sarwar [b], Roxie M. Albrecht [b, *]

[a] Division of Plastic Surgery, Department of Surgery, University of Oklahoma Health Sciences Center, 800 Stanton L. Young Blvd, Oklahoma City, OK, USA
[b] Department of Surgery, University of Oklahoma Health Sciences Center, 800 Stanton L. Young Blvd, Oklahoma City, OK, USA
[c] Department of Biostatistics and Epidemiology, University of Oklahoma Health Sciences Center, 800 Stanton L. Young Blvd, Oklahoma City, OK, USA

ARTICLE INFO

Article history:
Received 16 March 2018
Accepted 9 October 2018

ABSTRACT

Background: While negative pressure wound therapy (NPWT) has been used for decades, there is a paucity of data regarding the appropriate length of time between dressing changes.
Methods: This was a prospective, randomized control trial examining time to wound closure in open midline laparotomy wounds treated with NPWT. The control group received the standard thrice weekly sponge changes (thrice) and the treatment group received once weekly sponge changes (once).
Results: 44 patients met study criteria over a 3-year period. There was no difference in NPWT duration between the two groups (37.1 vs 34.7 days, $p = 0.7324$), even after adjusting for potential confounders ($p = 0.8091$). No differences were found in initial wound size or reduction. The wound complication profile was similar for both groups.
Conclusion: There is no difference in time to wound closure or complications with NPWT dressing changes once a week compared to the standard three times a week.

Introduction

Argenta and Morykwas[1,2] pioneered the use of negative-pressure wound therapy (NPWT) in the literature with the vacuum-assisted wound closure technique, first published in 1997. Since then, numerous of papers regarding the now-popular wound closure technique have been published and countless patients have been treated.[3–6] The name most synonymous with NPWT is the vacuum-assisted closure (V.A.C.®) device, made by Kinetics Concepts, Inc. (KCI). NPWT use has spread from simple wound closure to complex wounds including skin graft bolsters, management of enterocutaneous fistulas, temporary management of open abdomens, mediastinitis, treatment of diabetic foot ulcers, and even over closed surgical incisions.[7–12]

Despite the availability of NPWT devices for more than 20 years, its exact mechanism of action has yet to be proven.[13–17] The basic premise of NPWT involves the creation of a vacuum to deliver a negative pressure to the wound bed to promote granulation tissue formation and speed the healing process. Some of the effects that NPWT has been credited to produce include creating a moist environment; decreasing edema and bacterial load; increasing local blood flow; stimulating angiogenesis, cell proliferation, and granulation tissue formation; reducing the size of the wound; and favoring a high ratio of pro-healing cytokines to inhibitors of healing.[13] However, not all these outcomes have borne out in studies.

While NPWT is credited with many advantages, there exist several disadvantages to patients, healthcare providers, and hospitals. Patients report discomfort during NPWT treatment and pain during dressing changes.[18] Healthcare providers spend many labor hours caring for these wounds as dressing changes consume a significant amount of time more than traditional wet-to-dry dressings.[19] Finally, NPWT costs hospitals and healthcare systems significant charges in personnel and material.[20]

For acute wounds, KCI—the V.A.C.® manufacturer—recommends

* Corresponding author. Vice Chair of Surgery, Department of Surgery, Medical Director of Trauma, University of Oklahoma Health Sciences Center, 800 Stanton L. Young Blvd, Suite, 9000, Oklahoma City, OK, 73104, USA
E-mail address: Roxie-Albrecht@ouhsc.edu (R.M. Albrecht).

https://doi.org/10.1016/j.amjsurg.2018.10.015
0002-9610/

that the sponge be left in place for 3–5 days at a time,[21] therefore the dressing is typically changed two to three times a week. However, there is no literature to support this recommendation and no prior studies have specifically addressed the length of time between NPWT dressing changes. A non-inferiority study was designed to determine whether changing a NPWT dressing once a week is equivalent to changing it three times a week—the current standard—in midline laparotomy wounds. The study hypothesis was that there would be no difference in time to wound healing if changing the NPWT dressing once every 7 days as compared to every 2-3 days—the current standard of care.

Methods

This manuscript was prepared according to the Consolidated Standards of Reporting Trials (CONSORT) guidelines.

