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Original Article

Efficacy of a Novel Zinc-Pectin Hydrogel Versus Standard Silver Dressings for Chronic Venous Leg Ulcers

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ABSTRACT

Background: Chronic venous leg ulcers are difficult-to-heal wounds associated with persistent inflammation, recurrent infection, pain, exudate burden, and impaired quality of life. Although silver dressings are widely used for antimicrobial wound care, their effects on tissue repair may be inconsistent, supporting the need for biologically compatible alternatives that promote healing while controlling infection. Objective: To compare the clinical effectiveness of zinc–pectin hydrogel versus standard silver dressings in patients with chronic venous leg ulcers. Methods: A parallel-group randomized controlled trial was conducted among 84 adults with chronic venous leg ulcers, allocated equally to zinc–pectin hydrogel or silver dressing groups. Both groups received standardized wound cleansing, dressing changes every 48 hours, compression therapy, and routine wound-care education over six weeks. Primary outcomes were percentage reduction in ulcer area and time to 50% wound closure. Secondary outcomes included infection rate, pain intensity measured by Visual Analog Scale, and exudate score. Results: Seventy-seven participants completed follow-up, including 39 in the zinc–pectin hydrogel group and 38 in the silver dressing group. Zinc–pectin hydrogel produced greater ulcer area reduction than silver dressing (68.4% ± 15.2 vs 52.1% ± 14.7; $p<0.001$) and shorter time to 50% wound closure (3.8 ± 1.1 vs 4.9 ± 1.3 weeks; $p=0.002$). Infection frequency was lower with zinc–pectin hydrogel (12.8% vs 28.9%; $p=0.048$), with better pain and exudate improvement. Conclusion: Zinc–pectin hydrogel was more effective than standard silver dressings in improving short-term healing, infection control, pain, and exudate outcomes in chronic venous leg ulcers. Keywords: Chronic Venous Ulcer; Hydrogel; Infection; Pain; Randomized Controlled Trial; Silver; Zinc.

INTRODUCTION

Chronic venous leg ulcers represent one of the most persistent and clinically burdensome manifestations of chronic venous insufficiency, particularly among adults and older individuals with impaired lower-limb venous return. Sustained venous hypertension contributes to microcirculatory dysfunction, tissue hypoxia, leukocyte activation, and progressive breakdown of the skin barrier, resulting in wounds that frequently persist for weeks to months despite standard care. These ulcers are associated with chronic pain, reduced mobility, recurrent infection, social limitation, and repeated healthcare visits, placing a substantial burden on both patients and health systems. Although compression therapy remains the cornerstone of venous ulcer management, local wound dressings remain essential for controlling exudate, limiting microbial burden, maintaining a moist healing environment, and supporting tissue repair (1,2).

The impaired healing trajectory of venous leg ulcers is driven by a complex wound microenvironment characterized by prolonged inflammation, oxidative stress, extracellular matrix degradation, bacterial colonization, and delayed epithelialization. In chronic wounds, excessive protease activity and persistent inflammatory signaling disrupt the orderly transition from inflammation to proliferation and remodeling, thereby delaying granulation tissue formation and wound closure. Infection or high microbial burden further compromises healing by intensifying inflammation and increasing tissue damage, making antimicrobial control a clinically important component of wound management. Therefore, an ideal dressing for chronic venous leg ulcers should not only protect the wound surface but also actively support regeneration, modulate inflammation, manage exudate, and reduce infection risk while remaining biocompatible with healing tissue (3).

Silver-based dressings are widely used in chronic wound care because of their broad-spectrum antimicrobial activity and their established role in reducing bacterial contamination. In patients with venous leg ulcers, silver dressings are commonly selected when infection risk, colonization, or delayed healing is a concern. However, their clinical benefit for accelerating wound closure remains inconsistent, and concerns have been raised regarding potential cytotoxic effects on keratinocytes and fibroblasts, particularly with prolonged exposure. These limitations have encouraged investigation of alternative bioactive dressings that can provide antimicrobial protection while preserving or enhancing the cellular processes required for tissue repair. In this context, biologically compatible hydrogel-based systems have gained attention because they can maintain moisture balance, conform to irregular wound surfaces, improve patient comfort, and facilitate autolytic debridement (4-6).

