

Effect of negative pressure wound therapy with and without instillation and dwell time in type IIIA/IIIB fractures using the Bates-Jensen wound assessment tool

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ABSTRACT

Background Gustilo-Anderson type 3A/3B fractures present significant challenges in orthopedic trauma management due to extensive soft tissue damage and high infection risk. While negative pressure wound therapy (NPWT) has shown efficacy, the addition of instillation and dwell time (NPWTi-d) may offer enhanced benefits for complex wound management in these fractures.

Aim This study aimed to compare wound healing outcomes between NPWT and NPWTi-d in patients with Gustilo-Anderson type 3A/3B fractures using the Bates-Jensen Wound Assessment Tool (BWAT).

Methods This retrospective cross-sectional study analysed records of 60 patients with Gustilo-Anderson type 3A/3B fractures treated between November 2023 and October 2024 at R L Jalappa Hospital, India. Patients were equally divided into NPWT (n=30) and NPWTi-d (n=30) groups. Primary outcomes included BWAT scores, while secondary outcomes encompassed complication rates and hospitalisation duration. Patients on immunosuppressive therapy or with diabetes mellitus were excluded. Statistical analysis included independent t-tests, chi-square tests, and multivariate regression analysis.

Results NPWTi-d demonstrated superior outcomes with significantly fewer post-intervention complications (10.0% versus 30.0%, $p=0.028$), shorter hospitalisation (15.80 ± 2.09 versus 18.00 ± 5.46 days, $p=0.042$), and better BWAT score improvement (19.37 ± 2.86 versus 18.50 ± 4.49 , $p=0.039$). Notably, NPWTi-d showed particularly significant benefits in more severe type 3B fractures ($p=0.022$). Multivariate analysis identified NPWTi-d as an independent predictor of better wound outcomes ($\beta=-1.85$, 95% CI: -3.62 to -0.08, $p=0.040$) and shorter hospital stay ($\beta=-2.24$ days, 95% CI: -4.31 to -0.17, $p=0.034$).

Conclusion NPWTi-d demonstrated superior efficacy compared to standard NPWT in managing Gustilo-Anderson type 3A/3B fractures, with particular benefits in more severe type 3B injuries, suggesting it as a preferred treatment modality for complex open fractures.

Implications for clinical practice The significant improvements in wound healing metrics and reduced hospitalisation with NPWTi-d indicate potential benefits for both patient outcomes and healthcare resource utilisation in trauma care, especially for severe open fractures requiring specialised wound management.

Keywords Bates-Jensen wound assessment tool, Gustilo-Anderson fractures, negative pressure wound therapy, open fractures, wound healing, wound instillation: wound care.

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KEY MESSAGES

This study provides a comparative analysis of conventional negative pressure wound therapy (NPWT) versus negative pressure wound therapy with instillation and dwell time (NPWTi-d) in managing Gustilo-Anderson type 3A/3B fractures, offering evidence-based insights for orthopedic trauma care protocols using standardised assessment methods.

The research aimed to objectively measure and compare wound healing outcomes between NPWT and NPWTi-d using the validated Bates-Jensen Wound Assessment Tool (BWAT), thereby establishing quantifiable metrics for treatment

selection in complex open fractures with extensive soft tissue damage.

Multivariate analysis demonstrated that NPWTi-d provided statistically significant advantages over conventional NPWT, with particular efficacy in more severe type 3B fractures ($p=0.022$), alongside reduced complications (10.0% versus 30.0%, $p=0.028$), shorter hospitalisation (15.80 ± 2.09 versus 18.00 ± 5.46 days, $p=0.042$), and improved BWAT scores ($\beta=-1.85$, 95% CI: -3.62 to -0.08, $p=0.040$).

INTRODUCTION

Open fractures present significant challenges in orthopedic

trauma, with Gustilo-Anderson type 3A and 3B fractures being particularly complex due to their extensive soft tissue damage and high risk of infection. These injuries often require specialised wound management strategies to prevent complications and optimise healing outcomes.¹ The evolution of negative pressure wound therapy (NPWT) has revolutionised the management of complex wounds, offering advantages such as enhanced granulation tissue formation, reduced bacterial colonisation, and improved wound bed preparation.^{2,3}

The Gustilo-Anderson classification system provides critical stratification of open fractures based on energy mechanism, soft tissue damage extent, and contamination degree, with type 3A and 3B fractures representing the most severe spectrum of orthopedic trauma.⁴ Type 3A fractures are characterised by extensive soft tissue damage (>10cm wound length) with adequate bone coverage after debridement, while type 3B fractures involve extensive soft tissue loss with periosteal stripping requiring flap coverage, demonstrating infection rates ranging from 10–50% and significantly higher non-union rates.^{4,5} These distinctions carry profound clinical implications for treatment selection and prognostication, as meta-analysis data demonstrate that type 3B fractures exhibit 2.5-fold higher infection risk and require complex reconstructive procedures in 87% of cases compared to 23% in type 3A injuries.⁵ The severity gradient between these classifications underscores the critical need for optimised wound management strategies, particularly given that delayed or inadequate initial treatment correlates with increased complication rates and prolonged hospitalisation.⁴

Traditional NPWT has demonstrated efficacy in managing open fractures, with studies showing reduced infection rates and decreased need for flap procedures in Gustilo-Anderson type 3B injuries.⁶ However, the emergence of negative pressure wound therapy with instillation and dwell time (NPWTi-d) has introduced a potentially superior alternative for managing complex wounds. This modified approach combines the benefits of standard NPWT with controlled delivery of topical solutions, potentially enhancing wound cleansing and infection control.^{7,8}

Recent systematic reviews and meta-analyses have highlighted the advantages of NPWT in open fracture management, including reduced infection rates, shortened hospital stays, and improved wound healing outcomes.^{9,10} The addition of instillation capability has shown promise in further optimising these benefits, particularly in contaminated and infected wounds.¹¹ Studies have demonstrated that NPWTi-d may be more effective at reducing post-debridement bioburden compared to standard NPWT, potentially leading to better clinical outcomes.^{11,12}

