RESEARCH PAPER

Effectiveness of Cross-Running Polypropylene Intradermal Suture (Cr-Pis) for Improving Keloid Scars Following Lower Extremity Fractures

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ABSTRACT

Background: Abnormal scars, such as keloids, represent a significant clinical challenge following lower extremity fracture surgery. Mechanical tension is a key pathogenic factor, and suturing technique may influence scar outcome. This study aimed to evaluate the effectiveness of a novel modified Cross-Running Polypropylene Intradermal Suture (CR-PIS) technique in improving scar quality after keloid excision, compared to conventional simple intradermal suturing.

Methods: A randomized controlled trial with a pre-posttest design was conducted. Patients (n=15) with lower extremity keloids were allocated to receive total excision followed by wound closure with either the CR-PIS technique (treatment group) or simple intradermal polypropylene sutures (control group). Scar quality was assessed using the Vancouver Scar Scale (VSS), Manchester Scar Scale (MSS), and the Patient and Observer Scar Assessment Scale (POSAS) at baseline and at 3, 6, and 9 months postoperatively. Data were analyzed using two-way repeated measures ANOVA.

Results: Both groups showed significant improvement in scar scores over time ($p < 0.001$ for all scales). A significant time × group interaction was observed for VSS ($p=0.003$), MSS ($p=0.001$), and both observer and patient components of POSAS ($p < 0.001$). Post-hoc analysis revealed that the CR-PIS group demonstrated significantly earlier and greater reductions in scar assessment scores compared to the control group. Improvements in the CR-PIS group were significant from month 3 onwards for MSS and POSAS, and from month 6 for VSS.

Conclusion: The modified Cross-Running Polypropylene Intradermal Suture (CR-PIS) technique is more effective than conventional simple intradermal suturing in improving scar quality after keloid excision, as measured by validated scar assessment scales. CR-PIS leads to earlier and superior scar maturation, likely due to its enhanced biomechanical distribution of wound tension.

Keywords: Keloid; Hypertrophic Scar; Wound Closure Techniques; Suture Techniques; Polypropylene.

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INTRODUCTION

Scar formation represents the final outcome of the wound healing and can be classified into normal and

abnormal scars, including hypertrophic scars and keloids.[1] Keloids may develop following any cutaneous trauma or injury.[2] Trauma to the limbs most frequently involves the lower extremities[3], which consist of multiple musculoskeletal components, including bone. Injury to bone can result in fractures, and lower extremity fractures commonly involve the femur, tibia, and fibula.[4]

In many clinical scenarios, particularly fractures associated with displacement, instability, or significant soft tissue involvement, open reduction and internal fixation (ORIF) is the preferred treatment modality.[5] This procedure requires wide skin incisions for adequate anatomical visualization and implant placement, leading to substantial tissue trauma and increasing the risk of pathological scar formation. Surgical intervention, including ORIF, can trigger keloid development through the interaction of multiple risk factors.[6] These include incision placement in anatomically vulnerable areas such as the pretibial region, high skin tension in the lower extremities, personal or familial predisposition to keloid formation, postoperative wound infection, inadequate immobilization or excessive movement, and suboptimal wound closure techniques that leave excessive mechanical tension at the wound edges. Mechanical tension plays a key role by activating excessive wound healing responses, leading to fibroblast hyperproliferation and uncontrolled collagen production.[7] An imbalance between collagen synthesis and degradation during healing may result in keloid formation.[8]

Keloids remain a challenging condition, affecting not only patients but also reconstructive and aesthetic plastic surgeons, with limited therapeutic options. Numerous factors have been implicated in keloid pathogenesis, including patient-related factors such as race, genetic predisposition, and hormonal influences; skin topography-related factors such as skin type, pigmentation, and anatomical predilection sites; and environmental factors including trauma, inflammation, and surgical technique.[9] Among these, surgical technique and wound closure is particularly important, as meticulous suturing may contribute to keloid prevention.