Zinc is an essential trace element involved in multiple phases of wound healing, including immune regulation, collagen synthesis, epithelialization, cellular proliferation, and enzymatic activity required for extracellular matrix remodeling. Topical zinc delivery may enhance local tissue repair by supporting epithelial migration and moderating inflammatory responses within the wound bed. Pectin, a naturally derived polysaccharide, offers additional wound-healing advantages through its gel-forming capacity, biocompatibility, moisture-retentive properties, and potential to provide a protective matrix that supports cell migration (7). When incorporated into a hydrogel platform, zinc and pectin may provide complementary therapeutic effects by combining sustained local bioactive ion delivery with a moist, tissue-compatible wound interface. This makes zinc–pectin hydrogel a plausible alternative to conventional antimicrobial dressings for chronic venous leg ulcers, particularly where both infection control and active tissue regeneration are required (8).

Despite the biological rationale for zinc-based and hydrogel-based wound therapies, robust comparative clinical evidence in chronic venous leg ulcers remains limited. Much of the existing literature on advanced hydrogels focuses on diabetic wounds or broader chronic wound models, leaving uncertainty about their effectiveness in venous ulcers managed alongside standardized compression therapy. A direct comparison between zinc–pectin hydrogel and standard silver dressings is therefore clinically relevant because it evaluates whether a regenerative, biocompatible dressing can achieve superior healing outcomes while maintaining infection control in the target venous-ulcer population. Addressing this gap may help guide dressing selection in routine wound care and support the development of multifunctional treatments that improve both objective healing and patient-centered outcomes (9,10).

Based on this rationale, the present randomized controlled trial was designed using a PICO framework in which the population comprised adults with chronic venous leg ulcers, the intervention was topical zinc–pectin hydrogel applied with standardized compression therapy, the comparator was standard silver dressing with the same compression protocol, and the outcomes included percentage reduction in ulcer area, time to 50% wound closure, infection rate, pain intensity, and exudate control over a six-week intervention period. The study hypothesized that zinc–pectin hydrogel would be more effective than standard silver dressings in accelerating wound healing, reducing infection, and improving clinical outcomes among patients with chronic venous leg ulcers. This objective aligns with the manuscript's

stated aim to compare zinc–pectin hydrogel with standard silver dressings for healing, infection reduction, pain, and exudate outcomes in chronic venous leg ulcers.

MATERIALS AND METHODS

A parallel-group randomized controlled trial was conducted in the Industrial and Urban Core of Punjab to compare the efficacy of zinc–pectin hydrogel with standard silver dressings in patients with chronic venous leg ulcers. The setting was selected because it provided access to tertiary wound care services, enabled regular follow-up, and represented a population with relatively consistent healthcare access and dietary patterns that could influence wound healing outcomes. The total study duration was five months, from September 2025 to January 2026, including recruitment, intervention delivery, and follow-up, while the active treatment period for each enrolled participant was six weeks.

Adults aged 30–75 years with clinically diagnosed chronic venous leg ulcers persisting for more than six weeks were eligible for enrollment. Participants were required to have an ankle–brachial index between 0.8 and 1.2 and an ulcer area between 2 and 20 cm^2 to ensure inclusion of patients with venous ulcers of comparable clinical severity and without significant arterial insufficiency. Patients were excluded if they had arterial ulcers, diabetic foot ulcers, active malignancy, systemic infection, current immunosuppressive therapy, or known hypersensitivity to zinc, pectin, or silver-based products. These criteria were applied to reduce confounding from wound etiologies, systemic conditions, or treatments that could independently alter wound healing.

Eligible patients were recruited after clinical assessment and were enrolled after consent procedures had been completed. A total of 84 participants were included and randomly assigned in a 1:1 allocation ratio to receive either zinc–pectin hydrogel or standard silver dressings (11). The sample size was based on prior interventional wound-care studies using comparable group sizes and was planned to provide adequate power to detect clinically meaningful between-group differences in ulcer healing outcomes while allowing for potential attrition during follow-up.

