Am J Transl Res 2025;17(12):9894-9904
www.ajtr.org /ISSN:1943-8141/AJTR0168530

Original Article

Clinical efficacy of mechanically activated tissue retractor combined with vacuum sealing drainage for treating deep soft tissue defects: a prospective study

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Received September 2, 2025; Accepted November 27, 2025; Epub December 15, 2025; Published December 30, 2025

Abstract: Objective: This study aimed to compare the clinical efficacy of mechanically activated tissue retractor (MATR) combined with vacuum sealing drainage (VSD) versus conventional VSD for treating deep soft tissue defects. Methods: This prospective study included 53 patients with deep soft tissue defects treated between July 2024 and April 2025. The combination group (26 patients) received MATR combined with VSD, while the control group (27 patients) received conventional VSD. Outcome measures included defect healing time, rate of defect healing, mature granulation, graft survival status, pain (Visual Analog Scale, VAS), functional mobility (Activities of Daily Living Scale, ADLS), scarring (Vancouver Scar Scale, VSS), and perioperative complications. Chi-square test, t-test, and ANOVA were used to compare differences. Results: The combination group demonstrated a significantly shorter defect healing time and lower perioperative complication rate than the control group (all $P < 0.05$). At 14 days and 21 days after surgery, the combination group demonstrated superior defect healing, mature granulation, and skin survival status compared to the control group (all $P < 0.05$). Additionally, the combination group had significantly lower VAS scores and higher ADLS scores than the control group (all $P < 0.05$). At 3 months after defect healing, the combination group again showed significantly lower VAS and VSS scores, and higher ADLS scores than the control group (all $P < 0.05$). Conclusion: MATR combined with VSD was more effective in treating deep soft tissue defects compared to conventional VSD.

Keywords: Tissue retractor, vacuum sealing drainage, reconstruction, soft tissue, prospective

Introduction

With the advancement of surgical reconstruction techniques, clinicians can now successfully repair complex tissue defects of various regions [1]. However, the management of deep soft tissue defects remains a significant clinical challenge. These injuries are defined by full-thickness tissue loss extending beyond the subcutaneous layer to involve underlying structures such as fascia, muscle, tendon, or bone, resulting in functional compromise of the extremity and the exposure of structures devoid of epithelial regenerative capacity [2]. Such defects, frequently resulting from severe trauma, complicate the treatment process by disrupting local biomechanics and increasing susceptibility to infection [3]. Inadequate treatment can lead to prolonged wound non-healing, worsening patients' satisfaction and quality of life (QoL) [4]. Traditional flap transplantation (e.g., local, axial, or free flap) supports soft tissue healing but is associated with prolonged pain, suboptimal functional recovery, and various complications due to restricted daily activities [5-7]. Given the relative advantages and disadvantages of each approach, the optimal treatment for deep soft tissue defects remains controversial.

Since its commercial introduction in the 1990s, negative pressure wound therapy (NPWT) has

https://doi.org/10.62347/TORU2999

emerged as the gold standard for soft tissue defect management, with its clinical efficacy well-documented by extensive clinical studies [8-10]. The therapeutic mechanisms of NPWT involve four primary aspects [9]. Initially, the applied negative pressure generates macro-mechanical stress to facilitate defect contraction, as well as micro-mechanical stress to promote angiogenesis and granulation tissue formation. Subsequently, continuous exudate drainage alleviates edema by removing excessive wound fluid, thus reducing vascular compression and enhancing tissue perfusion. Concurrently, this drainage process removes pathogenic microorganisms and inflammatory mediators that may hinder wound healing. Ultimately, the system establishes and maintains an optimal moist wound environment while providing effective barrier protection.