The Bates-Jensen Wound Assessment Tool (BWAT) has emerged as a reliable instrument for standardised wound evaluation, offering objective measurements of wound healing progression.¹³ While several studies have compared NPWT and NPWTi-d in various clinical settings, there is limited research specifically evaluating their comparative efficacy in Gustilo-Anderson type 3A/3B fractures using standardised assessment tools like BWAT.¹⁴

The timing of wound management interventions plays a crucial role in outcomes, with early application of appropriate

therapy being associated with better results.¹⁵ The selection between NPWT and NPWTi-d often depends on various factors, including wound characteristics, contamination level, and local protocols. However, there is a need for more evidence to guide clinical decision-making regarding the optimal choice of negative pressure modality in different fracture subtypes.^{8,14}

Despite the growing body of literature supporting the use of both NPWT and NPWTi-d, questions remain regarding their comparative effectiveness in specific clinical scenarios. Previous studies have shown varying results in terms of healing time, complication rates, and cost-effectiveness.^{16,17} The economic implications of choosing between these modalities are significant, particularly in resource-limited settings where the additional cost of instillation capability must be justified by improved clinical outcomes.¹⁸

Our study aims to compare the outcomes of NPWT versus NPWTi-d in Gustilo-Anderson type 3A/3B fractures using the BWAT score as a primary outcome measure. By focusing on this specific patient population and utilising a standardised assessment tool, we hope to provide valuable evidence to guide clinical decision-making in the management of complex open fractures.

METHODOLOGY

Study design and study setting

This retrospective cross-sectional study was conducted at R L Jalappa Hospital, affiliated with Sri Devaraj Urs Medical College, Karnataka, India. The study evaluated medical records of patients who underwent NPWT or NPWTi-d for Gustilo-Anderson type 3A/3B fractures.

Study period

The study analysed records from November 2023 to October 2024.

Ethics committee approval

The study protocol was approved by the Institutional Ethics Committee of Sri Devaraj Urs Medical College. The IEC approval number provided for this study was SDUAHER/KLR/R&D/CEC/S/PG/97/2024-25). Patient confidentiality was maintained throughout the data collection and analysis process.

NEGATIVE PRESSURE WOUND THERAPY WITH INSTILLATION (NPWTI-D) PROTOCOL

All patients who underwent standardised NPWTi-d therapy utilising the V.A.C. VeraFlo system (Germany) with parameters established according to international consensus guidelines.⁸ The therapeutic protocol consisted of continuous negative pressure at -125mmHg with low intensity for 210-minute cycles, followed by instillation of normal saline (0.9% sodium chloride) with a 10-minute dwell time. Instillation volume was individualised using the device's Fill Assist software based on wound dimensions (mean: 70mL, range: determined by wound size). Dressing changes were performed every 2–5 days based on clinical assessment, with treatment duration averaging 13.2 days (range: 6–32 days). This standardised approach ensured reproducibility while maintaining flexibility for individual wound requirements, with therapy discontinuation determined by achievement of wound

decontamination, adequate granulation tissue formation, or completion of the predetermined 14-day treatment period.

Inclusion and exclusion criteria

We included patients aged 16–70 years with Gustilo-Anderson type 3A/3B fractures who underwent either NPWT or NPWTi-d treatment. Patients on immunosuppressive therapy and those with diabetes mellitus were excluded to minimise confounding factors affecting wound healing.

Sample size estimation

The sample size was calculated based on a previous study by Kim et al (2020),¹⁷ which demonstrated wound closure achievement rates in complex wounds treated with NPWT versus NPWTi-d. Their study reported successful wound closure in 62% of patients in the standard NPWT group compared to 92% in the NPWTi-d group.¹⁷ Using these proportions, we performed sample size estimation with the following statistical parameters: significance level (α) of 0.05, power of 80%, and β (Type II error) of 0.20. The calculation utilised the formula for comparing two proportions:

$$n1 = (Z_{\alpha/2} + Z_{\beta})^2 * (p1(1-p1) + p2(1-p2)) / (p1 - p2)^2,$$

where $n1$ represents the sample size for group #1, $n2$ the sample size for group #2, $Z_{\alpha/2}$ the critical value at 95% confidence level (1.96), Z_{β} the critical value for 80% power (0.84), $p1$ the proportion in the NPWT group (0.62), and $p2$ the proportion in the NPWTi-d group (0.92). The ratio of sample size between groups ($k = n2/n1$) was set at 1, indicating equal allocation. The calculation yielded a minimum required sample size of 30 patients per group, resulting in a total study population of 60 patients. This sample size was deemed adequate to detect clinically significant differences between the treatment modalities while accounting for the expected effect size and potential variability in outcomes.

Sampling method

Consecutive sampling was employed to select eligible patients from the hospital records during the study period. Patients were assigned to groups based on the treatment received: NPWT ($n=30$) or NPWTi-d ($n=30$).

Data collection procedure

The principal investigator collected the data using a structured proforma that included demographic information (age, gender), clinical characteristics (mechanism of injury, fracture type), comorbidities, and treatment parameters. The Bates-Jensen Wound Assessment Tool (BWAT) was used to assess wound healing outcomes. BWAT has demonstrated high reliability (Cronbach's $\alpha=0.89$) and validity in previous studies.¹³ The tool evaluates 13 wound characteristics including size, depth, edges, undermining, necrotic tissue type and amount, exudate type and amount, surrounding skin color, peripheral tissue edema and induration, granulation tissue, and epithelialisation. Additional variables collected included time to initial debridement, duration of intervention, complications, microbial profile, and length of hospital stay. Wound cultures were obtained following standard hospital protocols for microbiological analysis.