Randomization was performed using a computer-generated allocation sequence. Allocation concealment was maintained with sequentially numbered, sealed opaque envelopes prepared by an independent researcher who was not involved in participant recruitment or outcome assessment. Because the two dressings differed visibly, blinding of participants and treatment providers was not feasible. To reduce assessment bias, outcome assessors were blinded to treatment allocation throughout follow-up and outcome recording.

Participants assigned to the intervention group received topical zinc–pectin hydrogel applied directly to the ulcer bed after standard wound cleansing with normal saline. The dressing was changed every 48 hours. Participants assigned to the control group received commercially available silver-impregnated dressings after the same wound cleansing procedure, with dressing changes performed at the same 48-hour interval. Both groups received standardized compression bandaging during the treatment period, along with consistent education on limb elevation, mobility, wound hygiene, and adherence to dressing care. Treatment adherence was monitored using dressing logs and weekly clinical visits.

The primary outcomes were percentage reduction in ulcer area and time to achieve 50% wound closure. Ulcer area was measured using digital planimetry at baseline and at weekly intervals during the six-week intervention period. Percentage ulcer area reduction was calculated by comparing follow-up ulcer area with baseline ulcer area. Time to 50% wound closure was defined as the number of weeks required for the ulcer area to decrease by at least half from baseline. Secondary outcomes included wound infection status, pain intensity, and exudate level. Infection status was assessed using a standardized wound infection checklist. Pain intensity was measured using the Visual Analog Scale, and exudate level was graded using a validated wound assessment tool. All outcomes were recorded at baseline and at the

end of the six-week treatment period, with weekly measurements used for longitudinal assessment of ulcer healing.

Baseline demographic and clinical variables included age, sex, ulcer duration, ulcer area, and baseline pain score. The treatment group was the main exposure variable, while ulcer area reduction, time to 50% closure, infection rate, pain score, and exudate score were the main outcome variables. Standardization of wound cleansing, dressing frequency, compression therapy, patient education, follow-up schedule, and blinded outcome assessment was used to minimize procedural variability, performance differences, and measurement bias between groups.

Data were analyzed using an intention-to-treat approach, with all randomized participants included in the analytical framework. Missing outcome data resulting from loss to follow-up were managed using last observation carried forward. Normality of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables were summarized as mean ± standard deviation, while categorical variables were summarized as frequencies and percentages. Between-group comparisons for continuous outcomes were performed using independent-samples t-tests, and within-group pre–post changes were analyzed using paired-samples t-tests. Categorical outcomes, including infection status, were compared between groups using appropriate tests for proportions. Repeated-measures analysis of variance was used to evaluate changes in ulcer size across weekly assessments and to assess time, group, and time-by-group interaction effects. Pearson correlation analysis was conducted to examine the association between reduction in ulcer size and improvement in pain scores. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 112 patients with chronic venous leg ulcers were screened for eligibility during the study period. Of these, 84 participants met the inclusion criteria and were randomized equally into the zinc–pectin hydrogel group and the standard silver dressing group, with 42 participants allocated to each arm. During the six-week intervention period, seven participants were lost to follow-up, including three in the zinc–pectin hydrogel group and four in the silver dressing group. The final outcome dataset therefore included 77 participants, comprising 39 participants in the zinc–pectin hydrogel group and 38 participants in the silver dressing group. Baseline demographic and clinical characteristics were assessed in the full randomized cohort, while post-intervention outcomes were analyzed in the final evaluable sample.

Baseline characteristics were comparable between treatment groups, indicating balanced allocation at study entry. The mean age was 57.9 ± 10.8 years in the zinc–pectin hydrogel group and 58.5 ± 10.5 years in the silver dressing group, with no significant between-group difference. Male participants accounted for 54.7% of each group. Baseline ulcer duration, ulcer area, and pain intensity were also similar between groups, with mean ulcer areas of 8.7 ± 3.2 cm² and 8.5 ± 3.0 cm² in the zinc–pectin hydrogel and silver dressing groups, respectively. Baseline Visual Analog Scale pain scores were 6.2 ± 1.5 and 6.0 ± 1.3, respectively.