As a widely utilized NPWT modality, vacuum sealing drainage (VSD) has proven effective in enhancing microcirculation, diminishing edema, and stimulating granulation tissue formation through maintained negative pressure [11]. However, conventional VSD alone fails to reconstruct the three-dimensional space and complex biomechanical microenvironment required for functional tissue regeneration. Mechanobiologic research has revealed that cyclic mechanical stretching activates crucial cellular mechanotransduction pathways, modulating essential biological processes including angiogenesis and extracellular matrix (ECM) remodeling, which collectively contribute to improved soft tissue regeneration [12]. Building on this principle, the mechanically activated tissue retractor (MATR) represents a significant therapeutic innovation. Previous studies have demonstrated that devices applying controlled mechanical stimulation can enhance wound healing by upregulating vascular endothelial growth factor (VEGF) expression and promoting aligned collagen deposition, leading to a 30-40% improvement in tissue regeneration quality compared to static therapies [13, 14]. Therefore, the MATR combined with VSD may offer a promising strategy to address the limitations of conventional NPWT, presenting substantial potential for treating deep soft tissue defects by synergistically integrating macro-deformation with micro-mechanical signaling.

This study developed a novel MATR and applied it in combination with VSD for treating deep soft tissue defects. We conducted a prospective study at Xingyi People's Hospital from July 2024 to April 2025 to evaluate the clinical efficacy of MATR combined with VSD versus conventional VSD alone. We hypothesize that the MATR combined with VSD will demonstrate significantly better clinical efficacy and improve patient outcomes.

Materials and methods

Study design

This was a single-center, prospective study. 53 patients with deep soft tissue defects were included and randomly assigned to either the combination group (n = 26) or the control group (n = 27). Randomization was computer-generated [15]. The combination group received MATR combined with VSD, and the control group received conventional VSD. This study complied with the ethical rules for human experimentation as stated in the 1975 Declaration of Helsinki and was approved by the Ethics Committee of Xingyi People's Hospital (Ethics No. [IIT]-2024004).

Participants

All patients were admitted to Xingyi People's Hospital from June 2024 to April 2025. Inclusion criteria: (a) a confirmed diagnosis of deep soft tissue defects; (b) voluntary participation in this study. Exclusion criteria: (a) failure to complete follow-up; (b) metabolic diseases that affect wound healing, such as diabetes; (c) prolonged use of immunosuppressive drugs; (d) pregnant or lactating women; (e) psychiatric disorders that impair judgment or compliance (f) concurrent participation in other clinical trials. Informed consent was obtained from all patients before the trial.

Mechanically activated tissue retractor (MATR)

All steps were performed by experienced orthopedic surgeons. First, computed tomography (CT) data of the defect area were collected and saved as Digital Imaging and Communications in Medicine (DICOM) file from patients scheduled to receive MATR combined with VSD. Second, the DICOM file was imported into Mimics Research software for three-dimensional (3D) reconstruction of the soft tissue defect, and a MATR was designed based on the defect morphology. Third, the topology

Figure 1. Mechanically activated tissue retractor. A. Topology optimization; B. Preset space; C. Retractor installation schematic.

of the designed MATR was optimized to achieve high porosity, robust structural integrity, multidirectional internal channels, and favorable flow properties. A physical model of the MATR was printed using surgical guide resin with an Anycubic M5S 3D printer. The 3MF file of the MATR model was imported into Anycubic Photon Workshop software, where support columns were added to low points and island areas of the model. The model was then exported as a 1:1 scale 3D print file. Printing parameters were set as follows: layer thickness 0.05 mm, normal exposure time 6 s, bottom exposure time 30 s, anti-aliasing strength 16, with all other settings at default. Finally, the sliced files were imported into the 3D printer software and printed for 2-6 hours. After printing, the MATR was cleaned with medical ethanol, support structures were removed, and the final device was obtained (**Figure 1**).

Treatment protocol

For patients with deep soft tissue defects, the initial evaluation was based on the size and depth of the defect. Emergency Phase I management included thorough debridement to remove all necrotic tissue. Autologous skin grafting or flap transfer was performed in Phase II.

Patients in the control group received conventional VSD: The porous foam dressing was trimmed to cover the defect completely and sealed with a medical semipermeable membrane, with the edge extending 3-5 cm beyond the defect. The system was connected to -125 mmHg negative pressure for continuous suction, and the dressing was replaced every 3-5 days until granulation tissue coverage exceeded 80%, after which autologous skin grafting was performed.