One strategy to improve wound closure involves reinforcing sutures using nonabsorbable materials. Previous research by Ario[10] demonstrated that the intradermal sutures using polypropylene reduce postoperative scar formation. The underlying pathophysiological rationale is based on optimizing wound tensile strength by regulating pressure and resistance during wound approximation in accordance with the phases of wound healing, thereby promoting more favorable scar outcomes.[10] However, despite its potential, this approach remains suboptimal.

Running sutures are commonly applied to external skin closures in areas such as the eyelids, ears, and regions with relatively lax skin.[11] This technique can also be adapted as an intradermal suture to improve wound edge approximation, to improved scar quality. The cross-running intradermal suture (CRIS) technique was introduced by Xiong et al.[12] to enhance wound closure strength, reduce incision length, and minimize postoperative complications. The original CRIS technique utilized a single absorbable polyglycolic acid suture, with knots placed only at the beginning and end of the incision.[13] However, long-term evaluation data are limited.

Therefore, this study aims to develop and evaluate a modified CRIS technique using two polypropylene sutures, referred to as the Cross-Running Polypropylene Intradermal Suture (CR-PIS), to improve keloid scars following lower extremity fracture surgery as measured by validated scar evaluation scales.

METHODS

The use of polypropylene sutures as intradermal reinforcing sutures has evolved and gained acceptance as an “external” suture material implanted within the skin. Earlier concerns raised by some authors were related to the risk of fistula formation and infection, as the suture material was considered a foreign body. However, Ario and Wihastyoko [10] demonstrated that the use of polypropylene in simple intradermal knot sutures resulted in improved scar quality without complications such as fistula or infection. Building upon these findings, the present study developed a novel suturing method using two polypropylene sutures applied in a cross-running intradermal pattern with the addition of knots at multiple points. This study employed a randomized controlled trial with a pre–posttest design and was conducted in patients with keloid scars treated at Dr. Saiful Anwar General Hospital (RSSA), Malang. The treatment group consisted of keloid patients who underwent total excision followed by wound closure using the Cross-Running Polypropylene Intradermal Suture (CR-PIS) technique. The control group comprised keloid patients who underwent total excision followed by simple intradermal suturing using polypropylene.

The study was conducted at RSSA, Malang, over a 12-month period from June 2024 to June 2025. The study population included all patients with keloid scars scheduled for surgical correction at RSSA. Based on RSSA medical record data, the incidence of abnormal scars during 2024–2025 comprised 15 cases. The study sample consisted of patients who met the predefined inclusion and exclusion criteria.

Patients were eligible for inclusion if they were aged between 20 and 50 years, had a diagnosis of keloid with a width of less than 2 cm allowing primary closure using a simple advancement flap, and had not received any prior keloid therapy. Patients were excluded if they were younger than 20 years or older than 50 years, had medical conditions associated with impaired wound healing such as diabetes mellitus, malnutrition, or hemophilia, or had received treatment before being registered as RSSA patients. Sample size determination was calculated using the formula n=N1+N(d2)n = \frac{N}{1 + N(d^2)}n=1+N(d2)N, where nnn represents the sample size, NNN the population size (15 cases), and d2d^2d2 the desired confidence level of 1%. Based on this calculation, the required sample size was 14.97, which was rounded to 15 patients.

The dependent variable was the suturing technique using the CR-PIS method. The independent variables included scar assessment outcomes measured using the Vancouver Scar Scale (VSS), Manchester Scar Scale (MSS), and Patient and Observer Scar Assessment Scale (POSAS). Intradermal suturing was defined as a suturing technique in which knots were placed within the wound, with a ratio of intradermal sutures to skin sutures of 1:2. The CR-PIS technique was defined as an intradermal suturing method using polypropylene material applied in a cross-running pattern with knots placed at several points along the wound. Patients were categorized as either receiving CR-PIS (coded as 1) or simple intradermal suturing (coded as 0). Scar quality was evaluated using VSS, MSS, and POSAS through direct observation by the investigator, and the resulting scores were recorded on an ordinal scale. Data collection utilized a digital camera for documentation, syringes and needles, and a standard plastic surgery instrument set. Surgical materials included polypropylene 4-0 and polyglycolic acid 4-0 sutures, antiseptic solutions (povidone iodine and Savlon), sterile gauze, tulle, Hypafix® adhesive plaster, and lidocaine–epinephrine 1% for anesthesia.