Table 1. Baseline Demographic and Clinical Characteristics of Randomized Participants

Variable	Total Sample (N=84)	Zinc–Pectin Hydrogel (n=42)	Silver Dressing (n=42)	p-value
Age, years	58.2 ± 10.6	57.9 ± 10.8	58.5 ± 10.5	0.81
Male sex, n (%)	46 (54.8%)	23 (54.7%)	23 (54.7%)	1.00
Ulcer duration, weeks	14.3 ± 5.2	14.1 ± 5.4	14.5 ± 5.1	0.74
Ulcer area, cm²	8.6 ± 3.1	8.7 ± 3.2	8.5 ± 3.0	0.79
VAS pain score	6.1 ± 1.4	6.2 ± 1.5	6.0 ± 1.3	0.52

At the end of the six-week intervention period, the zinc–pectin hydrogel group demonstrated superior improvement in both primary healing outcomes. Mean ulcer area reduction was 68.4% ± 15.2 in the zinc–pectin hydrogel group compared with 52.1% ± 14.7 in the silver dressing group, giving a between-group mean difference of 16.3 percentage points. This difference was statistically significant, with a 95%

confidence interval of 9.8 to 22.7 and p<0.001. The time required to achieve 50% wound closure was also significantly shorter in the zinc–pectin hydrogel group, with a mean duration of 3.8 ± 1.1 weeks compared with 4.9 ± 1.3 weeks in the silver dressing group. The mean between-group difference was −1.1 weeks, with a 95% confidence interval of −1.9 to −0.3 and p=0.002.

Table 2. Comparison of Primary Healing Outcomes at Six Weeks

Outcome	Zinc–Pectin Hydrogel (n=39)	Silver Dressing (n=38)	Mean Difference (95% CI)	p-value
Ulcer area reduction, %	68.4 ± 15.2	52.1 ± 14.7	16.3 (9.8 to 22.7)	<0.001
Time to 50% wound closure, weeks	3.8 ± 1.1	4.9 ± 1.3	−1.1 (−1.9 to −0.3)	0.002

Within-group comparisons showed significant improvement in both treatment arms from baseline to the end of follow-up, although the magnitude of improvement was greater in the zinc–pectin hydrogel group. Mean ulcer area decreased from 8.7 ± 3.2 cm² to 2.7 ± 1.5 cm² in the zinc–pectin hydrogel group and from 8.5 ± 3.0 cm² to 4.1 ± 2.2 cm² in the silver dressing group. Pain intensity also declined significantly in both groups, with the zinc–pectin hydrogel group showing a reduction in mean VAS score from 6.2 ± 1.5 to 2.9 ± 1.2, while the silver dressing group showed a reduction from 6.0 ± 1.3 to 3.8 ± 1.4. Both within-group changes were statistically significant at p<0.001.

Table 3. Within-Group Pre–Post Changes in Ulcer Area and Pain Score

Outcome	Group	Baseline	Six Weeks	Within-Group Change	p-value
Ulcer area, cm²	Zinc–Pectin Hydrogel	8.7 ± 3.2	2.7 ± 1.5	−6.0	<0.001
Ulcer area, cm²	Silver Dressing	8.5 ± 3.0	4.1 ± 2.2	−4.4	<0.001
VAS pain score	Zinc–Pectin Hydrogel	6.2 ± 1.5	2.9 ± 1.2	−3.3	<0.001
VAS pain score	Silver Dressing	6.0 ± 1.3	3.8 ± 1.4	−2.2	<0.001

Secondary clinical outcomes also favored zinc–pectin hydrogel. Infection occurred in 5 of 39 participants in the zinc–pectin hydrogel group, corresponding to 12.8%, compared with 11 of 38 participants in the silver dressing group, corresponding to 28.9%. This difference was statistically significant with p=0.048. Exudate scores were lower after treatment in the zinc–pectin hydrogel group, with a mean score of 1.6 ± 0.7 compared with 2.3 ± 0.9 in the silver dressing group, p=0.01. The absolute reduction in infection frequency was 16.1 percentage points in favor of zinc–pectin hydrogel, while the mean exudate score difference was −0.7 points.