Patients in the combination group received MATR combined with VSD: A VSD foam was placed around the defect to prevent pressure injury. After pre-placing the space within the defect, the tissue retractor was sutured in place. The porous foam dressing was trimmed to cover the tissue retractor completely. A periodic retraction system was set up with an intelligent negative pressure system (-80 to 150 mmHg with dynamic adjustment) at 0.5 Hz with 10% strain. The defect was covered with the retraction system and the deformation of the retractor was monitored daily (error margin of < 0.1 mm). After 5-7 days, the defect was inspected. If the granulation tissue was mature, autologous skin grafting was performed. Otherwise, the defect was covered with VSD until the granulation tissue had matured, after which a skin graft was performed.

Mature granulation

Granulation tissue maturity was evaluated based on established clinical criteria, including tissue color, surface granularity, bleeding tendency, and adhesion to the wound bed. Mature granulation was defined as pink or bright red tissue with a finely granular surface, firm adhesion to the wound base, and minimal bleeding upon gentle debridement. In contrast, immature granulation presented as pale or dark red, with a smooth or edematous surface, fragile adhesion, and easy bleeding. Two independent plastic surgeons, blinded to the treatment allocation, performed the assessments.

Disagreements were resolved by consensus or consultation with a third senior surgeon.

Skin survival status

Skin graft survival was determined based on color match with surrounding tissue, capillary refill, tissue temperature, and the absence of necrosis or eschar formation. Survival rates were calculated as the percentage of the graft area maintaining viability relative to the initial grafted area.

Data collection

Patients were followed up at multiple time points. A multi-temporal follow-up protocol was applied. Baseline characteristics in patients were collected before surgery (T1), including age, sex, defect cause (external injury, ulceration), defect size (≤ 25, 25-100, > 100), and defect area (arm/leg, ankle/knee). The Visual Analog Scale (VAS) was used to assess the pain [16]. The VAS scores ranged from 0-10, with higher scores indicating more severe pain. The Activities of Daily Living Scale (ADLS) was used to assess functional mobility [17]. The ADLS scores ranged from 0-100, with higher scores indicating greater functional mobility.

At 7 days after surgery (T2), 14 days after surgery (T3), and 21 days after surgery (T4), the VAS scores and ADLS scores were reassessed, and defect healing, mature granulation, and skin survival status were assessed in combination group and control group. During treatment, the patient's defect healing time and perioperative complications were accurately documented. Perioperative complications including infection, bleeding, blister/ulceration, anchor point failure, and VSD air leak/blockage.

At 3 months after defect healing (T5), a comprehensive functional assessment of the patients was performed by repeating the VAS scores and ADLS scores. In addition, the Vancouver Scar Scale (VSS) was used to assess scarring [18]. The VSS scores ranged from 0-15, with lower scores indicating less scarring.

All follow-up assessments were conducted by uniformly trained researchers using standardized evaluation tools. To ensure data accuracy, a dual-entry and cross-verification system was implemented. The entire follow-up process strictly complied with the study protocol to maintain data integrity and reliability.

Statistical analysis

SPSS 26.0 software was used for statistical analysis. Continuous variables that conform to a normal distribution are expressed as mean ± standard deviation (SD), otherwise as median (P_{25}, P_{75}). Categorical variables were expressed as frequency and percentage. For continuous variables that conformed to normal distribution, t-test was used to compare differences. Otherwise, Mann-Whitney U test was used. For categorical variables, chi-square test was used to compare differences. However, to maintain the robustness of the analysis, Fisher's exact test was substituted in situations where the contingency table contained cells with an expected count of < 5. Repeated-measures analysis of variance (ANOVA) was used to compare the VAS and ADLS changes over time. $P < 0.05$ was considered significant.

Results

Comparison of baseline characteristics

The 26 patients in the combination group and 27 patients in the control group were included in this study. There were no significant differences between the combination group and control group in age, sex, defect cause, defect size, or defect area (all $P > 0.05$; **Table 1**).

