

Insulin as Anti-Scar Treatment: A Comprehensive Review

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Abstract

Background: Scar development is a typical consequence of skin injuries and surgical procedures, causing functional and aesthetic issues. Current approaches for scar care have limits, necessitating the investigation of alternative therapies. In addition to its well-known function in glucose metabolism, insulin has demonstrated promise as an anti-scar agent due to its effects on wound healing and tissue remodelling. **Objectives:** The purpose of this review is to investigate the role of Insulin and its mechanisms of action in scar reduction, evaluate the results of clinical trials, and address the problems and future directions of this field. **Conclusions:** Insulin exerts its anti-scar actions via multiple pathways, such as fibroblast proliferation, extracellular matrix remodelling, and regulation of scar-related gene expression. In vitro and animal research have shown good results, supporting insulin's potential as an efficient scar-reduction treatment. Nevertheless, obstacles pertaining to dosage determination, administration techniques, and potential adverse effects must be solved.

Keywords: Scar Formation; Insulin; Anti-Scar Treatment; Wound Healing; Tissue Remodeling.

1. Introduction

Scar development is a normal aspect of the wound healing process, resulting from dermal tissue repair after damage or surgery. Scars are a vital component of wound closure, but their appearance and functional implications can be a major source of stress for individuals. Scars can have psychological and emotional effects, influencing self-esteem, body image, and quality of life generally. In addition, certain forms of scars, such as hypertrophic and keloid scars, can be problematic due to their elevated, thickened, and occasionally itchy nature [1].

Scar management involves several issues. Despite the availability of numerous therapeutic methods, ideal scar results remain elusive in the majority of instances. Current scar care techniques include topical therapies (e.g., silicone sheets and gels), corticosteroid injections, laser therapy, cryotherapy, and surgical interventions such as scar revisions. Despite the fact that some of these modalities have demonstrated success in particular circumstances, they frequently exhibit limits in terms of efficacy, patient compliance, cost-effectiveness, and potential adverse effects [2].

The limitations of existing scar management solutions highlight the need to investigate alternative strategies that can control the scar development process. In recent years, the possible use of insulin as an anti-scar therapy has attracted interest. Insulin, generally recognised for its involvement in glucose metabolism, has showed a variety of other biological effects. Emerging research reveals that insulin may

possess qualities that could aid in scar reduction and promote enhanced wound healing results [3].

Exploring insulin as an anti-scar agent represents a viable approach to scar management. Insulin has been linked to various biological processes that contribute to scar formation, such as inflammation, collagen synthesis, angiogenesis, and fibroblast proliferation. By exploiting insulin's potential to regulate these processes, novel therapeutic techniques could be created to reduce scar development, improve scar appearance, and improve functional results [4].

In light of the limits of present therapy options and the expanding understanding of insulin's diverse effects, a full study of insulin's potential as an anti-scar agent is necessary. The purpose of this review is to investigate the role of Insulin and its mechanisms of action in scar reduction, evaluate the results of clinical trials, and address the problems and future directions of this field [5].

2. Scar Formation and Pathophysiology:

Scar development is an intricate biological process that takes place during the wound healing cascade. It involves a variety of dynamic processes and cellular reactions designed to repair damaged tissue and restore skin integrity. Understanding the process of scar development and its underlying mechanisms is necessary for assessing insulin's potential as an anti-scar treatment [6].

The creation of a scar can be roughly split into three stages that overlap: inflammation, proliferation, and remodelling (

Table (1) [7].

Table (1) The stages of scar formation] 8[.

Stage	Description
Inflammation	The initial stage of scar formation characterized by an inflammatory response immediately after tissue injury. Inflammatory cells, such as neutrophils and macrophages, migrate to the wound site to remove debris, bacteria, and damaged cells. Release of cytokines (e.g., interleukins, tumor necrosis factor-alpha) and growth