Institutional review board approval was obtained at our institution prior to the start of the study (IRB1675). This was a prospective, randomized controlled study over a 3-year period beginning in June of 2013 and ending in May of 2016. Eligible patients were adult patients 18 years and older who underwent exploratory laparotomy with fascial closure and 1) placement of subcutaneous NPWT or 2) initial skin closure with subsequent opening of the wound and treatment with NPWT over a closed fascia. Inclusion criteria were patients who underwent a laparotomy through a midline incision with fascia closure and placement of subcutaneous NPWT dressing. Informed consent was obtained from the patient or surrogate if the patient was not able to consent for themselves, however they were given the option to withdraw once able to make decisions for themselves. Both trauma and general surgery patients were eligible for inclusion in the study. Patients for whom a delayed primary closure was planned were excluded, as they would receive less than a week of NPWT. Patients were excluded if consent and randomization did not take place within 72 h of initiation of NPWT given the time-sensitive nature of dressing changes in the control group. Patients were further excluded from analysis if NPWT was discontinued prematurely for any reason or if measurements at time of initiation or discontinuation of NPWT were not accessible.

Interventions

Patients were randomly assigned 1:1 to either once a week NPWT dressing (ONCE) or thrice a week NPWT dressing (THRICE). The control arm (THRICE) underwent conventional thrice weekly dressing changes and the experimental arm (ONCE) underwent once weekly dressing changes starting on the day of initiation of NPWT. Patients in the group undergoing dressing changes three times a week fell into one of two groups, depending on the start day of therapy, with dressing changes performed either Monday/Wednesday/Friday or Tuesday/Thursday/Saturday. Due to the limited resources of wound care personnel on Sundays, patients who had NPWT initiated on a Sunday were transitioned to Saturday if randomized to the once weekly group or to Tuesday/Thursday/Saturday if randomized to the thrice weekly group. Any dressing change that occurred outside of a patient's study schedule along with the reason was recorded, and the patient remained on the same schedule despite the additional dressing change that week. The standard NPWT machine available at our institution is the V.A.C.® machine made by KCI (San Antonio, TX). All patients had a black sponge (V.A.C.® GRANUFOAM™) with clear adherent dressing and a trackpad that provided suction. Machine settings were set at a target pressure of 125 mm Hg, low intensity, and continuous suction.

Outcomes

The study's primary outcome was time to wound closure, measured as the total duration of NPWT, measured in days. The decision to discontinue NPWT was left to the discretion of the wound care team performing the dressing changes, generally when the wound depth was less than 0.3 cm and would no longer support a NPWT dressing. Secondary outcomes consisted of change in size of the wound over time and wound-related complications. Wound size was calculated using both area and volume. Area was calculated using the largest measurable length and width, and volume was calculated by multiplying area by the deepest portion of the wound.

Complications monitored were the number of NPWT leaks, malfunctions, or failures requiring take-down and re-dressing; wound complications such as wound infections—defined as that requiring antibiotics, dehiscence, evisceration, necrosis, fascia disruptions, enterocutaneous or enteroatmospheric fistulas, wound cellulitis; and returns to the operating room for wound complications issues.

If patients were discharged from the hospital with ongoing NPWT of the midline laparotomy wound, they were followed by a home health or wound care team. NPWT dressing changes after hospital discharge occurred on a similar schedule as to which the patient was randomized. Outside documentation was obtained as necessary to complete study records.

Sample size calculation and randomization

A target sample size of 250 patients (125 in each group) provided 88% power to detect a true difference of 2 days in the average time to wound closure between the two groups assuming a standard deviation of 5 days and a 2-sided α level of 0.05. Following sample size determination, stratified randomization based on diabetes and obesity status was performed using the SAS software package (PROC PLAN). Stratification was performed to ensure a balance of these strong prognostic factors between the two groups and to minimize any residual confounding by these factors. Four groups were created for randomization purposes: diabetic, BMI <30; diabetic, BMI ≥ 30; non-diabetic, BMI <30; and non-diabetic, BMI ≥ 30. Patients were classified as diabetic if they took any oral hypoglycemic or insulin at admission, and BMI was calculated based on the initial weight and height at admission. The random allocation sequence was generated by a statistician not involved with patient consent, enrollment, or intervention assignment. Randomization forms were generated and sealed within white opaque envelopes by the statistician. As patients consented and were enrolled in the study, randomization forms were faxed to a research coordinator not involved with patient consent/enrollment to track of compliance to the randomly allocated sequence and preserve the randomization process.

Data collection

Data collected included standard patient demographics; BMI; tobacco use at the time of admission; date and type of procedure performed; date of NPWT dressing placement; wound culture dates and results, if obtained; wound measurements and wound physical appearance at each dressing change; date that NPWT was discontinued; date and reason for unplanned dressing changes that were not part of the protocol; V.A.C.® dressing or machine complications; wound and systemic complications; and dates and indications for returns to the operating room.