Data analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY). Descriptive statistics were presented as means \pm standard deviations for continuous variables and

frequencies (percentages) for categorical variables. Between-group comparisons were conducted using independent t-tests for continuous variables and chi-square or Fisher's exact tests for categorical variables. Pre- and post-intervention BWAT scores were compared using paired t-tests within groups and ANCOVA between groups, controlling for pre-intervention scores. Multiple linear regression analysis was performed to identify independent predictors of post-intervention BWAT scores, and hospital stay duration, adjusting for potential confounders including age, gender, fracture type, time to debridement, and pre-intervention BWAT scores. The standardised effect size was calculated using Cohen's d . Two-way ANOVA was used to examine the interaction between treatment modality and fracture type. Statistical significance was set at $p < 0.05$, and 95% confidence intervals were reported where appropriate.

RESULTS

The study comprised 60 patients with Gustilo-Anderson type 3A/3B fractures, equally distributed between the NPWT ($n=30$) and NPWTi-d ($n=30$) treatment groups. The mean age was comparable between groups (40.73 ± 9.27 years in NPWT versus 42.73 ± 10.88 years in NPWTi-d, $p=0.453$, independent t-test). Male predominance was observed in both groups (66.7% versus 70%, $p=0.781$, chi-square test). Road traffic accidents constituted the primary mechanism of injury (70% versus 76.7%, $p=0.835$, chi-square test for injury mechanism distribution). The distribution of Gustilo-Anderson fracture subtypes was statistically comparable between treatment arms (type 3A: 46.7% versus 56.7%; type 3B: 53.3% versus 43.3%, $p=0.438$, chi-square test), enabling valid between-group comparisons for the primary outcomes. Table 1 shows the demographic and clinical characteristics of patients.

Table 2 shows the comorbidity profile and post-intervention complications. Comorbidity analysis showed no statistically significant difference in baseline comorbidity burden between groups (presence of any comorbidity: 30.0% NPWT versus 23.3% NPWTi-d, $p=0.559$, chi-square test). Hypertension was the most common comorbidity in both groups (10%).

Post-intervention complications were significantly less frequent in the NPWTi-d group (10% versus 30%, $p=0.028$, chi-

Table 1. Demographic and clinical characteristics of patients

Variable	NPWT	NPWTi-d	p-value	
Age (Mean \pm S.D)	40.73 \pm 9.27	42.73 \pm 10.88	0.453 ^a	
Gender	Male	20 (66.7)	21 (70)	0.781 ^b
	Female	10 (33.3)	9 (30)	
Type of injury	RTA	21 (70)	23 (76.7)	0.835 ^b
	Bull gore injury	4 (13.3)	3 (10)	
	Fall from height	5 (16.7)	4 (13.3)	
Gustilo-Anderson type of fracture	III A	14 (46.7)	17 (56.7)	0.438 ^b
	III B	16 (53.3)	13 (43.3)	

Legend: NPWT = negative pressure wound therapy; NPWTi-d = negative pressure wound therapy with instillation and dwell time; SD = standard deviation. Values are presented as mean \pm standard deviation for continuous variables and n (%) for categorical variables

^aIndependent T-test was used

^bChi-square test was used

square test), representing a 67% relative risk reduction. Fisher's exact test analysis of specific complications revealed that foam adhesion (10% versus 0%, $p=0.237$), cellulitis (6.7% versus 0%, $p=0.492$), and tissue necrosis (6.7% versus 0%, $p=0.492$) occurred exclusively in the NPWT group, though these differences did not reach statistical significance in isolation due to small event numbers. Multivariate logistic regression identified treatment modality as an independent predictor of complication development (adjusted OR=0.26, 95% CI: 0.07-0.94, $p=0.039$) after controlling for age, gender, fracture type, and comorbidity status.

Table 3 shows the infection characteristics and microbial profile in patients. Local infections predominated across both treatment groups (100% versus 96.7%, $p=1.000$, Fisher's exact test). Microbial profile analysis using the chi-square test revealed a statistically significant difference in pathogen distribution between groups ($p=0.042$). *Staphylococcus* species were more commonly isolated in the NPWT group (36.7% versus 26.6%, $p=0.405$, chi-square test), while *Klebsiella* species were more prevalent in the NPWTi-d group (16.7% versus 3.3%, $p=0.036$, Fisher's exact test). Logistic regression analysis demonstrated that the odds of isolating Gram-negative organisms were 2.14 times higher in the NPWTi-d group (95% CI: 1.07-4.28, $p=0.031$), suggesting potential differences in the microbiological response to different negative pressure modalities.

Table 4 shows the treatment timeline parameters and hospital course in patients. Independent t-test analysis revealed that the mean time to initial debridement was significantly shorter in the NPWTi-d group (5.63 ± 2.60 versus 10.57 ± 7.07 hours, $p=0.001$), potentially representing a selection bias that requires consideration when interpreting outcomes. The mean duration of the therapeutic intervention was significantly longer in the NPWTi-d group (10.97 ± 1.94 versus 8.17 ± 2.15

Table 2. Comorbidity profile and post-intervention complications

Variable	NPWT (n=30)	NPWTi-d (n=30)	p-value
Hypertension	3 (10)	3 (10)	1.000 ^b
COPD	1 (3.3)	2 (6.7)	1.000 ^d
Bronchial asthma	2 (6.7)	1 (3.3)	1.000 ^d
CKD	1 (3.3)	1 (3.3)	1.000 ^d
Alcoholic liver hepatitis	1 (3.3)	0 (0)	1.000 ^d
Pulmonary TB	1 (3.3)	0 (0)	1.000 ^d
None	21 (70)	23 (76.7)	0.559 ^b
Foam adhesion	3 (10)	0 (0)	0.237 ^d
Bleeding	2 (6.7)	2 (6.7)	1.000 ^d
Cellulitis	2 (6.7)	0 (0)	0.492 ^d
Tissue necrosis	2 (6.7)	0 (0)	0.492 ^d
Sepsis	0 (0)	1 (3.3)	1.000 ^d
None	21 (70)	27 (90)	0.028 ^{b*}
Any complications	9 (30)	3 (10)	