Keloid excision was performed using an elliptical incision design with a length-to-width ratio of 3:1, following the outer margin of the keloid. Procedures were conducted under either general or local anesthesia, and all patients received infiltrative anesthesia with lidocaine–epinephrine 1%. Following infiltration, the incision was made according to the design and deepened layer by layer to the base of the keloid, allowing complete excision. Hemostasis was achieved, and closure of the subcutaneous fat and fascia layers was performed using absorbable sutures (polyglycolic acid 4-0).

In the control group, after completion of keloid excision, skin closure was performed using simple intradermal knot sutures with polypropylene 4-0. The most superficial skin layer was closed with simple knots using the same suture material, following the technique described by Ario (2019). In the treatment group, after keloid excision, skin closure was performed using the CR-PIS technique. Polypropylene 4-0 sutures were applied intradermally in a cross-running pattern, with every five crossings terminated by a knot, and this process was continued until complete skin closure was achieved, as described by Xiong et al. (2012).

Data were presented in the form of tables and boxplots. Data normality was assessed using the Shapiro–Wilk test. If data were normally distributed, statistical analysis was performed using two-way repeated measures ANOVA. All statistical analyses were conducted using SPSS Statistics for Windows, Version 25.0 (Chicago: SPSS Inc.). A p-value of less than 0.05 was considered to indicate statistical significance.

RESULTS

Scar Assessment Outcomes Using VSS, MSS, and POSAS

The mean scar assessment scores for both the CR-PIS and control groups at baseline and during follow-up at 3, 6, and 9 months (Supplementary Table 1). At baseline, the two groups demonstrated comparable mean scores across all assessment instruments, including the Vancouver Scar Scale (VSS), Manchester Scar Scale (MSS), and Patient and Observer Scar Assessment Scale (POSAS), indicating similar initial scar severity prior to intervention. Over time, both groups exhibited a progressive reduction in mean scores; however, the magnitude and timing of improvement differed between groups, with the CR-PIS group demonstrating earlier and more pronounced reductions across all scales.

Normality Testing

Prior to inferential statistical analysis, data distribution was assessed using the Shapiro–Wilk test

due to the sample size being fewer than 50 participants. Normality testing was conducted for all outcome variables, including VSS, MSS, POSAS–Observer, and POSAS–Patient scores in both groups. All variables were normally distributed, with p-values exceeding 0.05 (Supplementary Table 2). Based on these results, parametric statistical analyses were deemed appropriate, and subsequent analyses were performed using two-way repeated measures ANOVA followed by Tukey post hoc tests.

Effect of CR-PIS on Vancouver Scar Scale (VSS) Scores

Changes in VSS scores over time between the CR-PIS and control groups were analyzed using two-way repeated measures ANOVA (Supplementary Table 3). A significant main effect of time was observed ($F = 68.7$, $p < 0.001$), indicating a significant reduction in VSS scores across follow-up periods in both groups. The main effect of group was not statistically significant ($F = 2.9$, $p = 0.09$), suggesting no overall difference in mean VSS scores between groups when time was not considered. However, a significant time × group interaction was identified ($F = 5.5$, $p = 0.003$), demonstrating that the pattern of VSS score reduction over time differed between the CR-PIS and control groups. Post hoc analysis using the Tukey multiple comparison test (Supplementary Table 4) revealed that the CR-PIS group exhibited significant reductions in VSS scores from baseline beginning at month 6 ($p < 0.001$) and continuing through month 9 ($p < 0.001$), with significant differences also observed between successive follow-up periods. In contrast, the control group showed significant reductions compared with baseline at months 6 and 9, while several comparisons between adjacent time points did not reach statistical significance. The distribution of VSS scores across follow-up periods is illustrated in Figure 1.