Statistical analyses

Intention-to-treat analyses were performed using SAS® software (SAS Institute Inc., Cary, NC). Means and proportions were used to summarize the data. To ensure adequacy of the randomization process, distributions of baseline characteristics for each group were compared using the student's *t*-test for continuous variables and chi-square of Fisher's exact test for categorical variables. A generalized estimating equation was used to fit a linear regression model to compare mean changes in time to wound closure (in days) between the two groups. The regression model was adjusted for remaining imbalances in covariate distribution post-randomization to minimize residual confounding. Unadjusted comparisons of the incidence of wound complications were also compared between the two groups.

Results

Eighty-three consecutive patients were screened for the study, with 70 enrolled in the study split equally between each treatment arm. Twenty-six patients—11 in the THRICE group and 15 in the ONCE group—were excluded from the final statistical analysis, leaving a total of 44 patients for group comparison, as outlined in Fig. 1. Patients were excluded for the following reasons: 13 underwent delayed primary closure (DPC) of the abdominal wound; 6 had missing initial or final wound measurements; 3 died; 1 underwent re-operation on the abdomen through the same midline incision; 1 refused discharge with NPWT; 1 was admitted to hospice which required discontinuation of NPWT; and 1 was lost to follow-up, all prior to the completion of the study period.

Patient demographics at admission and clinical characteristics along with *p* values are summarized in Tables 1 and 2. There were no significant demographic or clinical differences between the two treatment arms except for the distribution of admission serum albumin, patient type (general surgery or trauma), tube feeding, and pre-existing conditions. Patients who underwent dressing changes three times a week had higher mean serum albumin levels at admission (3.4 ± 0.7 vs 2.8 ± 1.3, $p = 0.0564$) and were more commonly administered tube feeds (92% vs 63%, $p = 0.0304$), while patients in the once weekly dressing change group had a higher prevalence of pre-existing conditions (63.2% vs 37.5%, $p = 0.0946$) and had antibiotics administered mostly via the intravenous route (39% vs 8%, $p = 0.0131$). Although not statistically significant, the thrice group had a disproportionately higher number of trauma patients (54% vs 30%, $p = 0.1071$).

Outcomes

Table 3 summarizes outcomes by treatment group. Unadjusted comparisons of the outcomes suggested no difference in NPWT duration for both groups: 37.1 and 34.7 days for the once and thrice groups, respectively ($p = 0.7324$). When analyzing trauma patients and general surgery patients as separate cohorts, no differences were found between the groups in time to wound closure or initial and mean reduction of wound volume. After discontinuation of NPWT, patients were most often transitioned to traditional wet-to-dry dressing changes or some other topical dressing, with no differences among the two groups.

Differences in initial wound size and reduction in wound size were similar, with a mean reduction volume of 351 cm^3 for the once weekly group and 360 cm^3 for the thrice weekly group ($p = 0.9610$). The wound complication profile was also similar for both groups, with an overall complication rate of 52.6% in the once weekly group and 41.7% in the thrice weekly group ($p = 0.4741$). Device related adverse events were also similar with 1 unplanned dressing change in each group (2.9%) due to concern for dehiscence, and none was found. Patients in the ONCE group were also significantly likely to be discharged home (79% vs 42%, $p = 0.0138$).

Multivariable analysis

After adjusting for patient type, albumin at admission and tube feeds, there was no significant ($p > 0.05$) association between treatment arm and reduction in wound size or time to wound closure (Table 4).

Discussion

Negative pressure wound therapy, almost ubiquitously referred to as the V.A.C.® system, has revolutionized wound care management in the last two decades. Complex, difficult-to-care for wounds that required dressing changes multiple times a day now only needed dressing changes every 2–3 days. The use of a closed suction system allowed for greater spacing of dressing changes. Since its introduction, the traditional NPWT afforded by the V.A.C.® system has been modified to include a variety of settings and tools to widen its use in the armamentarium of the wound care provider. Examples of these additions include options for intermittent suction; varying suction intensity; and installation of fluid or antibiotic therapy in the wound bed.[22–24]

This study suggests that for patients with subcutaneous abdominal wounds, dressing changes may be done once every 7 days as opposed to every 2–3 days. These surgically created wounds ranged from clean to dirty, and all had NPWT initiated in an inpatient setting. A continuous negative pressure of 125 mm Hg was used for the following reasons. For one, this is the setting most commonly used in clinical practice at the study institution, and changing the standard settings for purposes of the study would have introduced additional uncontrolled variables. A swine study by the originators of NPWT also demonstrated that a setting of 125 mm Hg was best at promoting granulation tissue formation.[25] Finally, continuous therapy was chosen over the intermittent option for patient comfort and ease of maintaining a seal.[22,26] Intermittent therapy causes foam deformation changes—expansion and contraction—at 5–10 min intervals, causing movement at the wound interface that may be painful for the patient.[27] Additionally, the loss of negative pressure for even brief periods of time can be problematic in holding a seal over a 7-day period.