Table 4. Secondary Clinical Outcomes at Six Weeks

Outcome	Zinc–Pectin Hydrogel (n=39)	Silver Dressing (n=38)	Between-Group Difference	p-value
Infection, n (%)	5 (12.8%)	11 (28.9%)	−16.1 percentage points	0.048
Exudate score	1.6 ± 0.7	2.3 ± 0.9	−0.7	0.01

Longitudinal analysis of ulcer size across weekly assessments demonstrated a consistent reduction in mean ulcer area in both groups, with a steeper decline in the zinc–pectin hydrogel arm. Repeated-measures ANOVA showed a significant time effect, indicating that ulcer area decreased over the six-week treatment period across participants. A significant group effect demonstrated overall separation between the two treatment arms, and the significant time-by-group interaction confirmed that the rate of ulcer area reduction differed between groups. The time effect was F=112.6 with p<0.001, the group effect was F=18.4 with p<0.001, and the time-by-group interaction was F=9.7 with p=0.003. Pearson correlation analysis showed a moderate positive association between ulcer size reduction and improvement in pain scores, with r=0.52 and p<0.001, indicating that greater wound reduction was associated with greater pain improvement.

Table 5. Longitudinal and Correlation Analyses of Treatment Response

Analysis	Statistic	Result	p-value
Repeated-measures ANOVA: time effect	F	112.6	<0.001
Repeated-measures ANOVA: group effect	F	18.4	<0.001
Repeated-measures ANOVA: time × group interaction	F	9.7	0.003
Correlation between ulcer size reduction and pain improvement	r	0.52	<0.001

Overall, the zinc–pectin hydrogel group showed greater wound healing, faster achievement of 50% wound closure, lower infection frequency, better exudate control, and greater pain improvement than

the silver dressing group over six weeks. The most pronounced between-group difference was observed for ulcer area reduction, where zinc–pectin hydrogel achieved a 16.3 percentage-point greater mean reduction than silver dressing. The longitudinal findings further supported this treatment effect, showing that the advantage of zinc–pectin hydrogel increased progressively across weekly assessments.

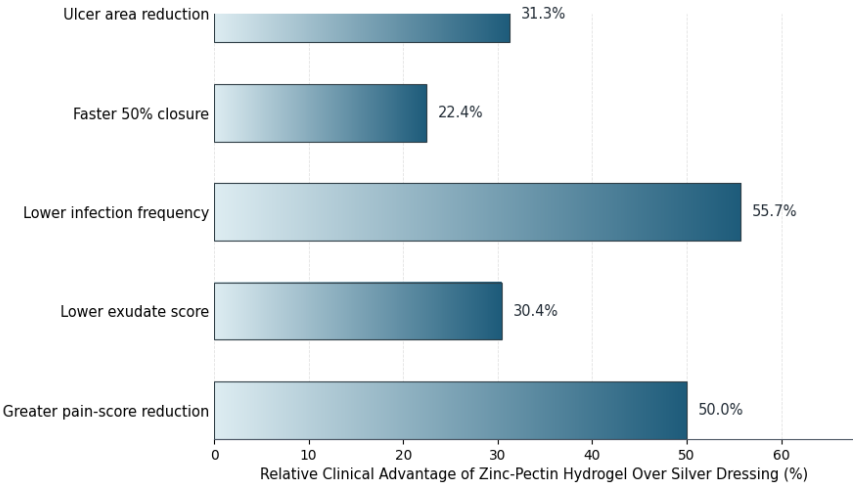

Figure 1. Integrated Six-Week Clinical Benefit Profile in Chronic Venous Leg Ulcers

The integrated clinical benefit profile demonstrates that zinc–pectin hydrogel produced a consistent advantage over standard silver dressing across all evaluated therapeutic domains. The largest relative difference was observed for infection frequency, with a 55.7% lower infection burden in the zinc–pectin hydrogel group, followed by a 50.0% greater pain-score reduction and a 31.3% greater ulcer area reduction compared with silver dressing. Exudate control also favored zinc–pectin hydrogel, showing a 30.4% relative improvement, while time to 50% wound closure was 22.4% faster, indicating that the intervention provided not only superior wound-size reduction but also broader clinical benefit across inflammatory, symptomatic, and healing-related outcomes over six weeks.