Effect of CR-PIS on Manchester Scar Scale (MSS) Scores

Two-way repeated measures ANOVA demonstrated a significant main effect of time on MSS scores ($F = 93.2$, $p < 0.001$), indicating progressive scar improvement throughout the observation period (Supplementary Table 5). The main effect of group was not significant ($p = 0.94$), whereas a significant interaction between time and group was observed ($F = 7.59$, $p = 0.001$), suggesting differential temporal changes between the CR-PIS and control groups. Tukey post hoc analysis (Supplementary Table 6) showed that the CR-PIS group experienced significant reductions in MSS scores as early as month 3 compared with baseline ($p < 0.01$), with continued and greater reductions at months 6 and 9 ($p < 0.001$). In the control group, significant improvements were first observed at month 6, with fewer significant differences between later follow-up intervals. MSS score distributions over time are presented in Figure 2.

Effect of CR-PIS on Patient and Observer Scar Assessment Scale (POSAS) Scores

Analysis of POSAS scores was conducted separately for patient-reported and observer-reported components. For POSAS–Patient scores, two-way repeated measures ANOVA revealed a significant main effect of time ($p < 0.001$), while the main effect of group was not significant ($p > 0.05$). A significant time × group interaction was identified ($p = 0.001$), indicating differing patterns of score reduction between groups (Supplementary Table 9). Post hoc Tukey analysis (Supplementary Table 10) demonstrated that the CR-PIS group showed significant reductions in patient-reported POSAS scores from baseline beginning at month 3 ($p < 0.0001$), with progressive improvements through month 9. The control group also exhibited significant reductions, though the magnitude of change was smaller and occurred more gradually.

Similarly, analysis of POSAS–Observer scores revealed a significant main effect of time ($p < 0.001$) and a significant time × group interaction ($p < 0.001$), while the main effect of group was not significant (Supplementary Table 7). Post hoc comparisons (Supplementary Table 8) indicated that the CR-PIS group demonstrated significant observer-rated improvements beginning at month 3, whereas significant changes in the control group were primarily observed at later follow-up points. The overall distribution of POSAS scores is illustrated in Figure 3.

Collectively, the results demonstrated significant temporal improvements in scar quality across all assessment instruments in both groups, with the CR-PIS group consistently showing earlier and greater reductions in VSS, MSS, and POSAS scores throughout the follow-up period.

DISCUSSION

This randomized controlled clinical study evaluated the effectiveness of the Cross-Running Polypropylene Intradermal Suture (CR-PIS) technique compared with conventional intradermal suturing in improving scar quality following keloid excision. Scar

outcomes were assessed using three widely validated instruments—Vancouver Scar Scale (VSS), Manchester Scar Scale (MSS), and Patient and Observer Scar Assessment Scale (POSAS)—allowing a comprehensive evaluation of both objective and subjective aspects of scar formation. The findings indicate that CR-PIS provides superior scar outcomes, particularly in terms of vascularity, pigmentation, pliability, scar height, and patient-reported symptoms, supporting its potential role as an improved wound closure technique in keloid-prone patients.

Baseline characteristics of the study population were comparable between the intervention and control groups, including age, sex distribution, anatomical location of the keloid, lesion size, and history of prior treatment. This homogeneity strengthens the internal validity of the study and supports the interpretation that differences in scar quality observed during follow-up were attributable to the suturing technique rather than confounding baseline variables. The predominance of young to middle-aged adults is consistent with the known epidemiology of keloid formation, which more frequently affects individuals in productive age groups. Moreover, the inclusion of keloids located on the lower extremities, an area subject to moderate to high skin tension, provides a relevant clinical context for evaluating the biomechanical performance of the CR-PIS technique.

The significant reduction in VSS scores observed in the CR-PIS group suggests improved scar maturation across multiple dimensions, including pigmentation, vascularity, pliability, and scar height. These parameters are critical indicators of scar quality and reflect underlying biological processes during wound healing. From a biomechanical perspective, these findings align with the established concept that excessive and uneven mechanical tension at wound edges promotes abnormal scar formation through fibroblast overactivation and increased collagen synthesis, particularly type III collagen.[14,15] The cross-running configuration of CR-PIS, combined with periodic knot placement, appears to distribute tensile forces more evenly along the wound edge, thereby minimizing localized stress concentrations that are commonly observed with conventional simple knot intradermal sutures.