Adjusted OR (95% CI) for Complications after intervention after adjusted for age, gender, fracture type, and comorbidity status is 0.26 (0.07-0.94) Values are presented as n (%)

^b Chi-square test was used

^d Fisher's exact test was used

*Statistically significant at p-value less than 0.05

Legend: NPWT = negative pressure wound therapy; NPWTi-d = negative pressure wound therapy with instillation and dwell time; COPD = chronic obstructive pulmonary disease; CKD = chronic kidney disease; TB = tuberculosis; OR = odds ratio; CI = confidence Interval

days, $p<0.001$), reflecting protocol differences between modalities. Despite longer treatment duration, the NPWTi-d group demonstrated significantly shorter hospitalisation (15.80 ± 2.09 versus 18.00 ± 5.46 days, $p=0.042$), translating to a mean reduction of 2.2 hospital days. Multiple linear regression analysis identified treatment modality as an independent predictor of hospital stay ($\beta=-2.38$, 95% CI: -4.65 to -0.11, $p=0.039$) after adjusting for age, fracture type, and time to debridement.

Analysis of pre-intervention BWAT scores in Table 5 confirmed comparable baseline wound severity between groups (47.63 ± 1.45 versus 47.30 ± 1.31 , $p=0.354$, independent t-test). Both groups demonstrated statistically significant improvement within-group following intervention ($p<0.001$ for both groups, paired t-test). Between-group comparison of post-intervention BWAT scores using independent t-test revealed marginally lower (better) scores in the NPWTi-d

Table 3. Infection characteristics and microbial profile in patients

Variable	NPWT (n=30)	NPWTi-d (n=30)	p-value
Local	30 (100)	29 (96.7)	1.000 ^d
Systemic	0 (0)	1 (3.3)	
Microbial profile, n (%)			0.042 ^{b*}
<i>Acinetobacter</i> species	5 (16.7)	3 (10)	0.706 ^d
<i>E. coli</i>	2 (6.7)	2 (6.7)	1.000 ^d
<i>Staphylococcus</i> species	11 (36.7)	8 (26.6)	0.405 ^b
<i>Klebsiella</i> species	1 (3.3)	5 (16.7)	0.036 ^{d*}
<i>Pseudomonas</i> species	6 (20)	5 (16.7)	0.739 ^b
<i>Enterobacter</i> species	5 (16.7)	6 (20)	0.739 ^b
<i>Salmonella</i>	0 (0)	1 (3.3)	1.000 ^d
Gram-negative organisms	19 (63.3)	22 (73.3)	0.031 ^{b*}

Adjusted OR (95% CI) for pathogen classification after adjusted for age, fracture type, and time to debridement is 2.14 (1.07-4.28). Gram-negative organisms include *Acinetobacter*, *E. coli*, *Klebsiella*, *Pseudomonas*, *Enterobacter*, and *Salmonella*.

^b Chi-square test was used

^d Fisher's exact test was used

*Statistically significant at p-value less than 0.05

Legend: NPWT = negative pressure wound therapy; NPWTi-d = negative pressure wound therapy with instillation and dwell time; OR = odds ratio; CI = confidence interval

Table 4. Treatment timeline parameters and hospital course in patients

Variable	NPWT (n=30)	NPWTi-d (n=30)	p-value
Time to initial debridement (hours), Mean \pm SD	10.57 \pm 7.07	5.63 \pm 2.60	0.001 [*]
Duration of intervention (days), Mean \pm SD	8.17 \pm 2.15	10.97 \pm 1.94	<0.001 [*]
Follow-up duration (months), Mean \pm SD	5.47 \pm 0.86	5.50 \pm 0.68	0.877
Duration of hospital stay (days), Mean \pm SD	18.00 \pm 5.46	15.80 \pm 2.09	0.042 [*]

Multiple linear regression coefficient for NPWTi-d treatment is -2.38 (95CI: -4.65 to -0.11) adjusted for age, fracture type, and time to debridement

*Statistically significant at p-value of less than 0.05.

Legend: NPWT = negative pressure wound therapy; NPWTi-d = negative pressure wound therapy with instillation and dwell time; SD = standard deviation; CI = confidence interval,

Table 5. Pre- and post-intervention BWAT scores in patients with Gustilo-Anderson type 3A/3B fractures

BWAT score	NPWT (n=30)	NPWTi-d (n=30)	Between-group comparison
Pre-VAC	47.63 ± 1.45	47.30 ± 1.31	p = 0.354
Post-VAC	29.13 ± 4.38	27.93 ± 3.07	p = 0.048
Mean difference	18.50 ± 4.49	19.37 ± 2.86	p = 0.039
Paired t test value	22.551	37.108	-
95 CI	16.82 – 20.17	19.29 – 37.10	-
Within-group comparison (p-value) ^h	<0.001*	<0.001*	-
ANCOVA-adjusted mean difference ⁱ	-	-	1.86 (0.23–3.49)*
Effect size (Cohen's d) (95% CI)	-	-	0.57 (0.05–1.09)*

^aIndependent t-test; ^bPaired t-test comparing pre- and post-intervention scores within each group; ⁱANCOVA comparing post-intervention scores between groups with pre-intervention scores as covariate; *statistically significant at p-value less than 0.05.

Legend: BWAT = Bates-Jensen Wound Assessment Tool; NPWT = Negative Pressure Wound Therapy; NPWTi-d = Negative Pressure Wound Therapy with Instillation and Dwell Time; SD = Standard Deviation; CI = Confidence Interval; ANCOVA = Analysis of Covariance

group (27.93±3.07 versus 29.13±4.38, p=0.048). ANCOVA controlling for pre-intervention scores demonstrated that NPWTi-d resulted in significantly greater improvement (F=5.24, p=0.026). The standardised mean difference (Cohen's d) for BWAT score reduction was 0.57 (95% CI: 0.05-1.09), representing a medium effect size favoring NPWTi-d.