Comparison of clinical outcome

The defect healing time in the combination group was 13.1 ± 5.7 days, significantly faster than 22.0 ± 5.9 days in the control group ($P < 0.05$; **Table 2**). Additionally, at T2, the combination group demonstrated superior mature granulation compared to the control group, with statistically significant differences; At T3, and T4, the combination group demonstrated superior defect healing, mature granulation, and skin survival status compared to the control group, (all $P < 0.05$; **Table 2**).

Comparison of VSS

At T3, the VSS scores in the combination group were 4.0 (3.0, 5.0), which was significantly lower than 5.0 (4.0, 5.5) in the control group ($P < 0.05$; **Table 3**). Furthermore, in patients with

Table 1. Comparison of baseline characteristics in patients (n, %)

Characteristic	Combination group (n = 26)	Control group (n = 27)	t/χ^2	*P*-value
Age (years, mean ± SD)	55.0 ± 16.0	47.4 ± 18.1	1.631	0.109[a]
Sex			3.182	0.074[b]
Male	16 (61.5)	10 (37.0)		
Female	10 (38.5)	17 (63.0)		
Defect cause			-	0.961[c]
External injury	23 (88.5)	24 (88.9)		
Ulceration	3 (11.5)	3 (11.1)		
Defect size (cm^2)			0.092	0.955[b]
≤ 25	4 (15.4)	5 (18.5)		
25-100	17 (65.4)	17 (63.0)		
> 100	5 (19.2)	5 (18.5)		
Defect area			2.297	0.130[b]
Arm/Leg	13 (50.0)	19 (70.4)		
Ankle/Knee	13 (50.0)	8 (29.6)		

Note: a, t-test; b, chi-square test; c, fisher's exact test.

Table 2. Comparison of clinical outcomes in patients (n, %)

Clinical outcome	Combination group (n = 26)	Control group (n = 27)	t/χ^2	*P*-value
Defect healing time (days, mean ± SD)	13.7 ± 5.1	22.0 ± 5.9	-5.506	< 0.001[a]
Defect healing - T2	0 (0.0)	0 (0.0)	-	-
Defect healing - T3	17 (65.4)	6 (22.2)	10.046	0.002[b]
Defect healing - T4	24 (92.3)	10 (37.0)	17.594	0.019[b]
Mature granulation - T2	20 (76.9)	13 (48.1)	4.668	0.047[b]
Mature granulation - T3	24 (92.3)	17 (63.0)	6.512	0.019[b]
Mature granulation - T4	26 (100.0)	19 (70.4)	-	0.004[c]
Skin survival status - T2	0 (0.0)	0 (0.0)	-	-
Skin survival status - T3	22 (84.6)	6 (22.2)	20.691	< 0.001[b]
Skin survival status - T4	26 (100.0)	11 (40.7)	22.070	< 0.001[b]

Note: T2, 7 days after surgery; T3, 14 days after surgery; T4, 21 days after surgery; a, t-test; b, chi-square test; c, fisher's exact test.

defect size of 25-100 cm^2, the VSS scores in the combination group were 4.0 (3.0, 4.0), which was also significantly lower than the VSS scores of 5.0 (4.0, 5.0) in the control group ($P < 0.05$; **Table 3**).

Comparison of VAS and ADLS

Repeated-measures ANOVA results showed significant differences in patients' VAS scores and ADLS scores between the combination group and control group at T1, T2, T3, T4, and T5 ($P < 0.001$; **Table 4**). *Post hoc* pairwise comparisons showed that patients in the combination group had the highest VAS scores at T1 (5.5 ± 2.0), followed by T2 (3.2 ± 1.3), T3 (1.9 ± 1.1), T4 (1.5 ± 0.8), and T5 (1.0 ± 0.7), and the difference was significant. Patients in the control group had the highest VAS scores at T1 (5.5 ± 1.9), followed by T2 (4.4 ± 1.6), T3 (3.1 ± 1.4), T4 (2.5 ± 1.2), and T5 (2.0 ± 0.8), and the difference was significant ($P < 0.05$; **Table 4**). In addition, patients in the combination group had the highest ADLS scores at T5 (99.1 ± 1.4), followed by T4 (66.4 ± 8.0), T1 (45.7 ± 9.3), T3 (45.4 ± 7.2), and T2 (40.8 ± 8.4), and the difference was statistically significant. Patients in the control group had the highest ADLS scores at T5 (95.3 ± 5.0), followed by T4 (60.5 ± 6.0), T1 (46.2 ± 8.9), T3 (39.4 ± 7.1), and T2 (38.0 ± 7.1), also significant (all $P < 0.05$ **Table 4**).