This mechanism is consistent with wound healing principles described by Gurtner et al. [16], who emphasized that controlled mechanical environments promote optimal healing, whereas excessive tension contributes to chronic inflammation and fibrotic scar formation. The use of polypropylene sutures further supports this outcome, as polypropylene is nonabsorbable, exhibits minimal tissue reactivity, and maintains tensile strength over time. Previous work by Ario [10] demonstrated that polypropylene intradermal suturing significantly reduced abnormal scar formation and the present study extends these findings by showing that a cross-running configuration enhances the biomechanical advantages of this material.[13,17] In addition, the results are consistent with those reported by Xiong et al. [12], who found that cross-running intradermal sutures improved wound closure strength and aesthetic outcomes, despite differences in suture material.

Evaluation using the Manchester Scar Scale further demonstrated improved scar quality in the CR-PIS group, particularly regarding surface texture, contour, smoothness, border definition, and color similarity to surrounding skin.[18] MSS emphasizes aesthetic and structural features of scars, and its improvement suggests that CR-PIS contributes to a more natural and uniform healing process. Excessive mechanical tension has been shown to disrupt extracellular matrix organization, resulting in irregular, raised, and coarse scars.[14] By providing a more stable and evenly distributed mechanical environment, CR-PIS likely facilitates orderly collagen alignment and surface remodeling. This interpretation is supported by findings from Gurtner et al. [16], who demonstrated that mechanically stable wounds exhibit more parallel collagen deposition and smoother scar architecture. Although MSS improvement did not reach statistical significance in all parameters, the observed trend remains clinically relevant, particularly given the limited sample size.

The POSAS findings further reinforce the advantages of CR-PIS, as significant improvements were observed in both observer and patient-reported assessments. Observer scores indicated better scar thickness, softness, color, and surface characteristics, reflecting improved tissue remodeling. Patient-reported outcomes demonstrated reduced symptoms such as pruritus, pain, and discomfort, which are commonly associated with keloid scars. These subjective improvements are clinically meaningful, as chronic mechanical irritation and persistent inflammation have been linked to heightened sensory symptoms in abnormal scars.[15] By stabilizing wound edges and reducing

excessive mechanical stimulation, CR-PIS may attenuate inflammatory signaling and nociceptor activation, thereby improving patient comfort and satisfaction.

From a mechanistic standpoint, CR-PIS appears to optimize the biomechanical microenvironment of the healing wound. Uneven mechanical load can induce microvascular compression and localized hypoxia, which in turn alters fibroblast behavior and increases expression of profibrotic mediators such as transforming growth factor-beta 1 (TGF-β1), a key driver of keloid pathogenesis.[14] The cross-running configuration of CR-PIS maintains wound edge stability and minimizes abrupt changes in tensile forces, thereby reducing hypoxic stress and excessive fibroblast activation.[12] This balanced mechanical load supports physiological collagen synthesis and degradation, preventing the excessive matrix accumulation characteristic of keloid scars.[19] Additionally, the inert, monofilament nature of polypropylene minimizes inflammatory tissue responses, further contributing to a favorable healing environment.[20] This randomized controlled trial enhances internal validity through its design and provides a comprehensive, multi-tool assessment of scars with a biomechanical rationale and a clinically meaningful nine-month follow-up; however, its statistical power is limited by a small sample size, and its generalizability is constrained by the single-center setting and restrictive inclusion criteria, while unmeasured confounders like genetics and lifestyle may introduce bias. Clinically, CR-PIS is a practical modification to intradermal suturing for keloid-prone patients, improving scar quality by addressing biomechanical forces, and scientifically reinforces the role of mechanical stress in scar formation. To confirm these findings, future studies require larger, multicenter cohorts with longer follow-up and blinded assessments, alongside investigation into the technique's molecular effects on collagen remodeling. This study provides a foundational, promising step toward integrating mechanically optimized techniques into keloid management.

CONCLUSION

This randomized controlled study demonstrates that the Cross-Running Polypropylene Intradermal Suture (CR-PIS) technique is effective in improving scar quality following keloid excision, as evidenced by reductions in Vancouver Scar Scale (VSS), Manchester Scar Scale (MSS), and Patient and Observer Scar Assessment Scale (POSAS) scores. These findings indicate that CR-PIS provides superior biomechanical stability at wound edges, leading to more favorable scar maturation and improved patient-reported outcomes compared with conventional intradermal suturing. Although the results are encouraging, the relatively small sample size and limited follow-up duration highlight the need for further studies with larger populations, better control of potential confounding variables, and longer observation periods to confirm the durability of scar improvement and assess long-term keloid recurrence risk.