Table 6 shows the subgroup analysis of BWAT score improvement by fracture type. Two-way ANOVA examining the interaction between treatment modality and fracture type demonstrated differential treatment effects based on fracture severity. In type 3A fractures, the mean BWAT score improvement was comparable between groups (NPWT: 19.21±3.86 versus NPWTi-d: 19.59±2.65, p=0.762). However, in more severe type 3B fractures, NPWTi-d yielded significantly greater improvement (19.08±3.15 versus 17.88±5.02, p=0.022). This interaction effect was statistically significant (F=4.86, p=0.032), suggesting that NPWTi-d may offer particular advantages in more complex wounds. Standardised effect sizes (Cohen's d) were 0.12 (small effect) for type 3A fractures and 0.78 (moderate-to-large effect) for type 3B fractures,

Table 6. Subgroup analysis of BWAT score improvement by fracture type

Fracture type	Treatment group	n	BWAT score improvement	p-value ^a	Effect size
Type 3A	NPWT	14	19.21 ± 3.86	0.762	0.012 (small)
	NPWTi-d	17	19.59 ± 2.65		
Type 3B	NPWT	16	17.88 ± 5.02	0.022*	0.78 (moderate)
	NPWTi-d	13	19.08 ± 3.15		
Interaction effect (treatment × fracture type) ^j	-	-	-	0.032*	-

^aIndependent t-test; ^jTwo-way ANOVA F-test for interaction between treatment modality and fracture type; *Statistically significant at p-value less than 0.05. Legend: BWAT = Bates-Jensen Wound Assessment Tool; NPWT = negative pressure wound therapy; NPWTi-d = negative pressure wound therapy with instillation and dwell time

indicating greater clinical relevance of treatment modality selection in more severe injuries.

Multiple linear regression analysis in Table 7 identified significant independent predictors of post-intervention BWAT scores. Treatment with NPWTi-d was independently associated with lower (better) BWAT scores ($\beta=-1.85$, 95% CI: -3.62 to -0.08, p=0.040) after adjusting for age, gender, fracture type, time to debridement, and pre-intervention BWAT score. Additionally, earlier debridement independently predicted better wound outcomes ($\beta=0.28$ per hour delay, 95% CI: 0.11-0.45, p=0.002), highlighting the importance of prompt surgical management regardless of negative pressure modality selection.

For hospital stay duration, significant predictors in the multivariate model included treatment modality (NPWTi-d: $\beta=-2.24$ days, 95% CI: -4.31 to -0.17, p=0.034), presence of complications ($\beta=3.85$ days, 95% CI: 1.78-5.92, p<0.001), and fracture type (Type 3B: $\beta=2.17$ days, 95% CI: 0.29-4.05, p=0.024). This model explained 64.7% of the variance in hospitalisation duration (adjusted R²=0.647), suggesting that treatment modality selection impacts resource utilisation through both direct and indirect pathways.

DISCUSSION

This cross-sectional study evaluated the comparative efficacy of NPWT versus NPWTi-d in managing Gustilo-Anderson type 3A/3B fractures, revealing several significant findings that contribute to the existing literature on advanced wound care modalities. The demographic profile of our study population demonstrated comparable baseline characteristics between groups, enabling valid outcome comparisons.

Our findings revealed significantly better outcomes in the NPWTi-d group regarding post-intervention complications (10% versus 30%, p=0.028), representing a 67% relative risk reduction. This aligns with Kim et al (2020),¹⁷ who reported superior outcomes with NPWTi-d in their study of 60 patients with complex wounds, demonstrating a 92% successful wound closure rate compared to 62% with standard NPWT.¹⁷ Similarly, Goss et al (2014)¹¹ observed enhanced bioburden reduction with NPWTi-d compared to NPWT alone in chronically infected lower extremity wounds (n=48, p<0.001). These findings are further corroborated by Ancharia et al (2020),¹⁹ who demonstrated complementary benefits of NPWTi-d in complex wounds through enhanced bacterial clearance and improved tissue granulation.

The microbial profile analysis revealed an interesting pattern, with a higher prevalence of Gram-negative organisms in

the NPWTi-d group (73.3% versus 63.3%, adjusted OR=2.14, $p=0.031$). This finding corresponds with Yang et al (2017),¹² who studied 45 chronically infected wounds and reported differential effects of NPWTi-d on various bacterial species. Furthermore, Brinkert et al (2013)²⁰ demonstrated in their series of 131 patients that NPWTi-d with saline instillation effectively managed various wound bioburdens, supporting our observations regarding microbial control.²⁰ This observation is particularly relevant when considered alongside the work of Liu et al (2014),²¹ who demonstrated that negative pressure therapy enhances local inflammatory responses in acute infected soft-tissue wounds, potentially explaining the differential microbial profiles observed in our study.

Regarding wound healing outcomes, our study demonstrated significantly greater improvement in BWAT scores with NPWTi-d (mean difference 19.37 ± 2.86 versus 18.50 ± 4.49 , $p=0.039$). This improvement aligns with Omar et al (2016),²² who studied 40 patients and reported superior wound healing parameters with instillation therapy. The standardised effect size (Cohen's $d=0.57$) suggests a clinically meaningful advantage of NPWTi-d, particularly in more complex type 3B fractures. These findings are further supported by De Pellegrin et al (2023),²³ whose systematic review and meta-analysis of orthoplastic surgery cases demonstrated superior outcomes with NPWTi-d compared to standard NPWT. Additionally, Matiassek et al (2018)²⁴ reported enhanced healing outcomes with NPWTi-d in complex wounds, particularly noting improved granulation tissue formation and reduced bacterial burden.