DISCUSSION

This randomized controlled trial demonstrated that zinc–pectin hydrogel produced superior short-term healing outcomes compared with standard silver dressings in patients with chronic venous leg ulcers managed under standardized compression therapy. Over the six-week intervention period, patients treated with zinc–pectin hydrogel achieved a greater mean ulcer area reduction, faster attainment of 50% wound closure, lower infection frequency, better exudate control, and greater improvement in pain intensity. The between-group difference in ulcer area reduction was clinically meaningful, with zinc–pectin hydrogel producing a 16.3 percentage-point greater reduction than silver dressing, while the time to 50% wound closure was shortened by 1.1 weeks. These findings suggest that zinc–pectin hydrogel may offer advantages beyond passive wound coverage by improving the local wound environment in a manner that supports both tissue repair and symptom relief.

The observed improvement in wound closure is biologically plausible because chronic venous leg ulcers are characterized by prolonged inflammation, impaired extracellular matrix remodeling, excess exudate, and delayed epithelial migration. Zinc has an established role in multiple processes central to wound repair, including epithelialization, collagen synthesis, immune regulation, antioxidant defense, and enzymatic activity involved in matrix remodeling. Local zinc delivery through a hydrogel matrix may support sustained availability of bioactive ions at the wound surface, thereby promoting tissue repair while reducing excessive inflammatory activity. Pectin may further enhance this effect by maintaining a moist wound interface, supporting autolytic debridement, absorbing exudate, and forming a biocompatible matrix that conforms to the ulcer bed. The combined zinc–pectin platform

therefore provides a mechanistic rationale for the greater reduction in ulcer area and faster progression toward partial closure observed in the intervention group (12,13).

The lower infection frequency in the zinc–pectin hydrogel group is also clinically relevant, particularly because infection and high microbial burden are major contributors to delayed healing in chronic venous ulcers. Infection occurred in 12.8% of patients receiving zinc–pectin hydrogel compared with 28.9% of patients receiving silver dressings, corresponding to an absolute reduction of 16.1 percentage points. Although silver dressings are widely used because of their antimicrobial properties, their effect on wound closure has been variable, and concerns have been raised regarding possible cytotoxic effects on fibroblasts and keratinocytes during prolonged exposure. In contrast, the zinc–pectin hydrogel appeared to combine infection control with a wound-compatible regenerative environment, which may explain why healing, exudate, and pain outcomes improved together rather than infection reduction occurring in isolation (14,15).

Pain reduction represents an important patient-centered outcome in chronic venous ulcer care because pain affects mobility, sleep, adherence to compression therapy, quality of life, and willingness to attend follow-up. In this study, VAS pain scores decreased from 6.2 to 2.9 in the zinc–pectin hydrogel group and from 6.0 to 3.8 in the silver dressing group, indicating greater symptomatic improvement with zinc–pectin hydrogel. The moderate positive correlation between ulcer size reduction and pain improvement further supports the clinical relationship between structural healing and symptom relief. As ulcer size decreases and exudate and inflammation are better controlled, nociceptive stimulation from the wound bed may decline, resulting in improved comfort and functional tolerance during treatment (16,17).

The exudate findings further strengthen the interpretation that zinc–pectin hydrogel improved the local wound environment. At six weeks, the exudate score was lower in the zinc–pectin hydrogel group than in the silver dressing group, suggesting better moisture balance and inflammatory control. In venous ulcers, uncontrolled exudate can cause maceration of the surrounding skin, increase dressing burden, worsen odor, and impair epithelial advancement (18). A dressing that reduces excessive exudate while preserving a moist wound-healing environment may therefore improve both biological healing conditions and practical wound management. The hydrogel structure may have contributed to this balance by maintaining hydration without allowing excessive fluid accumulation at the wound surface (19).

The longitudinal healing pattern provides additional support for treatment benefit. Repeated-measures analysis showed a significant time effect, group effect, and time-by-group interaction, indicating that ulcer area decreased over time in both groups but declined more rapidly in the zinc–pectin hydrogel arm. This interaction is important because it suggests that the treatment effect was not limited to a single end-point measurement but emerged progressively across weekly assessments. The pattern is consistent with an intervention that modifies the wound environment over time, allowing gradual acceleration of tissue repair compared with standard antimicrobial dressing care (20).