The study was designed to analyze wound healing, so stratified randomization was used to minimize the effect of factors that could bias the outcomes of one treatment arm. Obesity, defined as BMI $\geq$ 30,[28] and diabetes are risk factors associated with delayed wound healing or wound healing complications.[29,30] Therefore, randomization was stratified by these major prognostic factors to decrease the risk of having a large effect on one arm of the study.

The results of this study can likely be applied to wounds in other anatomic regions, given comparable size and contour parameters. NPWT dressings are difficult to maintain for prolonged periods over areas with major concavities or convexities,[21] such as on the groin or toes. The authors do not recommend NPWT dressings in such areas be left in place for longer than 3–4 days at a time. Similarly, one must be careful to extrapolate these findings to wounds that may need more careful observation. While the output is collected in a clear canister and therefore changes in quality or consistency of drainage can be detected, wounds that require more frequent examination by the healthcare team should be treated accordingly.

No other study has examined the frequency of dressing changes using NPWT, although a study by Kamamoto et al.[31] did look at the length of treatment. The authors examined treatment of acute

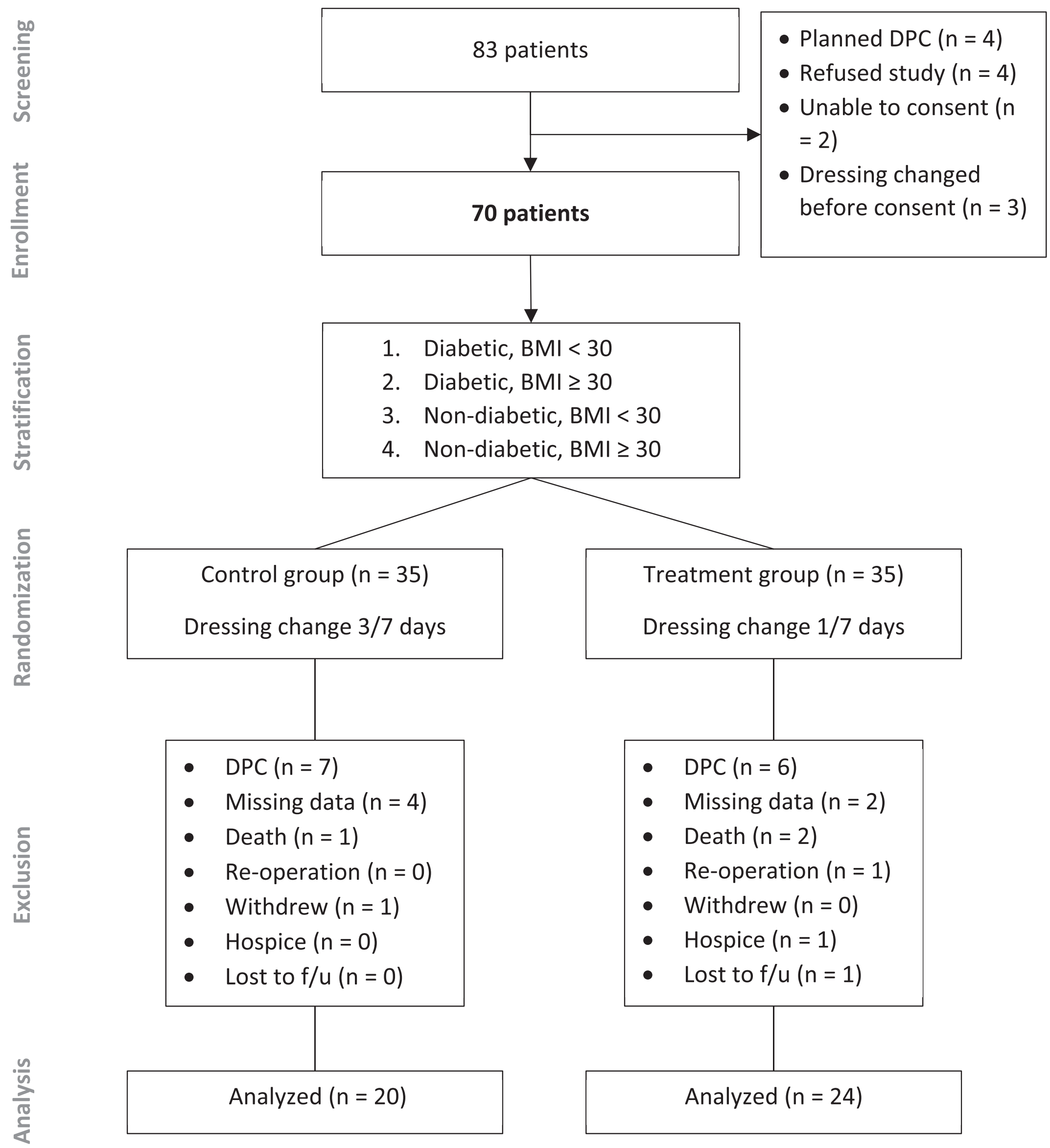

Fig. 1. Patient enrollment and eligibility criteria, along with exclusion criteria and final number analyzed in each group.

traumatic wounds caused by open fractures. Wounds were treated with either V.A.C.® therapy or a low-cost alternative, and the primary endpoint was time required to achieve a wound that was ready for surgery. All 51 wound dressings were changed twice a week, and outcomes showed time to a ready-for-surgery state was approximately 10 days in either group.

While this study was not intended to examine patient pain levels or cost to the healthcare system, expectations would be that both would be decreased because of fewer dressing changes during a given interval. Wound care teams did not report any patients complaining of more pain than usual, and no patients withdrew secondary to pain measures. While it is plausible that patient pain may be increased at each NPWT dressing change due to the ingrowth of tissue into the micropores after 7 days,[26] we would expect overall pain to be reduced secondary to fewer dressing changes.