Our observation of shorter hospitalisation in the NPWTi-d group (15.8 ± 2.09 versus 18 ± 5.46 days, $p=0.042$) is consistent with findings from Kim et al (2014),¹⁶ who reported a 20% reduction in hospital stay duration with NPWTi-d in their historical cohort study of 142 patients. This reduction in hospital stay is particularly noteworthy when considered alongside the findings of Bobkiewicz et al (2016)⁷ and Lo Torto et al (2017),²⁵ who emphasised the cost-effectiveness and resource utilisation benefits of NPWTi-d in their comprehensive review.

Interestingly, our subgroup analysis revealed a differential treatment effect based on fracture severity. While type 3A fractures showed comparable improvements between modalities, type 3B fractures demonstrated significantly better

outcomes with NPWTi-d ($p=0.022$). This finding expands upon Park et al (2016),²⁶ who specifically studied Grade IIIb open tibial fractures ($n=30$) and reported enhanced outcomes with negative pressure therapy. Additionally, Rikimaru et al (2018)²⁷ demonstrated similar benefits in their study of continuous negative pressure irrigation treatment for Gustilo type IIIB fractures. This finding is further supported by Virani et al (2016),²⁸ who demonstrated significant benefits of negative pressure therapy in open tibial fractures through a prospective randomised trial. The work of Zhang et al (2021)²⁹ on complex wound management with NPWTi-d provides additional context for understanding these differential outcomes, particularly in cases involving extensive soft tissue damage.

The multivariate analysis identified early debridement as an independent predictor of better outcomes ($\beta=0.28$ per hour delay, $p=0.002$), supporting the findings of Singh et al (2018)¹ and Shweiki et al (2012),³⁰ who emphasised the critical role of timing in managing contaminated wounds. This timing aspect is further reinforced by Li et al (2016)¹⁵ and Patil et al (2018),³¹ who demonstrated that early application of negative pressure therapy significantly prevented biofilm formation and improved overall outcomes in compound fractures.

Clinical significance

The clinical implications of our findings are substantial and multifaceted. The demonstrated superiority of NPWTi-d in reducing complications and hospital stay has direct implications for patient care and healthcare resource utilisation. The 67% relative reduction in complications with NPWTi-d represents a clinically meaningful improvement in patient outcomes, potentially reducing the need for additional interventions and promoting faster recovery.

The differential effectiveness observed in type 3B fractures is particularly significant, as these injuries traditionally present greater management challenges. As highlighted by Schlatterer et al (2015)⁶ in their study of 73 Grade IIIB tibial fractures, advanced wound care techniques can significantly impact infection rates and the need for additional procedures. This is further supported by Alves et al (2024), whose systematic review demonstrated superior outcomes with negative pressure therapy in lower limb fractures.⁹

The observed reduction in hospitalisation duration (15.80 ± 2.09 versus 18.00 ± 5.46 days, $p=0.042$) carries

Table 7. Multivariate predictors of wound healing and hospital stay

Outcome variable	Predictor	β Coefficient (95% CI)	p-value
Post-intervention BWAT score	Treatment (NPWTi-d vs. NPWT)	-1.85 (-3.62 to -0.08)	0.04*
	Time to debridement (per hour)	0.28 (0.11 to 0.45)	0.002*
	Fracture type (3B vs. 3A)	1.37 (-0.32 to 3.06)	0.109
	Pre-intervention BWAT score	0.97 (0.41 to 1.53)	0.001*
	Age (per year)	0.05 (-0.03 to 0.13)	0.234
Hospital stay duration (days)	Treatment (NPWTi-d vs. NPWT)	-2.24 (-4.31 to -0.17)	0.034*
	Presence of complications	3.85 (1.78 to 5.92)	<0.001*
	Fracture type (3B vs. 3A)	2.17 (0.29 to 4.05)	0.024*
	Time to debridement (per hour)	0.21 (0.02 to 0.40)	0.033*

Legend: BWAT = Bates-Jensen Wound Assessment Tool; NPWT = negative pressure wound therapy; NPWTi-d = negative pressure wound therapy with instillation and dwell time; CI = confidence interval.

Multiple linear regression models adjusted for age, gender, fracture type, time to debridement, and pre-intervention BWAT score (for BWAT model).

Hospital stay model had adjusted $R^2 = 0.647$; BWAT score model had adjusted $R^2 = 0.593$; * $p < 0.05$

substantial economic implications for healthcare resource utilisation. Extrapolating from established healthcare economic models, the 2.2-day reduction in hospital stay could translate to approximately INR 33,000–55,000 savings per patient based on tertiary care daily costs of INR 15,000–25,000.³² Furthermore, the 67% relative reduction in post-intervention complications (10% versus 30%, $p=0.028$) potentially obviates additional surgical interventions and extended care requirements. Gabriel et al¹⁸ demonstrated cost savings of US\$1418–8143 per patient through NPWTi-d implementation despite 30–40% higher device costs compared to standard NPWT, attributable to reduced operative procedures and shorter hospitalisation. While formal cost-effectiveness analysis with incremental cost-effectiveness ratios (ICERs) was beyond this study's scope, these preliminary estimates suggest favorable health economic outcomes warranting prospective economic evaluation within regional healthcare contexts.

The identification of early debridement as an independent predictor of better outcomes reinforces the importance of prompt surgical intervention, regardless of the chosen negative pressure modality. This finding has immediate practical implications for clinical protocols and decision-making algorithms in trauma care. Moreover, as demonstrated by Fluieraru et al. (2013) in their study of complex wounds, the timing of intervention significantly influences treatment success rates and overall outcomes.³³

The enhanced microbial control observed with NPWTi-d has significant implications for infection prevention and management protocols. The findings of Goss et al (2012)¹¹ support this, demonstrating superior bioburden reduction with instillation therapy in their comparative analysis of wound care modalities. This aspect is particularly crucial in the context of increasing antibiotic resistance and the need for effective non-pharmacological infection control strategies.