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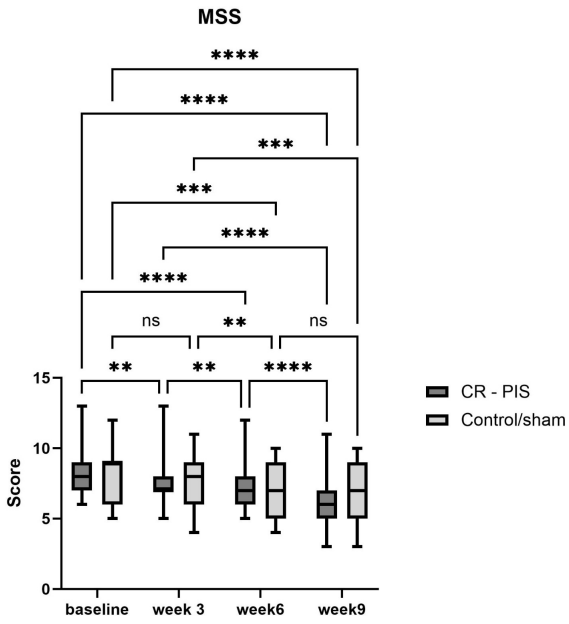

Figure 1. Comparison of VSS Scores Between CR-PIS and Control Groups Over 9 Weeks.

As illustrated in Figure 1, there were no statistically significant differences (ns) in the Vancouver Scar Scale (VSS) scores between the **CR-PIS** and **Control** groups at baseline and the 3-week follow-up. However, a significant divergence in clinical outcomes emerged starting from the 6th week. The CR-PIS group exhibited markedly lower VSS scores compared to the control group at Week 6 ($p < 0.0001$) and maintained this statistical superiority at Week 9 ($p < 0.01$).

The longitudinal analysis within the intervention cohort revealed a highly significant reduction in VSS scores over time. Comparison of baseline data to Week 6 and Week 9 demonstrated a substantial improvement in scar quality ($p < 0.0001$), represented by the downward shift in median scores and narrowing of the interquartile range (IQR). This indicates that the cross-running polypropylene intradermal suture technique provides a more consistent and rapid maturation of the scar tissue.

In contrast to the control group, which showed a slower and less pronounced decline in scores, the CR-PIS group achieved a median VSS score of approximately 3.0 by Week 9, whereas the control group remained at a median score of approximately 5.0. These findings suggest that the CR-PIS technique is more effective in reducing the severity of scarring following lower extremity fracture surgery.

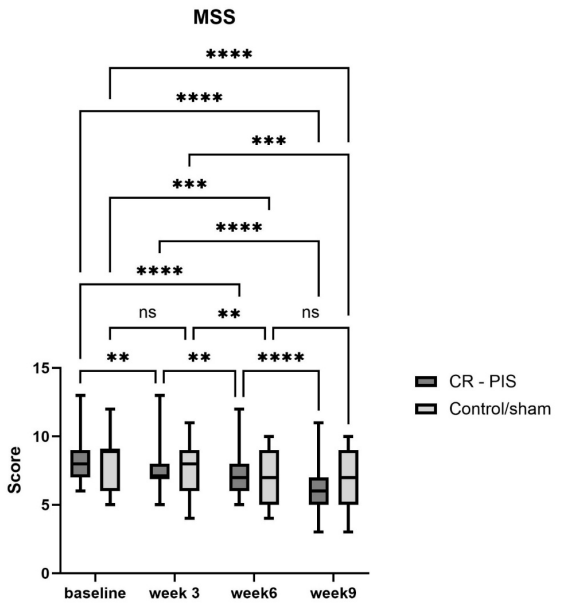

Figure 2. Longitudinal Comparison of MSS Scores Between CR-PIS and Control Groups.