Proliferation	<p>factors (e.g., transforming growth factor-beta, platelet-derived growth factor (PDGF)) that orchestrate subsequent stages of wound healing.</p> <p>Excessive and prolonged inflammation can contribute to scar formation.</p> <p>Fibroblasts play a crucial role in scar development during the proliferation stage.</p> <p>Activated fibroblasts proliferate and synthesize extracellular matrix components, primarily collagen.</p> <p>Collagen provides structural support to the healing wound and bridges the gap between the wound edges.</p> <p>Imbalance in collagen synthesis and degradation can lead to excessive collagen deposition and altered collagen organization, resulting in the characteristic appearance of scars.</p> <p>Angiogenesis, the formation of new blood vessels, supplies oxygen and nutrients to the healing tissue. However, abnormal angiogenesis can contribute to scar formation, particularly in hypertrophic and keloid scars.</p> <p>The remodeling stage involves the reorganization and modification of the newly formed scar tissue.</p> <p>Collagen composition, cross-linking, and alignment undergo changes during scar maturation.</p>
Remodeling	<p>The balance between collagen synthesis and degradation is crucial for scar remodeling.</p> <p>Enzymes such as matrix metalloproteinases (MMPs) degrade excess collagen, while tissue inhibitors of metalloproteinases (TIMPs) regulate MMP activity.</p> <p>Wound depth, extent, and severity influence scar formation. Deeper and larger wounds are more prone to scar formation.</p> <p>The location of the wound can impact scar formation. Wounds in areas with high tension or mobility, such as joints or the chest, tend to result in more prominent scars.</p>
Factors influencing scar formation	<p>Individual variations in healing capacity, including genetic factors, comorbidities, and age, can influence scar development.</p> <p>Factors such as infection, poor wound care, and mechanical stress on the wound can exacerbate scar formation.</p>

3. Epidemiology of Scars:

Scarring is a frequent consequence of wound healing, affecting people of all ages and ethnicities. Scars' epidemiology provide light on their occurrence and effect on public health. Numerous research on scar formation rates have shown diverse findings based on variables such as wound kind, location, and patient group^[9].

As a result of the enormous number of surgical operations done globally, surgical scars are common. In addition, scars originating from accidents or traumas contribute considerably to the burden of scars. Understanding the epidemiology of scars is essential for determining the amount of healthcare resources necessary for scar treatment and for creating appropriate therapies^[10].

4. Types of Scars:

Scars may vary greatly depending on a number of variables, including the type of the damage, the individual's healing process, and genetics. The categorization of scars facilitates comprehension of their unique properties and aids in determining treatment options. There are a number of common scar types, including

hypertrophic scars, keloids, atrophic scars, and normotrophic scars^[11].

Clinicians must comprehend the many forms of scars in order to establish the most effective therapy methods. Each form of scar may need therapies that are particular to its features and the individual's circumstances. By categorising scars, healthcare providers may establish individualised treatment strategies focused at decreasing the scars' appearance, pain, and functional restrictions^[12].

Hypertrophic scars

Hypertrophic scars are characterised by excessive collagen formation, which results in elevated and thicker scars within the original wound's borders. These scars often occur from an excessive healing reaction, which is commonly encountered in surgical wounds, burns, and severe traumas^[13].

Scar tissue is raised and more noticeable than the surrounding skin as a result of the excessive collagen deposition. It is possible for hypertrophic scars to seem red, itchy, and painful. Location determines the symptoms and functional restrictions associated with hypertrophic scars. While some hypertrophic scars may progressively resolve and flatten

with time, others may remain for extended durations, causing patients to seek therapy with silicone gel sheets, corticosteroid injections, or surgical treatments to ease discomfort and improve cosmetic results^[14].

Keloid Scars

Keloid scars vary from hypertrophic scars in that they spread beyond the original wound's borders. Abnormal collagen production and fibroblast activity define them. Keloids may get progressively bigger than the original lesion, and their growth is often linked to genetic susceptibility, darker skin types, and certain precipitating circumstances^[15].

Keloids may develop from small injuries, surgical procedures, or spontaneously in the absence of an evident injury. In addition to presenting symptoms such as itching, discomfort, and soreness, they may also create severe cosmetic difficulties. Injections of corticosteroid, silicone gel sheets, cryotherapy, laser treatment, and surgical excision are among the methods used to treat keloid scars, which may be tough to treat. A combination of treatments is often used to reduce keloid recurrence and enhance their look^[16].

Atrophic scars

Atrophic scars are the consequence of tissue loss during wound healing. They appear as depressions or indentations on the skin and are often caused by disorders such as acne, chickenpox, or traumas causing substantial tissue damage. Atrophic scars may have a depressed look and alter the skin's texture and shape. In atrophic scars, the indentation is caused by the loss of underlying tissue, such as fat or collagen^[17].

Ice-pick scars, rolling scars, and boxcar scars are distinguishable forms of atrophic scars. Depending on their severity, treatment options for atrophic scars may include dermal fillers, microneedling, chemical peels, laser resurfacing, or surgical treatments. These therapies attempt to enhance the texture of the skin and stimulate collagen formation in order

to diminish the appearance of atrophic scars^[18].