These findings have practical implications for chronic venous ulcer management. Compression therapy remains the foundation of treatment, but dressing selection can influence exudate handling, infection control, patient comfort, and healing progression. Zinc–pectin hydrogel may be particularly useful in patients with chronic venous ulcers requiring a dressing that supports regeneration while maintaining acceptable antimicrobial and moisture-control properties. The shorter time to 50% wound closure may also be clinically meaningful because early reduction in wound size is often used as an indicator of healing trajectory and treatment responsiveness. If sustained over longer follow-up, such early improvement could reduce dressing frequency burden, clinic visits, pain-related disability, and overall wound-care costs (17).

Despite these encouraging findings, the results should be interpreted within the context of the study design and follow-up duration. The intervention period was limited to six weeks, which is sufficient to

assess early healing response but does not determine complete wound closure, recurrence, long-term safety, or durability of benefit. Chronic venous leg ulcers often recur, particularly when venous hypertension and compression adherence remain ongoing challenges. Longer follow-up would therefore be necessary to determine whether early improvements in ulcer area reduction translate into sustained closure and lower recurrence rates. The single geographic and healthcare setting may also limit generalizability to populations with different comorbidity profiles, nutritional status, wound-care access, or compression adherence patterns.

The lack of participant and provider blinding is another relevant consideration. Although outcome assessors were blinded, visible differences between the two dressing types made treatment blinding impractical. This may have influenced subjective outcomes such as pain reporting or adherence behavior. However, the inclusion of objective measures such as digital planimetry and the use of standardized compression therapy, wound cleansing, dressing-change intervals, and follow-up schedules helped reduce procedural variability between groups. Infection assessment was based on clinical criteria, and the absence of microbiological confirmation limits interpretation of antimicrobial efficacy. Future studies should incorporate wound cultures or molecular microbial assessment where clinically appropriate to distinguish colonization from confirmed infection and to evaluate changes in microbial burden more precisely (19).

The sample size was adequate to detect differences in the main healing outcomes but limited for subgroup analyses and less frequent safety or infection-related endpoints. Larger multicenter trials would allow evaluation across clinically important subgroups, including ulcer duration, ulcer size category, recurrent versus first ulcer, baseline exudate burden, and comorbidity status. Future research should also compare zinc–pectin hydrogel with other advanced dressings, evaluate cost-effectiveness, assess patient-reported quality of life, and include longer endpoints such as complete epithelialization, recurrence, and time to sustained closure. Mechanistic studies examining inflammatory markers, protease activity, epithelial migration, collagen deposition, and zinc release kinetics may further clarify how zinc–pectin hydrogel influences the chronic wound microenvironment (18).

Overall, the findings indicate that zinc–pectin hydrogel provided a broader therapeutic benefit than standard silver dressings over six weeks, with advantages across wound-size reduction, closure speed, infection frequency, exudate control, and pain improvement. The consistency of benefit across objective and patient-centered outcomes supports its potential role as a biologically favorable dressing option for chronic venous leg ulcers when used alongside standardized compression therapy. Further large-scale and longer-duration trials are warranted to establish durability, safety, recurrence outcomes, and implementation value in diverse wound-care settings.

CONCLUSION

Zinc–pectin hydrogel demonstrated superior short-term clinical effectiveness compared with standard silver dressings in patients with chronic venous leg ulcers treated with standardized compression therapy. Over six weeks, the hydrogel group achieved greater ulcer area reduction, faster time to 50% wound closure, lower infection frequency, improved exudate control, and greater pain reduction, indicating a broader therapeutic benefit across both objective healing outcomes and patient-centered clinical measures. These findings support zinc–pectin hydrogel as a promising biologically compatible dressing option for chronic venous leg ulcers, particularly where simultaneous promotion of tissue repair, moisture balance, infection control, and symptom relief is required. Larger multicenter studies with longer follow-up are needed to confirm complete healing rates, recurrence outcomes, long-term safety, and cost-effectiveness before wider routine implementation.

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