The comparative analysis of Manchester Scar Scale (MSS) scores between the two cohorts is depicted in Figure 2. At the **9-week follow-up**, the CR-PIS group demonstrated a highly significant reduction in MSS scores compared to the control group ($p < 0.0001$). While significant differences were already observed at Week 3 and Week 6 ($p < 0.01$), the divergence became most pronounced at the final time point, indicating that the cross-running polypropylene intradermal suture technique provides superior long-term stabilization of the scar structure.

Within the **CR-PIS group**, there was a remarkable temporal improvement in scar quality. Compared to baseline, the MSS scores showed highly significant reductions at Week 6 and Week 9 ($p < 0.0001$). In contrast, the control group exhibited a less consistent improvement pattern. Although the control group showed some reduction by Week 9, the magnitude of change was less substantial than that observed in the intervention group, as evidenced by the higher median scores and wider distribution in the control cohort.

The data suggests that while both groups underwent natural scar maturation, the CR-PIS technique accelerated the process and resulted in a significantly better aesthetic outcome. By Week 9, the median MSS score in the CR-PIS group dropped to approximately 6.0, whereas the control group remained at a median score of approximately 7.0, reinforcing the clinical effectiveness of the tension-distributing properties of the CR-PIS method.

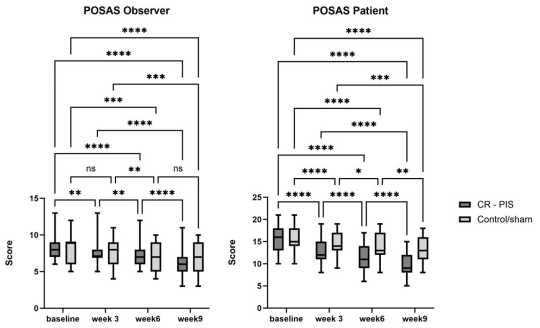

Figure 3. Comparative Analysis of POSAS Observer and Patient Scores.

The left panel of Figure 3 delineates the professional assessment of the scars. While the **CR-PIS group** initially presented with slightly higher scores at baseline compared to the control group ($p < 0.01$), it demonstrated a rapid and superior clinical improvement. By the 9th week, the CR-PIS group achieved a highly significant reduction in score compared to the control group ($p < 0.0001$).

Crucially, the **control group** showed no significant improvement (ns) when comparing their baseline scores to the 6-week and 9-week follow-ups, suggesting a plateau in scar maturation. In contrast, the CR-PIS group maintained a steady decline in scores ($p < 0.0001$), reflecting better outcomes in parameters such as vascularity, pigmentation, and pliability as assessed by the clinician.

The right panel illustrates the patient's perspective, which is often the primary concern in keloid management. The **CR-PIS group** showed a drastic reduction in subjective complaints (including itchiness, pain, and color) from baseline to Week 9 ($p < 0.0001$). The difference between the two groups remained highly significant ($p < 0.0001$) throughout every follow-up interval.

By Week 9, the median patient score in the CR-PIS group was approximately 9.0, whereas the control group remained significantly higher at approximately 13.0. This indicates that patients in the CR-PIS cohort were substantially more satisfied with their scar's appearance and experienced fewer symptoms than those in the conventional suture group.

Overall, the POSAS data confirms that the **CR-PIS technique** not only provides a better aesthetic result from a surgical standpoint but also significantly improves the patient's quality of life by reducing the symptoms and

psychological burden associated with keloid formation after lower extremity fractures.