Table 3. Comparison of VSS scores in patients at T5 [Median (Q1, Q3)]

Characteristic	Combination group (n = 26)	Control group (n = 27)	*Z*	*P*-value
Defect cause				
External injury	4.0 (3.0, 5.0)	4.5 (4.0, 6.0)	363.500	0.056[d]
Ulceration	4.0 (3.0, 4.5)	5.0 (4.0, 5.0)	6.000	0.700[d]
Defect size (cm^2)				
≤ 25	2.0 (1.5, 2.0)	2.0 (2.0, 3.0)	15.500	0.190[d]
25-100	4.0 (3.0, 4.0)	5.0 (4.0, 5.0)	217.000	0.012[d]
> 100	5.0 (5.0, 6.0)	8.0 (6.0, 8.0)	21.000	0.095[d]
Defect area				
Arm/Leg	4.0 (3.0, 5.0)	5.0 (4.0, 5.0)	155.500	0.223[d]
Ankle/Knee	4.0 (3.0, 4.0)	4.5 (4.0, 6.0)	108.500	0.140[d]
Total	4.0 (3.0, 5.0)	5.0 (4.0, 5.5)	461.000	0.045[d]

Note: VSS, Vancouver Scar Scale; T5, 3 months after defect healing; d, Mann-Whitney U test.

Table 4. Comparison of VAS scores and ADLS scores in patients at T1, T2, T3, T4 and T5 (mean ± SD)

Indicators	Time	Combination group (n = 26)	Control group (n = 27)	*t*	*P*-value
VAS	T1	5.5 ± 2.0	5.5 ± 1.9	-0.034	0.973[a]
	T2	3.2 ± 1.3	4.4 ± 1.6	-2.838	0.006[a]
	T3	1.9 ± 1.1	3.1 ± 1.4	-3.445	0.001[a]
	T4	1.5 ± 0.8	2.5 ± 1.2	-3.631	0.001[a]
	T5	1.0 ± 0.7	2.0 ± 0.8	-4.911	< 0.001[a]
F		51.493	27.124		
P-value		< 0.001[e]	< 0.001[e]		
Post hoc pairwise comparisons		T5 < T4 < T3 < T2 < T1	T5 = T4 < T3 < T2 < T1		
ADLS	T1	45.7 ± 9.3	46.2 ± 8.9	-0.212	0.833[a]
	T2	40.8 ± 8.4	38.0 ± 7.1	1.297	0.200[a]
	T3	45.4 ± 7.2	39.4 ± 7.1	3.085	0.003[a]
	T4	66.4 ± 8.0	60.5 ± 6.0	3.028	0.004[a]
	T5	99.1 ± 1.4	95.3 ± 5.0	3.753	< 0.001[a]
F		276.944	315.864		
P-value		< 0.001[e]	< 0.001[e]		
Post hoc pairwise comparisons		T5 > T4 > T3 = T1 > T2	T5 > T4 > T1 > T3 = T2		

Note: VAS, Visual Analog Scale; ADLS, Activities of Daily Living Scale; T1, before surgery; T2, 7 days after surgery; T3, 14 days after surgery; T4, 21 days after surgery; T5, 3 months after defect healing; a, t-test; e, ANOVA.

There were no significant differences in VAS scores and ADLS scores between the combination group and the control group at T1 (all $P > 0.05$; **Table 4**). At T2, there was no significant difference in ADLS scores between the combination group and the control group ($P > 0.05$; **Table 4**). However, the combination group exhibited lower VAS scores than the control group ($P < 0.05$; **Table 4**). At T3, T4, and T5, the VAS scores in the combination group were lower than in the control group, while the ADLS scores in the combination group were higher than in the control group (all $P < 0.05$; **Table 4**). The trends of VAS and ADLS scores at T1, T2, T3, T4, and T5 in the combination group and control group are shown in **Figure 2**.