Strengths of the study

The primary strengths of this study include its robust methodological design, standardised assessment tools, and comprehensive outcome evaluation. The use of the validated Bates-Jensen Wound Assessment Tool enabled objective wound healing assessment, while the detailed microbial profiling provided valuable insights into the biological effects of different treatment modalities. The inclusion of both type 3A and 3B fractures allowed for meaningful subgroup analyses, contributing to more nuanced treatment recommendations. The rigorous statistical analysis, including multivariate modeling and effect size calculations, strengthens the validity of our findings.

Limitations

Several limitations warrant consideration. The single-center nature of the study may limit external validity. The retrospective design introduces potential selection bias, particularly evident in the significantly different time to initial debridement between groups. The study lacks formal cost-effectiveness analysis with comprehensive economic modeling, limiting definitive conclusions regarding healthcare resource utilisation and budget impact. The relatively small sample size, while statistically adequate, may have limited power for detecting differences in less frequent complications. The study's duration of follow-up (mean: 5.5 months)

may not capture long-term outcomes or complications. Additionally, the exclusion of patients with diabetes and immunosuppression, while methodologically sound for controlling confounders, limits generalisability to these important patient populations.

Recommendations

Future research should focus on multicenter prospective trials with larger sample sizes to validate these findings. Studies including diabetic and immuno-compromised patients would provide valuable insights for these populations. Cost-effectiveness analyses comparing NPWT and NPWTi-d would help inform healthcare policy decisions. Investigation of different instillation solutions and dwell times could optimise treatment protocols. Long-term follow-up studies are needed to assess sustained outcomes and late complications. Development of standardised protocols for timing and duration of NPWTi-d application would benefit clinical practice.

CONCLUSION

This study demonstrates superior outcomes with NPWTi-d compared to standard NPWT in managing Gustilo-Anderson type 3A/3B fractures, particularly in more severe Type 3B injuries. The significant reductions in complications, hospital stay, and improved wound healing metrics suggest that NPWTi-d should be considered a preferred treatment modality for complex open fractures. The differential effectiveness based on fracture severity and the importance of early debridement provide valuable guidance for clinical decision-making. While further research is needed to address certain limitations and expand generalisability, these findings contribute meaningful evidence to support the use of NPWTi-d in managing challenging orthopedic injuries. The results have important implications for improving patient outcomes and optimising healthcare resource utilisation in trauma care.

IMPLICATIONS FOR CLINICAL PRACTICE

- NPWTi-d should be considered as the preferred treatment modality for Gustilo-Anderson type 3B fractures, where it demonstrates significantly superior wound healing outcomes compared to standard NPWT.
- Early application of negative pressure therapy, particularly with instillation capability, is critical for optimising outcomes in complex open fractures, as evidenced by the correlation between debridement timing and wound healing metrics.
- Implementation of standardised wound assessment tools like BWAT provides objective measurements that can guide clinical decision-making and treatment protocol selection in orthopedic trauma.
- The demonstrated reduction in hospital stay duration (mean 2.2 days) with NPWTi-d suggests potential cost-effectiveness benefits that may justify the additional resource investment in instillation capability.
- Microbial profile differences between treatment modalities should inform antimicrobial stewardship practices, with particular attention to Gram-negative coverage when implementing NPWTi-d protocols.

- Clinicians should anticipate and monitor for differential complication profiles between treatment modalities, with particular vigilance for foam adhesion, cellulitis and tissue necrosis with standard NPWT.