LIST OF TABLE

Table 1. Mean Scores of Scar Assessment Between Control and Intervention Groups

Time Point	Intervention Group (CR-PIS)				Control Group			
	VSS (Mean ± SD)	MSS (Mean ± SD)	POSAS (Observer) (Mean ± SD)	POSAS (Patient) (Mean ± SD)	VSS (Mean ± SD)	MSS (Mean ± SD)	POSAS (Observer) (Mean ± SD)	POSAS (Patient) (Mean ± SD)
Baseline	5.1 ± 1.7	8.5 ± 2.2	8.5 ± 2.2	15.7 ± 3.5	5.7 ± 1.6	8.0 ± 2.0	8.0 ± 2.0	15.6 ± 3.3
Month 3	4.8 ± 1.6	8.0 ± 2.1	8.0 ± 2.1	13.3 ± 3.4	5.4 ± 1.4	7.8 ± 2.1	7.8 ± 2.1	14.5 ± 3.2
Month 6	3.9 ± 1.4	7.3 ± 1.9	7.3 ± 1.9	11.5 ± 3.1	5.0 ± 1.5	7.0 ± 2.0	7.0 ± 2.0	14.0 ± 3.3
Month 9	3.3 ± 1.4	6.0 ± 2.0	6.0 ± 2.0	9.7 ± 2.9	4.7 ± 1.2	6.7 ± 2.3	6.7 ± 2.3	13.0 ± 2.9

Legend: VSS = *Vancouver Scar Scale*; MSS = *Manchester Scar Scale*; POSAS = *Patient and Observer Scar Assessment Scale*; SD = *Standard Deviation*.

Table 1 presents the mean scores of scar assessment scales, including the **Vancouver Scar Scale (VSS)**, **Manchester Scar Scale (MSS)**, and **Patient and Observer Scar Assessment Scale (POSAS)**, recorded from baseline to the 9-month follow-up.

1. Baseline Comparability

At the initial baseline assessment, both the intervention (CR-PIS) and control groups exhibited comparable scar characteristics. For instance, the mean VSS score was 5.1 \ 1.7 in the CR-PIS group versus 5.7 \ 1.6 in the control group. Similarly, the POSAS (Patient) scores were nearly identical at 15.7 \ 3.5 and 15.6 \ 3.3, respectively, ensuring a balanced starting point for the longitudinal analysis.

2. Progressive Improvement in CR-PIS Group

The intervention group (CR-PIS) demonstrated a consistent and progressive decline in all scar assessment scores over the 9-month period. The **VSS score** in the CR-PIS cohort decreased from 5.1 \ 1.7 at baseline to 3.3 \ 1.4 at Month 9. A more pronounced improvement was observed in the **POSAS (Patient)** scores, which dropped significantly from 15.7 \ 3.5 to 9.7 \ 2.9, suggesting a substantial improvement in patient-reported satisfaction and scar quality.

3. Comparison with Control Group

In contrast, the control group showed a slower rate of improvement. By the end of the 9th month, the mean VSS score in the control group remained higher at 4.7 \ 1.2 compared to 3.3 \ 1.4 in the CR-PIS group. Furthermore, the final **POSAS (Observer)** and **MSS** scores in the CR-PIS group (6.0 \ 2.0) were lower than those of the control group (6.7 \ 2.3), highlighting the superior efficacy of the cross-running polypropylene intradermal suture technique in mitigating keloid scar progression following lower extremity fractures.

Table 2. Results of Data Normality Testing (Shapiro–Wilk Test)

Variable	Group	p-Value	Distribution
VSS	CR-PIS	0.95	Normal
	Control	0.98	Normal
MSS	CR-PIS	0.96	Normal
	Control	0.93	Normal
POSAS (Observer)	CR-PIS	0.96	Normal
	Control	0.94	Normal
POSAS (Patient)	CR-PIS	0.99	Normal
	Control	0.99	Normal

Legend: VSS = Vancouver Scar Scale; MSS = Manchester Scar Scale; POSAS = Patient and Observer Scar Assessment Scale.

Table 2: Prior to the comparative analysis, the distribution of the data was assessed using the Shapiro-Wilk test to determine the appropriate statistical approach. As shown in Table 2, all primary outcome variables—including the Vancouver Scar Scale (VSS), Manchester Scar Scale (MSS), and both components of the Patient and Observer Scar Assessment Scale (POSAS)—demonstrated a normal distribution across both the intervention (CR-PIS) and control groups.

The p-values for all variables ranged from 0.93 to 0.99, which are considerably higher than the standard significance threshold of 0.05. These results indicate that the null hypothesis of non-normal distribution was rejected, confirming that the data for both cohorts are normally distributed. Consequently, parametric statistical tests were employed for the subsequent longitudinal and comparative analyses of scar outcomes.