Normotrophic scars

Scars that display a balanced healing response termed normotrophic. In general, they are flat and blend in with the surrounding skin, closely mimicking the texture and colour of healthy skin. Normotrophic scars are often the desired result of wound healing since they are less apparent and offer no functional or cosmetic difficulties. The healing process for normotrophic scars comprises the regeneration of injured tissue and the synthesis of collagen to form a scar that resembles the surrounding skin^[19].

Although normotrophic scars may still be evident, they do not exhibit notable variations in texture, colour, or form. As a consequence, the majority of treatment options for normotrophic scars concentrate on alleviating related symptoms, such as itching or pain, rather than modifying their look^[20].

5. Grading Scales:

Scar grading scales are vital for analysing and evaluating the severity and appearance of scars. These standardised scales offer a uniform framework for healthcare providers to objectively quantify and follow the advancement of scar features. Here are short explanations of three frequently used scar grading systems^[21]:

Vancouver Scar Scale:

The Vancouver Scar Scale is a commonly used grading system that evaluates several scar features. It assesses the thickness, vascularity (blood flow), coloration, and pliability of the scar (softness or flexibility). Each category is granted a number score based on precise criteria, allowing for a thorough examination of the look and features of the scar. This scale gives a systematic, quantitative method for assessing scars (

Table (2)^[22].

Table (2): Vancouver Scar Scale^[23].

Scar characteristic	Score
Vascularity	
Normal	0
Pink	1
Red	2
Purple	3
Pigmentation	
Normal	0
Hypopigmentation	1
Hyperpigmentation	2
Pliability	
Normal	0
Supple	1
Yielding	2
Firm	3
Ropes	4
Contracture	5
Height (mm)	
Flat	0
<2	1
2~5	2
>5	3
Total score	13

Patient and Observer Scar Assessment Scale (POSAS):

POSAS is a comprehensive grading scale that incorporates both patient and observer perspectives. It assesses various scar parameters, including color, thickness, relief (texture), pliability, and symptoms (such as itching or pain). The scale consists of two parts: the observer scale (

Table (3), completed by a healthcare professional, and the patient scale (**Table (4)**), completed by the individual with the scar. By considering both subjective and objective evaluations, POSAS offers a more holistic assessment of scar characteristics [23].

Table (3) The patient and observer scar assessment scale (Observer Component) [22].

Observer component*	Normal skin					Worst scar imaginable				
	1	2	3	4	5	6	7	8	9	10
Vascularity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Pigmentation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Thickness	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Relief	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Pliability	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Surface area	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Overall opinion	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Table (4) The patient and observer scar assessment scale (Patient Component) [22].

Patient component	No					Yes				
	1	2	3	4	5	6	7	8	9	10
Is the scar painful?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the scar itching?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the color of the scar different?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the scar more stiff?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the thickness of the scar different?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Is the scar irregular?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Overall opinion	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Manchester Scar Scale:

The Manchester Scar Scale is a grading system for assessing the overall look of scars. It is mostly concerned with pigmentation (colour), texture, and deformation. Each category is evaluated and given a score, which contributes to an overall scar evaluation. The scale considers hyperpigmentation, skin texture abnormalities, and scar deformation to provide a full assessment of scar aesthetics (

Table 5) [24].

Table 5: Manchester Scar Assessment Scale Assessor [25].

Excellent	Visual Analogue Scale		Poor
Lighter <input type="checkbox"/> or Darker <input type="checkbox"/>	A	Colour (c/To surrounding skin)	
		Perfect	1
		Slight mismatch	2
		Obvious mismatch	3
		Gross mismatch	4
	B	Matte (1)/Shiny (2)	
	C	Contour	
		Flush with surrounding skin	1
		Slightly proud/indented	2
		Hypertrophic	3
		Keloid	4
	D	Distortion	
		None	1
		Mild	2
		Moderate	3
		Severe	4
	E	Texture	
		Normal	1
		Just palpable	2
		Firm	3
		Hard	4

6. Insulin and its Mechanisms of Action:

Insulin, a hormone produced mostly by the pancreas, is essential for regulating glucose metabolism and maintaining appropriate blood sugar levels. Its principal purpose is to enhance glucose uptake from the bloodstream into cells, especially in muscle, adipose tissue, and liver. Insulin enhances glucose storage as glycogen in the liver and muscles, slows the breakdown of glycogen into glucose (glycogenolysis), and suppresses the liver's glucose synthesis (gluconeogenesis) [26].