Comparison of perioperative complications

During treatment, there was one case each of infection, blister/ulceration, and VSD air leak/blockage in the combination group, with a perioperative complications rate of 11.5%. In the control group, there were two cases of infection, one case of bleeding, three cases of blister/ulceration, one case of anchor point failure,

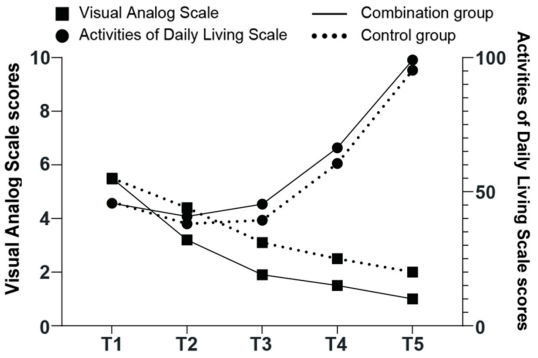

Figure 2. Trends in Visual Analog Scale scores and Activities of Daily Living Scale scores. T1, before surgery; T2, 7 days after surgery; T3, 14 days after surgery; T4, 21 days after surgery; T5, 3 months after defect healing.

and three cases of VSD air leak/blockage, with a perioperative complications rate of 37.0%. The combination group had a significantly lower perioperative complication rate than the control group ($P < 0.05$; **Table 5**).

A typical case in the combination group

A 61-year-old male patient whose defects were treated with MATR combined with VSD. The patient was admitted to the hospital with a deep soft tissue defect in his right foot caused by a heavy object. The defect size was 160 cm^2 (**Figure 3A**); Treatment with MATR combined with VSD after thorough debridement is shown (**Figure 3B**); followed by a check for mature granulation after 5-7 days (**Figure 3C**) and performing a skin graft (**Figure 3D** and **3E**); Finally, the patient was cured and discharged in 22 days (**Figure 3F**).

Discussion

The purpose of this study was to compare the clinical efficacy of MATR combined with VSD versus conventional VSD for treating deep soft tissue defects. Therefore, this study prospectively examined 53 patients with deep soft-tissue defects treated at Xingyi People's Hospital, and 26 patients received MATR combined with VSD, and 27 patients received conventional VSD. Our findings confirmed that the MATR combined with VSD was more effective in treating deep soft tissue defects. Several findings warrant further exploration.

Our results found that, compared to the control group, the combination group demonstrated superior defect healing, mature granulation, and skin survival status at 14 and 21 days after surgery (all $P < 0.05$). These findings highlight the critical role of mechanical activation in accelerating defect repair processes. Previous literature on wound healing indicated that complete mature granulation typically required more than 7 days during the inflammatory-proliferative transition phase [10, 19]. This temporal pattern could be explained by the biological timeline of defect healing, as the initial 7-day period predominantly represents the inflammatory phase, during which the combination group and control group would be expected to elicit similar physiologic responses. During this early phase, defect healing mechanisms are principally mediated by intrinsic biological pathways [20]. Moreover, the therapeutic benefits of mechanical activation are usually clinically evident over the long term, since mechanotransduction-mediated tissue remodeling represents a time-dependent biological process [21]. The significantly better outcomes observed in the combination group from day 14 onward may reflect the cumulative effect of continuous mechanical stimulation on key processes such as angiogenesis, fibroblast proliferation, and organized extracellular matrix deposition. Notably, the observed decline in ADLS scores at T2 in combination group and control group reflected expected postoperative functional mobility limitations. Supporting this observation, a clinical study demonstrated that even minimally invasive procedures can reduce physical activity capacity by 30-50% during the first postoperative week [13]. Psychological factors such as movement apprehension further contribute to this early functional limitation [22]. However, while both groups exhibited significant pain reduction, the combination group achieved lower VAS scores alongside significantly higher ADLS scores ($P < 0.05$), indicating not only improved pain control but also better functional recovery. The superior ADLS recovery in the combination group suggests that mechanical activation may facilitate earlier and more confident mobilization, thereby mitigating postoperative functional decline. These findings suggest that MATR combined with VSD enhances deep soft tissue defect repair not only by structurally expediting wound healing but also by functionallyimproving pain and mobility outcomes, highlighting its clinical value.