An analysis of cost burden to the healthcare system was also not performed, although many other studies have looked at this in the past. Buller et al. calculated the material cost of NPWT at $0.47/cm^2$, excluding the cost of the machine.[32] In two separate articles analyzing the cost-effectiveness of the V.A.C.®, the cost of the V.A.C.® machine and supplies was $96.51 and $111.18 per day.[19,20] In two separate articles analyzing the cost of V.A.C.® therapy, the average time for a dressing change was 31 min at cost of $20.11 and $40.70 in labor per dressing change.[19,20] A decrease in number of dressing changes would be expected to cut hospital costs—at least in terms of dressing material and labor by an estimated $50–100 per week.

Limitations/critiques

A limitation of this study is the small sample size, as we did not meet our target estimate of 250 patients. Therefore, the cohort size may be underpowered to detect differences in outcomes and does not allow for meaningful subgroup analyses. The university center where this study was performed is the only Level 1 trauma center in the state, and therefore the catchment area includes the entire state as well as adjacent parts of neighboring states. While this

Table 1
Patients demographics and clinical characteristics by treatment randomization. †, Chi sq test of independence; *, Fishers exact test; ‡, student's t-test.

Variables	Once Weekly (n = 20)	Thrice Weekly (n = 24)	*p*-value
Patient Type, n (%)			0.1071†
Trauma	6 (30.0)	13 (54.2)	
General Surgery	14 (70.0)	11 (45.8)	
Age, mean (SD)	46.1 (12.6)	49.8 (16.4)	0.4228‡
Gender, n (%)			0.3211†
Male	9 (47.4)	15 (62.5)	
Female	10 (52.6)	9 (37.5)	
Race, n (%)			0.4301*
White	12 (63.2)	20 (83.3)	
African American	4 (21.1)	3 (12.5)	
Native American	2 (10.5)	1 (4.2)	
Other	1 (5.3)	0 (0.0)	
BMI at admission, mean (SD)	30.5 (11.7)	30.8 (8.1)	0.9075‡
Albumin at admission g/dl, mean (SD)	2.8 (1.3)	3.4 (0.7)	0.0564‡
Tobacco use (current or former), n (%)	11 (57.9)	12 (50.0)	0.6062†
Pre-existing conditions at admission, n (%)	12 (63.2)	9 (37.5)	0.0946†
Diabetes Mellitus	0 (0.0)	2 (8.3)	0.4950*
Liver Cirrhosis	1 (5.3)	0 (0.0)	0.4419*
Cancer	7 (36.8)	2 (8.3)	**0.0304***
Steroids/Immunosuppression	1 (5.3)	1 (4.2)	1.0000*
Renal Conditions (Dialysis & Renal Failure)	5 (26.3)	5 (20.8)	0.7279*

provides a large patient population to draw on, coordinating care for patients who are discharged to various facilities across the state and out-of-state remains difficult. Despite this, we could capture initial and final wound measurements for all but 6 patients. DPC allows for surgical closure of wounds and earlier discharge from the hospital, but unfortunately this intervention excluded a large proportion (18.6%) of our sample. While it would seem impossible for a patient with a V.A.C.® machine to be lost to follow-up, despite many attempts at reaching this patient, one patient (1.4%) could not be located.