Insulin, in addition to its well-known involvement in glucose metabolism, may have additional impacts on wound healing and scar reduction, according to recent studies. Various cell types involved in the wound healing process, including fibroblasts, endothelial cells, and keratinocytes, include insulin receptors. This indicates that insulin may exert direct effects on these cells and affect the wound-healing cascade [27].

Insulin has been proven to stimulate wound healing mechanisms such as cell proliferation, collagen formation, and extracellular matrix remodelling. It encourages the migration of fibroblasts to the wound site, hence boosting collagen deposition and speeding tissue repair. In addition, insulin contains anti-inflammatory characteristics and can control the inflammatory response, both of which are crucial for wound healing [28].

In animal models, insulin treatment or the application of insulin-like growth factors have been shown to promote wound healing. These results imply that insulin may have a role in boosting wound healing, minimising scar

formation, and enhancing the overall quality of repaired tissue [29].

The precise mechanisms behind the benefits of insulin on wound healing and scar reduction are currently being explored. Insulin may activate multiple signalling pathways, including the PI3K/Akt pathway and the MAPK pathway, which govern cell proliferation, survival, and tissue remodelling. Insulin may also modulate the expression of wound-healing growth factors, cytokines, and MMPs [30].

Although the potential benefits of insulin as an anti-scar medication are encouraging, additional research is required to completely comprehend its mechanisms of action and determine its therapeutic efficacy. Ongoing clinical trials examining the use of insulin-based therapeutics, such as topical insulin formulations or insulin injections, in the management of scars may shed light on its therapeutic potential [31].

7. Mechanisms of Action of Insulin in Scar Reduction:

Insulin exerts its anti-scarring properties through several cellular and molecular mechanisms. Understanding these pathways is essential for appreciating insulin's potential as a therapeutic drug for the management of scars. Insulin has a critical role in improving wound healing outcomes and minimising scar formation by increasing fibroblast proliferation, encouraging extracellular matrix (ECM) remodelling, and regulating expression of scar-related genes (

Table (6) Overview of the key mechanisms of action through which insulin exerts its anti-scar effects.

Mechanisms of Action of Insulin in Scar Reduction			
Fibroblast Proliferation	<ul style="list-style-type: none"> - Insulin promotes fibroblast proliferation through activation of signaling pathways like PI3K/Akt and MAPK. - Increased fibroblast proliferation leads to accelerated wound closure and collagen synthesis. 		
ECM Remodeling	<ul style="list-style-type: none"> - Insulin stimulates ECM remodeling by promoting collagen synthesis and activating enzymes like collagenases and MMPs. - It influences the balance between MMPs and TIMPs, favoring ECM remodeling and scar reduction. - Insulin modulates the expression of scar-related genes, including transforming growth factor-beta (TGF-β) and other cytokines and growth factors. 		
Scar-Related Expression	<table border="0"> <tr> <td style="vertical-align: top;">Gene</td> <td> <ul style="list-style-type: none"> - It downregulates TGF-β signaling, leading to decreased collagen deposition and scar formation. - Insulin affects the expression of angiogenic factors like vascular endothelial growth factor (VEGF), fibroblast growth factor (FGF), and PDGF, contributing to tissue regeneration. </td> </tr> </table>	Gene	<ul style="list-style-type: none"> - It downregulates TGF-β signaling, leading to decreased collagen deposition and scar formation. - Insulin affects the expression of angiogenic factors like vascular endothelial growth factor (VEGF), fibroblast growth factor (FGF), and PDGF, contributing to tissue regeneration.
Gene	<ul style="list-style-type: none"> - It downregulates TGF-β signaling, leading to decreased collagen deposition and scar formation. - Insulin affects the expression of angiogenic factors like vascular endothelial growth factor (VEGF), fibroblast growth factor (FGF), and PDGF, contributing to tissue regeneration. 		

Insulin influences scar removal through one of its key biological mechanisms, fibroblast proliferation. Fibroblasts are essential cells for wound healing and scar formation. Insulin increases fibroblast proliferation, resulting in enhanced collagen production and expedited wound healing. It activates signalling pathways that are essential for cell growth and survival, such as the PI3K/Akt pathway and the MAPK pathway. Insulin stimulates fibroblast proliferation by increasing the expression of genes involved in cell cycle progression, such as cyclin-dependent kinases (CDKs) and cyclins [33].