Table 5. Comparison of perioperative complications in patients (n, %)

Perioperative complication	Combination group (n = 26)	Control group (n = 27)	χ^2	*P*-value
Infection	1 (3.8)	2 (7.4)		
Bleeding	0 (0.0)	1 (3.7)		
Blister/Ulceration	1 (3.8)	3 (11.1)		
Anchor point failure	0 (0.0)	1 (3.7)		
VSD air leak/blockage	1 (3.8)	3 (11.1)		
Total	3 (11.5)	10 (37.0)	4.652	0.031[b]

Note: VSD, vacuum sealing drainage; b, chi-square test.

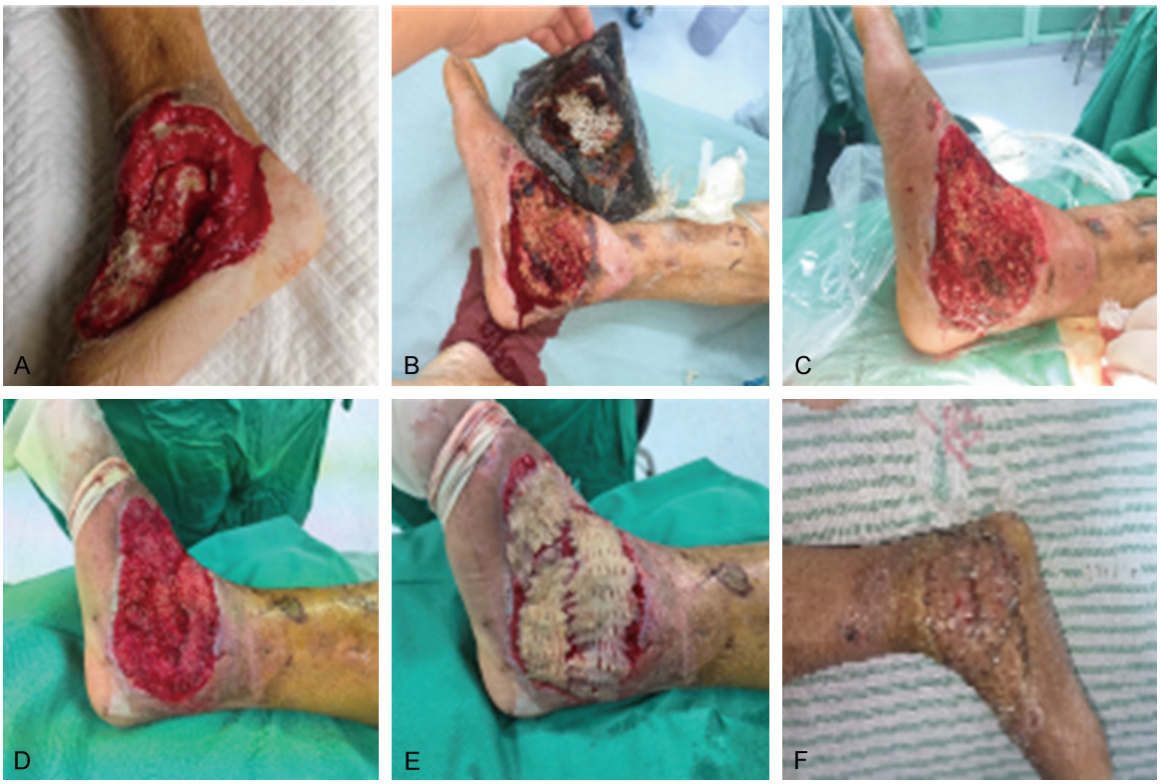

Figure 3. A typical case in the combination group. A. Size and area of defect; B. MATR combined with VSD; C. Checking for defect; D and E. Skin graft; F. Defect healing.