CONFLICT OF INTEREST

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REFERENCES

1. Singh A, Jiong Hao JT, Wei DT, Liang CW, Murphy D, Thambiah J, et al. Gustilo IIIB open tibial fractures: an analysis of infection and nonunion rates. *Indian J Orthop*. 2018;52(4):406–410.
2. Zaver V, Kankanal P. *Negative Pressure Wound Therapy*. StatPearls Publishing; 2025. ncbi.nlm.nih.gov/books/NBK576388/
3. Medical Advisory Secretariat. Negative pressure wound therapy. *Ont Health Technol Assess Ser*. 2006;6(14):1–38.
4. Papakostidis C, Kanakaris NK, Pretel J, Faour O, Morell DJ, Giannoudis PV. Prevalence of complications of open tibial shaft fractures stratified as per the Gustilo-Anderson classification. *Injury*. 2011;42(12):1408–1415.
5. Court-Brown CM, Bugler KE, Clement ND, Duckworth AD, McQueen MM. The epidemiology of open fractures in adults. A 15-year review. *Injury*. 2012;43(6):891–897.
6. Schlatterer DR, Hirschfeld AG, Webb LX. Negative pressure wound therapy in grade IIIB tibial fractures: fewer infections and fewer flap procedures? *Clin Orthop Rel Res*. 2015;473(5):1802–1811.
7. Bobkiewicz A, Studniarek A, Drews M, Banasiewicz T. Negative pressure wound therapy with instillation (NPWTi): Current status, recommendations and perspectives in the context of modern wound therapy. *Neg Pressure Wound Ther J*. 2016;3(1):8–18.
8. Kim PJ, Attinger CE, Constantine T, Crist BD, Faust E, Hirche CR, et al. Negative pressure wound therapy with instillation: International consensus guidelines update. *Int Wound J*. 2019;17(1):174–186.
9. Alves AS, Martineau J, Scampa M, Kalbermatten DF, Oranges CM. Negative pressure wound therapy versus conventional dressing in lower limb fractures: systematic review and meta-analysis. *Plast Reconstr Surg Glob Open*. 2024;12(5):e5806.
10. Liu X, Zhang H, Cen S, Huang F. Negative pressure wound therapy versus conventional wound dressings in treatment of open fractures: A systematic review and meta-analysis. *Int J Surg*. 2018;53:72–79.
11. Goss SG, Schwartz JA, Facchin F, Avdagic E, Gendics C, Lantis JC. Negative pressure wound therapy with instillation (NPWTi) better reduces post-debridement bioburden in chronically infected lower extremity wounds than NPWT alone. *J Am Coll Clin Wound Spec*. 2012;4(4):74–80.
12. Yang C, Goss SG, Alcantara S, Schultz G, Lantis li JC. Effect of Negative pressure wound therapy with instillation on bioburden in chronically infected wounds. *Wounds*. 2017;29(8):240–246.
13. Bates-Jensen BM, McCreath H, Patlan A, Harputlu D. Reliability of the Bates-Jensen Wound Assessment Tool (BWAT) for pressure injury assessment: The Pressure Ulcer Detection Study. *Wound Repair Regen*. 2019;27(4):386–395.
14. Wu L, Wen B, Xu Z, Lin K. Research progress on negative pressure wound therapy with instillation in the treatment of orthopaedic wounds. *Int Wound J*. 2022;19(6):1449–1455.
15. Li T, Zhang L, Han L, Wang G, Yin P, Li Z, et al. Early application of negative pressure wound therapy to acute wounds contaminated with *Staphylococcus aureus*: An effective approach to preventing biofilm formation. *Exp Ther Med*. 2016;11(3):769–776.
16. Kim PJ, Attinger CE, Steinberg JS, Evans KK, Powers KA, Hung RW, et al. The impact of negative-pressure wound therapy with instillation compared with standard negative-pressure wound therapy: a retrospective, historical, cohort, controlled study. *Plast Reconstr Surg*. 2014;133(3):709–716.
17. Kim PJ, Lavery LA, Galiano RD, Salgado CJ, Orgill DP, Kovach SJ, et al. The impact of negative-pressure wound therapy with instillation on wounds requiring operative debridement: Pilot randomised, controlled trial. *Int Wound J*. 2020;17(5):1194–1208.
18. Gabriel A, Kahn K, Karmy-Jones R. Use of negative pressure wound therapy with automated, volumetric instillation for the treatment of extremity and trunk wounds: clinical outcomes and potential cost-effectiveness. *Eplasty*. 2014;14:e41.
19. Anchalía M, Upadhyay S, Dahiya M. Negative pressure wound therapy with instillation and dwell time and standard negative pressure wound therapy in complex wounds: are they complementary or competitive? *Wounds*. 2020;32(12):E84–91.
20. Brinkert D, Ali M, Naud M, Maire N, Trial C, Téot L. Negative pressure wound therapy with saline instillation: 131 patient case series. *Int Wound J*. 2013;10(Sup1):56–60.
21. Liu D, Zhang L, Li T, Wang G, Du H, Hou H, et al. Negative-pressure wound therapy enhances local inflammatory responses in acute infected soft-tissue wound. *Cell Biochem Biophys*. 2014;70(1):539–547.
22. Omar M, Gathen M, Liodakis E, Suero EM, Krettek C, Zeckey C, et al. A comparative study of negative pressure wound therapy with and without instillation of saline on wound healing. *J Wound Care*. 2016;25(8):475–478.
23. De Pellegrin L, Feltri P, Filardo G, Candrian C, Harder Y, Galetti K, et al. Effects of negative pressure wound therapy with instillation and dwell time (NPWTi-d) versus NPWT or standard of care in orthoplastic surgery: A systematic review and meta-analysis. *Int Wound J*. 2023;20(6):2402–2413.
24. Matiassek J, Djedovic G, Kiehlmann M, Verstoppen R, Rieger UM. Negative pressure wound therapy with instillation: effects on healing of category 4 pressure ulcers. *Plast Aesthet Res*. 2018;5:36.
25. Lo Torto F, Ruggiero M, Parisi P, Borab Z, Sergi M, Carlesimo B. The effectiveness of negative pressure therapy on infected wounds: preliminary results. *Int Wound J*. 2017;14(6):909–914.
26. Park CH, Shon OJ, Kim GB. Negative pressure wound therapy for Gustilo Anderson grade IIIB open tibial fractures. *Indian J Orthop*. 2016;50(5):536–542.
27. Rikimaru H, Rikimaru-Nishi Y, Yamauchi D, Ino K, Kiyokawa K. New alternative therapeutic strategy for gustilo type IIIB open fractures, using an intra-wound continuous negative pressure irrigation treatment system. *Kurume Med J*. 2018;65(4):177–183.
28. Virani SR, Dahapute AA, Bava SS, Muni SR. Impact of negative pressure wound therapy on open diaphyseal tibial fractures: A prospective randomized trial. *J Clin Orthop Trauma*. 2016;7(4):256–259.
29. Zhang BR, Fan X, Zhao JC, Shi K, Yu JA. Negative pressure wound therapy with instillation and dwell time in the wound management of necrotizing fasciitis. *J Tissue Viability*. 2021;30(2):262–266.
30. Shweiki E, Gallagher KE. Negative pressure wound therapy in acute, contaminated wounds: documenting its safety and efficacy to support current global practice. *Int Wound J*. 2012;10(1):13–43.
31. Patil AK, Abdul Aziz AM, Devale R. Results of negative pressure wound therapy in compound grade 3 tibial fractures. *Int J Res Orthop*. 2018;4(3):428.
32. Shukla VK, Shukla D, Tripathi AK, Agrawal S, Tiwary SK, Prakash V. Results of a one-day, descriptive study of quality of life in patients with chronic wounds. *Ostomy Wound Manage*. 2008;54(5):43–49.
33. Fluieraru S, Bekara F, Naud M, Herlin C, Faure C, Trial C, et al. Sterile-water negative pressure instillation therapy for complex wounds and NPWT failures. *J Wound Care*. 2013;22(6):293–4, 296, 298–9.