Wound measurement was performed using the maximum measurements of each length, width, and depth. While this gives a representation of wound area and volume, it is not the most accurate method as it will overestimate both measurements. Other studies used various methods to more accurately measure wound dimensions. Kundin used a disposable tool with 3 axes and developed a formula to calculate wounds.[33] Alternatively, a more accurate measurement method could be obtained with the use transparent plastic to trace the area of the wound then multiplying by deepest part of wound.[13] Many of these studies were designed to measure sizes of complex, irregularly-shaped wounds such as pressure ulcers. The study described herein used simple measurements given the simple linear nature of the wound. Any overestimation of wound measurements would have permeated both groups equally and thus should not skew results in one group's favor. Additionally, our primary outcome was not reduction in size but number of days treated with NPWT.

Conclusions

In open midline laparotomy wounds treated with NPWT, there is no difference in time to wound closure or wound-related

Table 2
Surgical intervention and wound details information from initial laparotomy. †, Chi sq test of independence; *, Fishers exact test; ‡, student's t-test.

Variables	Once Weekly (n = 20)	Thrice Weekly (n = 24)	*p*-value
Laparotomy indication, n (%)			
Emergent	16 (84.2)	22 (91.7)	0.6404*
Non-Emergent	3 (15.8)	2 (8.3)	
Wound closure, n (%)			0.0797*
Skin closed	0 (0.0)	2 (8.3)	
Open abdomen	10 (55.6)	18 (75.0)	
Subcutaneous WVAC	8 (44.4)	4 (16.7)	
Tube feeds, n (%)	12 (63.2)	22 (91.7)	**0.0304***
Wound vitamins, n (%)	5 (26.3)	16 (66.7)	**0.0086†**
Infection, n (%)			0.2115*
None	14 (73.7)	22 (91.7)	
Abscess (intra-abdominal)	5 (26.3)	2 (8.3)	
Antibiotics administered, n (%)	7 (38.9)	5 (20.8)	0.1999†
PCN/Lactamase	0	3 (12.5)	
Carbapenem	4 (22.2)	2 (8.3)	
Vancomycin	3 (16.7)	0	
Antifungal	2 (11.1)	2 (8.3)	
Cipro	1 (5.6)	0	
Metronidazole	1 (5.6)	1 (4.2)	
IV antibiotics, n (%)	7 (38.9)	2 (8.3)	**0.0251***
Post-VAC treatment, n (%)			0.8626*
None (wound closed)	0	1 (4.8)	
Wet to dry	12 (66.7)	12 (57.1)	
Other (topical dressing)	6 (33.3)	8 (38.1)	

Table 3
Unadjusted outcomes by treatment group. †, Chi sq test of independence; *, Fishers exact test; ‡, student's t-test.

Variables	Once **Weekly (n = 20)**	Thrice **Weekly (n = 24)**	*p*-value
Wound-related Complications, n (%)	10 (52.6)	10 (41.7)	0.4741†
SSI	2 (10.5)	0 (0.0)	0.1894*
Evisceration	1 (5.3)	0 (0.0)	0.4419*
Wound dehiscence	5 (26.3)	1 (4.2)	0.0723*
Intra-abdominal infection	9 (47.4)	10 (41.7)	0.7085*
Hernia	1 (5.3)	0 (0.0)	0.4419*
Systemic Complications, n (%)	13 (68.4)	17 (70.8)	0.8642†
Pneumonia	7 (36.8)	12 (50.0)	0.3882*
UTI	3 (15.8)	5 (20.8)	1.0000*
DVT	2 (10.5)	5 (20.8)	0.4370*
Myocardial Infarction	0 (0.0)	3 (12.5)	0.2425*
Coagulopathy	2 (10.5)	5 (20.8)	0.4370*
CVA/Stroke	0 (0.0)	1 (4.2)	1.0000*
Sacral Ulcer	0 (0.0)	3 (12.5)	0.2425*
Renal Conditions (Renal Failure and Dialysis)	6 (31.6)	6 (25.0)	0.6329*
Death	0 (0.0)	2 (8.3)	0.4950*
Relative Reduction in Wound, mean % ± SD			
Area overall (cm^2)	50.5 ± 39.9	74.3 ± 31.0	0.5722‡
General Surgery patients	52.1 ± 46.9	53.3 ± 35.3	0.9460‡
Trauma Patients	47.3 ± 23.9	33.2 ± 43.8	0.4799‡
Volume overall (cm^3)	43.2 ± 40.2	56.8 ± 77.6	0.3418‡
General Surgery patients	72.9 ± 35.9	69.1 ± 38.3	0.8091‡
Trauma Patients	77.1 ± 20.5	44.5 ± 104.1	0.3367‡
Time to Closure (NPWT days), mean % ± SD	37.1 ± 19.6	34.7 ± 22.5	0.7324‡
Trauma Patients	34.5 ± 16.2	31.4 ± 23.6	0.7767‡
General Surgery Patients	38.3 ± 21.6	38.1 ± 22.0	0.9790‡
Disposition			
Home	15 (78.9)	10 (41.7)	**0.0138***
LTAC	1 (5.3)	6 (25.0)	
SNF	2 (10.5)	0 (0.0)	
Rehab	1 (5.3)	6 (25.0)	
Death	0 (0.0)	2 (8.3)	