Insulin regulates ECM remodelling, which is necessary for scar removal. To generate a more structured and effective tissue structure, ECM remodelling entails the breakdown of old, disorderly matrix components and the synthesis of new collagen fibres. Insulin stimulates the manufacture of collagen and other ECM components by activating collagen-related genes and boosting the activities of collagenases and MMPs. In addition, insulin affects the equilibrium between MMPs and TIMPs, hence promoting ECM remodelling and scar removal [34].

Additionally, insulin can control the expression of genes involved in scar formation. It has been demonstrated to affect the expression of the major regulator of fibrosis and scar formation, TGF-. Insulin can inhibit TGF- signalling, resulting in less collagen deposition and scarring. Insulin regulates the expression of other cytokines and growth factors involved in wound

healing, including VEGF, FGF, and PDGF. These factors have crucial roles in angiogenesis, cell migration, and tissue regeneration, hence contributing further to the reduction of scar formation [35].

Using in vitro and animal models, researchers have gained vital insights into the processes of insulin in scar removal. Insulin has been proven in cell culture studies to increase fibroblast proliferation, boost collagen synthesis, and promote ECM remodelling. Insulin treatment has been shown to promote wound healing and minimise scar formation in animal experiments. In diabetic animal models with decreased wound healing, insulin therapy has been found to restore normal healing mechanisms, resulting in less scar formation. These results support the concept that insulin has favourable effects on scar reduction via its impact on wound healing-related cellular processes and signalling pathways [36].

Despite the fact that the evidence from in vitro and animal studies is encouraging, additional study is required to transfer these discoveries into therapeutic applications. To determine the efficacy and safety of insulin, clinical trials investigating the use of insulin-based treatments for scar management are required [37].

8. Challenges and Future Directions:

Although insulin shows promise as a treatment for scars, various obstacles and restrictions must be overcome prior to its broad clinical adoption. Determining the correct dosage of insulin for scar reduction is

a considerable obstacle. To guarantee successful scar reduction while minimising potential side effects associated with excessive insulin delivery, such as hypoglycemia or insulin resistance, the dosage must be properly regulated. It is crucial to strike the proper balance, and substantial research is required to determine dose guidelines particular to scar care^[38].

The selection of optimal delivery mechanisms for insulin is a further obstacle. Various modes of administration, including topical treatment, injection, and new approaches such as microneedles or sustained-release formulations, are now being investigated. Each approach has benefits and drawbacks, such as restricted skin penetration, the possibility of pain or discomfort during injections, and inconsistent administration. Identifying the most effective and patient-friendly delivery strategy is essential for the successful use of insulin in scar reduction^[39].

In addition, potential adverse effects and long-term safety implications must be examined properly. While insulin is generally regarded as safe when used for glycemic control in diabetes, its use as a therapy for scars may necessitate greater doses or other delivery routes. It is crucial to watch for side effects, including as local skin reactions, allergic reactions, and systemic problems. To evaluate the safety profile of insulin-based therapy specifically for scar control, long-term trials are required^[40].

To overcome these obstacles and improve the field, future research initiatives can concentrate on a number of crucial areas. First, by refining insulin formulations for scar reduction, its effectiveness and usability could be enhanced. This may involve the development of innovative delivery mechanisms that enhance insulin penetration into scar tissue, or the investigation of sustained-release formulations for extended therapeutic effects^[41].

In addition, researching the possibility of combining insulin with other therapy methods may result in synergistic effects and enhanced scar results. Utilizing growth factors, cytokines, or other drugs known to promote wound healing and scar reduction may be part of a combinational approach. Exploring the interconnections and potential additive or synergistic effects of these combinations could lead to the development of novel scar-management techniques^[42].

In addition, large-scale clinical trials are required to examine the safety and effectiveness of insulin-based treatments for scar removal in varied patient populations.

For establishing evidence-based guidelines and determining the clinical viability of insulin as an anti-scar treatment, rigorous clinical studies that assess scar improvement, patient satisfaction, quality of life, and long-term results are critical^[43].

9. Conclusion

Insulin exerts its anti-scar effects through various mechanisms, including fibroblast proliferation, extracellular matrix remodelling, and modulation of scar-related gene expression. In vitro and animal studies have demonstrated promising results, supporting the potential of insulin as an effective treatment for scar reduction. However, challenges related to dosage determination, delivery methods, and potential side effects need to be addressed. Future research should focus on optimizing insulin formulations, exploring combination therapies, and conducting large-scale clinical trials to establish the safety, efficacy, and optimal use of insulin-based treatments for scar management.

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