At the 3 month follow-up after defect healing, patients in the combination group and control group exhibited continued reduction in VAS scores and marked improvement in ADLS scores, demonstrating effective recovery ($P < 0.05$). Consistent with the results at T2, T3, and T4, the combination group also maintained superior clinical efficacy at T5. The combination group showed significantly lower VAS scores and higher ADLS scores compared to control group. These differences confirm that the MATR combined with VSD provides short- and long-term therapeutic advantages for deep soft tissue defects. Additionally, the combination group showed significantly lower VSS scores than control group, suggesting improved aesthetic and functional scar maturation ($P < 0.05$). This improvement can be attributed to the mechanical loading imposed by MATR, which promotes organized collagen fiber alignment and increases scar flexibility, as supported by previous ultrasound elastography studies [23]. Beyond structural benefits, the superior scar outcomes also positively influenced patients' psychological and social well-being, reducing anxiety and self-esteem concerns related to cosmetic appearance [24]. These findings indicate that MATR combined with VSD

establishes a favorable biomechanical milieu that enhances early angiogenesis, optimizes collagen remodeling, and modulates neuropathic pain signaling. The sustained and progressive nature of these therapeutic effects suggests that mechanical stimulation may induce adaptive tissue responses that continue to evolve over time, underscoring the long-term clinical value of this combinatory strategy.

Perioperative complications, including infection and bleeding, are well-documented contributors to suboptimal outcomes in soft tissue reconstruction [25]. A systematic review highlighted that perioperative complication rates in soft tissue reconstruction range from 20% to 60% [26]. Notably, such perioperative complications not only prolong hospitalization but also may necessitate reoperation, further increasing patient morbidity and healthcare costs [27]. Given these risks, a critical evaluation of perioperative complications profiles associated with different reconstructive techniques is essential to optimize clinical decision-making. This study demonstrated that MATR combined with VSD resulted in significantly fewer postoperative complications compared to conventional VSD ($P < 0.05$). Results are consistent with the accelerated defect healing time observed in the combination group. A possible explanation for these findings may lie in the biomechanical effects of tissue stretching. Previous studies have demonstrated that mechanical stretching of vascular networks can significantly upregulate the expression of VEGF and platelet-derived growth factor (PDGF), thereby enhancing capillary formation in soft tissue defects [28]. Furthermore, compared to static VSD therapy, intermittent tension cycles have been shown to more effectively disrupt biofilm formation, consequently reducing bacterial load at the defect site [29]. Supporting this observation, a clinical study reported a 2.3-fold increase in bacterial clearance rates when mechanical stimulation was applied to soft tissue defects [30]. The clinical advantages of MATR combined with VSD in the treatment of deep soft tissue defects were further demonstrated in this study.

Although tissue retractor devices have been clinically available for some time [31, 32], the application of MATR combined with VSD in treating deep soft tissue defects remains limited. Our study provides novel evidence supporting the therapeutic efficacy of MATR combined with VSD in deep soft tissue reconstruction. However, several limitations should be considered. First, while baseline characteristics showed no significant differences, the single-center design and sample size (53 patients) may have limited the generalizability of our conclusions, necessitating future multicenter validation with larger cohorts. Secondly, the maximum follow-up period of 3 months after defect healing precludes assessment of long-term outcomes such as mechanical stability of regenerated tissue, or late-stage functional recovery. The follow-up (≥ 12 months) should be extended in the future to assess long-term tissue integrity and functional outcomes. Thirdly, VAS scores and ADLS scores relied on subjective patient reports, which may have introduced recall bias. The use of objective biomarker measurements will strengthen evidence quality.

In conclusion, our findings provide strong evidence that MATR combined with VSD significantly accelerates defect healing time, reduces scarring, pain, and perioperative complications, and enhances functional mobility in patients with deep soft tissue defects compared to conventional VSD. This approach represents a promising therapeutic strategy for deep soft tissue defects.

Acknowledgements

We extend our gratitude to medical staff of Xingyi People's Hospital for their support and assistance. We also thank all the participants in this study. This study was supported by Guizhou Provincial Science and Technology Program Project (No. LC2025036) and 2025 Qianxinan Prefecture Medical Research Collaborative Project (No. 2025-10).

Disclosure of conflict of interest

None.

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