Table 4
Adjusted association between intervention group and wound outcomes. †Adjusted for patient type; albumin at admission; overall preexisting conditions; and tube feeds.

Variable	†**Adjusted Estimate (S.E)**	*p*-value
Reduction in wound area		
Thrice group	−14.4 (26.9)	0.5960
Once group		Reference
Reduction in wound volume		
Thrice group	28.2 (206.2)	0.8922
Once group		Reference
Time to wound closure		
Thrice group	2.04 (8.4)	0.8091
Once group		Reference

complications with dressing changes once a week compared to the standard three times a week. Further studies are likely to corroborate these findings for many, but not all, anatomical regions. A shift in treatment modality for these wounds would be expected to reduce patient discomfort and pain, increase healthcare worker time and patient satisfaction, and decrease hospital costs and charges. Future studies should include larger populations, a patient-reported patient satisfaction and pain levels across groups, and an in-depth cost analysis to evaluate the cost savings of this new paradigm.

Conflicts of interest and source of funding

We have no conflicts of interest to disclose. There was no funding for this project. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2018.10.015.

References

1. Morykwas MJ, Argenta LC, Shelton-Brown EI, McGuirt W. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. *Ann Plast Surg*. 1997;38(6):553–562.
2. Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. *Ann Plast Surg*. 1997;38(6):563–577.
3. Quyn AJ, Johnston C, Hall D, et al. The open abdomen and temporary abdominal closure systems–historical evolution and systematic review. *Colorectal Dis*. 2012;14(8):e429–e438.
4. Misky A, Hotouras A, Ribas Y, Ramar S, Bhan C. A systematic literature review on the use of vacuum assisted closure for enterocutaneous fistula. *Colorectal Dis*. 2016;18(9):846–851.
5. Cirocchi R, Birindelli A, Biffl WL, et al. What is the effectiveness of the negative pressure wound therapy (NPWT) in patients treated with open abdomen technique? A systematic review and meta-analysis. *J Trauma Acute Care Surg*. 2016;81(3):575–584.
6. Kantak NA, Mistry R, Halvorson EG. A review of negative-pressure wound therapy in the management of burn wounds. *Burns*. 2016;42(8):1623–1633.
7. Blackburn 2nd JH, Boemi L, Hall WW, et al. Negative-pressure dressings as a bolster for skin grafts. *Ann Plast Surg*. 1998;40(5):453–457.
8. Verhaalen A, Watkins B, Brasel K. Techniques and cost effectiveness of enteroatmospheric fistula isolation. *Wounds*. 2010;22(8):212–217.
9. Song DH, Wu LC, Lohman RF, Gottlieb LJ, Franczyk M. Vacuum assisted closure for the treatment of sternal wounds: the bridge between débridement and definitive closure. *Plast Reconstr Surg*. 2003;111(1):92–97.
10. Etoz A, Kahveci R. Negative pressure wound therapy on diabetic foot ulcer. *Wounds*. 2007;19(9):250–254.
11. Stannard JP, Gabriel A, Lehner B. Use of negative pressure wound therapy over clean, closed surgical incisions. *Int Wound J*. 2012;9(Suppl 1):32–39.
12. Argenta LC, Morykwas MJ, Marks MW, DeFranzo AJ, Molnar JA, David LR. Vacuum-assisted closure: state of clinic art. *Plast Reconstr Surg*. 2006;117(Suppl 7S):127S–142S.
13. Mouës CM, Vos MC, van den Bemd GJ, Stijnen T, Hovius SE. Bacterial load in

relation to vacuum-assisted closure wound therapy: a prospective randomized trial. *Wound Repair Regen*. 2004;12(1):11–17.
14. Kairinos N, Solomons M, Hudson DA. Negative-pressure wound therapy I: the paradox of negative-pressure wound therapy. *Plast Reconstr Surg*. 2009;123(2):589–598.
15. Kairinos N, Voogd AM, Botha PH, et al. Negative-pressure wound therapy II: negative-pressure wound therapy and increased perfusion. Just an illusion? *Plast Reconstr Surg*. 2009;123(2):601–612.
16. Mouës CM, Heule F, Hovius SE. A review of topical negative pressure therapy in wound healing: sufficient evidence? *Am J Surg*. 2011;201(4):544–556.
17. Schintler MV. Negative pressure therapy: theory and practice. *Diabetes Metab Res Rev*. 2012;28(Suppl 1):72–77.
18. Upton D, Andrews A. Negative pressure wound therapy: improving the patient experience. Part 1 of 3. *J Wound Care*. 2013;22(10):552–557.
19. Kim JJ, Franczyk M, Gottlieb LJ, Song DH. Cost-effective alternative for negative-pressure wound therapy. *Plast Reconstr Surg Glob Open*. 2017;5(2), e1211.
20. Dorafshar AH, Franczyk M, Gottlieb LJ, Wroblewski KE, Lohman RF. A prospective randomized trial comparing subatmospheric wound therapy with a sealed gauze dressing and the standard vacuum-assisted closure device. *Ann Plast Surg*. 2012;69(1):79–84.
21. Medical Education Instructions for Use. *Acelity*. Available at: http://www.acelity.com/healthcare-professionals/instructions-for-use. Accessed February 4, 2018.
22. Borgquist O, Ingemansson R, Malmsjö M. The effect of intermittent and variable negative pressure wound therapy on wound edge microvascular blood flow. *Ostomy/Wound Manag*. 2010;56(3):60–67.
23. Birke-Sorensen H, Malmsjo M, Rome P, et al. International Expert Panel on Negative Pressure Wound Therapy [NPWT-EP], Martin R, Smith J. Evidence-based recommendations for negative pressure wound therapy: treatment variables (pressure levels, wound filler and contact layer)–steps towards an international consensus. *J Plast Reconstr Aesthetic Surg*. 2011;64(Suppl):S1–S16.
24. Lessing C, Slack P, Hong KZ, Kilpadi D, McNulty A. Negative pressure wound therapy with controlled saline Instillation (NPWTi): dressing properties and granulation response in vivo. *Wounds*. 2011;23(10):309–319.
25. Morykwas MJ, Faler BJ, Pearce DJ, Argenta LC. Effects of varying levels of subatmospheric pressure on the rate of granulation tissue formation in experimental wounds in swine. *Ann Plast Surg*. 2001;47(5):547–551.
26. Krasner DL. Managing wound pain in patients with vacuum-assisted closure devices. *Ostomy/Wound Manag*. 2002;48(5):38–43.
27. Webb LX. New techniques in wound management: vacuum-assisted wound closure. *J Am Acad Orthop Surg*. 2002;10(5):303–311.
28. BMI Classification. *Global Database on Body Mass Index*. World Health Organization; 2017. Available at: http://apps.who.int/bmi/index.jsp?introPage=intro_3.html. Accessed February 11, 2018.
29. Momeni A, Heier M, Bannasch H, Stark GB. Complications in abdominoplasty: a risk factor analysis. *J Plast Reconstr Aesthetic Surg*. 2009;62(10):1250–1254.
30. Amri R, Bordeianou LG, Sylla P, Berger DL. Obesity, outcomes and quality of care: body mass index increases the risk of wound-related complications in colon cancer surgery. *Am J Surg*. 2014;207(1):17–23.
31. Kamamoto F, Lima ALM, Rezende MR, et al. A new low-cost negative-pressure wound therapy versus a commercially available therapy device widely used to treat complex traumatic injuries: a prospective, randomized, non-inferiority trial. *Clinics (Sao Paulo)*. 2017;72(12):737–742.
32. Buller M, Lee TJ, Davis J, Wilhelmi BJ. Bolstering skin grafts with a surgical scrub brush: a cost-effective solution. *Eplasty*. 2017;7(17):e21.
33. Kundin JI. A new way to size up a wound. *Am J Nurs*. 1989;89(2):206–207.