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Microneedling in the Management of Atrophic Acne Scars: Mechanisms, Clinical Applications, and Future Perspectives

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Abstract:

Background: Microneedling, also known as percutaneous collagen induction therapy, is a minimally invasive dermatologic procedure widely used for the management of post-acne atrophic scars. The technique creates controlled micro-injuries within the epidermis and dermis, thereby initiating a coordinated wound-healing cascade involving inflammation, cellular proliferation, angiogenesis, extracellular matrix deposition, and subsequent collagen remodeling. These biological responses promote fibroblast activation and increase the synthesis of collagen types I and III, elastin, and glycosaminoglycans, leading to dermal thickening and improvement in scar texture and depth. Microneedling also produces transient microchannels that bypass the stratum corneum and enhance the transdermal delivery of topical and biologic agents, making it a valuable platform for combination therapies such as platelet-rich plasma. Clinical evidence demonstrates that microneedling can significantly improve rolling and boxcar acne scars, whereas icepick scars generally show a limited response and often require additional procedures. Automated pen devices provide more consistent and controllable needle penetration than manual rollers, while fractional radiofrequency microneedling adds thermal stimulation to further enhance collagen formation. The procedure has a favorable safety profile across different skin phototypes, including darker skin, with mostly mild and transient adverse effects such as erythema, edema, and pinpoint bleeding. However, treatment outcomes remain influenced by scar type, needle depth, device configuration, number of sessions, and the use of adjunctive therapies.

Keywords: Microneedling; Percutaneous collagen induction therapy; Atrophic acne scars; Collagen remodeling; Transdermal drug delivery; Platelet-rich plasma; Fractional radiofrequency microneedling.

Introduction:

Microneedling, also known as percutaneous collagen induction therapy, is a minimally invasive procedure that has emerged as a versatile treatment modality for atrophic acne scars. The technique utilises fine needles to create controlled micro-injuries in the skin initiating a wound healing cascade that ultimately results in collagen synthesis and dermal remodelling **(1)**.

Beyond its direct therapeutic effects, microneedling creates transient microchannels that enhance the transdermal delivery of topically applied agents establishing it as an ideal platform for combination therapies with biologics **(2)**.

Mechanism of Action

I- Wound Healing Cascade

The therapeutic efficacy of microneedling is predicated on the controlled induction of a wound healing response. When microneedles penetrate the epidermis and papillary dermis, they trigger the three-phase healing cascade of inflammation, proliferation, and remodelling **(3)**.

The inflammatory phase initiates immediately following needle penetration with disruption of the dermal microvasculature resulting in platelet aggregation and fibrin clot formation with subsequent release of growth factors and cytokines from activated platelets and injured keratinocytes. Neutrophils and macrophages are recruited to the wound site clearing debris and releasing additional signalling molecules that orchestrate the subsequent phases of healing **(1)**.

The proliferative phase occurring from approximately day three to day fourteen is characterised by fibroblast migration and activation. Fibroblasts synthesise new ECM components such as collagen types I, III, and VII, elastin, and glycosaminoglycans while angiogenesis establishes new vascular networks to support the metabolically active tissue **(3)**.

The remodelling phase extends from several weeks to months following the procedure **(4)**. During this phase, collagen type III is progressively replaced by the more structurally robust collagen type I, and the newly deposited matrix undergoes reorganisation to achieve optimal tensile strength and architectural arrangement **(5)**.

II- Growth Factor Release

The wound healing response induced by microneedling involves the release of growth factors that drive tissue regeneration. The action of these growth factors results in dermal thickening, increased collagen density, and improved skin texture. These outcomes directly address the pathological collagen deficiency in atrophic acne scars **(6)**.

Key mediators include PDGF which stimulates fibroblast proliferation and chemotaxis, transforming growth factor-beta (TGF-β) which promotes collagen synthesis and ECM deposition, VEGF which induces angiogenesis, EGF which accelerates re-epithelialisation, and fibroblast growth factor (FGF) which supports fibroblast activity and neovascularisation **(6)**.

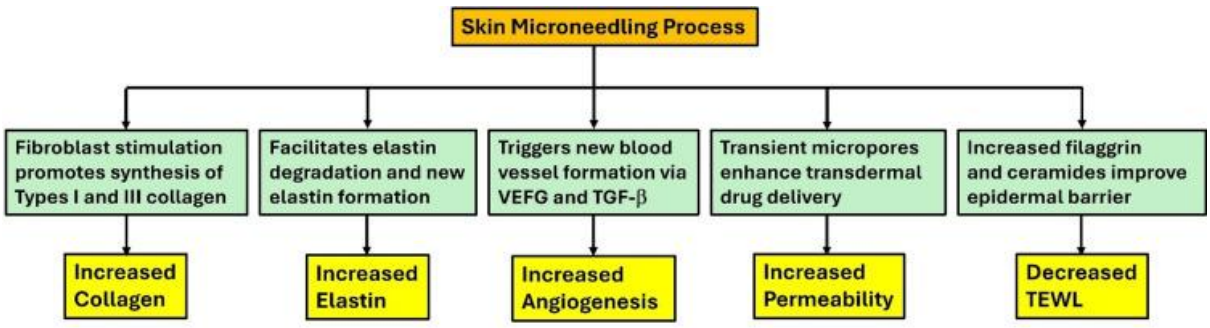

Figure 1. Cellular mechanisms and physiological outcomes of the skin microneedling process, leading to increased structural proteins, angiogenesis, permeability, and decreased transepidermal water loss (TEWL) **(1)**

Device Parameters

I- Needle Lengths and Thickness

Microneedle devices are available with needle lengths typically ranging from 0.25 mm to 3.0 mm with selection guided by the treatment indication and anatomical site **(2)**. For atrophic acne scars, needle lengths of 1.0 mm to 2.0 mm are most employed to ensure penetration into the papillary and reticular dermis where collagen remodelling occurs **(1)**.

Automated microneedling devices accommodate variable cartridge configurations, typically ranging from 12 to 36 pins. While individual needle gauge typically remains uniform across these configurations, the spatial density of the array dictates the skin's mechanical puncture resistance. Twelve-pin cartridges feature a wider inter-needle spacing than 24- or 36-pin alternatives. This lower density minimizes the 'bed-of-nails' mechanical phenomenon, wherein closely packed needles induce interacting strain fields that cause the elastic skin to deflect rather than pierce **(7, 8).**

By concentrating the device's mechanical insertion force onto fewer points, 12-pin cartridges reliably breach the stratum corneum to deliver clean, perpendicular microchannels at the intended dermal depth. These well-defined pathways drastically increase skin permeability, acting as a functional funnel for the transdermal influx and uptake of macro-molecular or viscid biological topicals (**9**).

II- Types of Devices

Microneedling has evolved from traditional manual rollers into advanced automated pen devices and radiofrequency systems. While handheld manual rollers provide an accessible option for at-home use to improve mild skin texture, their shallow and inconsistent needle penetration limits their ability to address deep dermal concerns **(4)**.

In contrast, professional automated pen devices utilize a motorized mechanism to precisely deliver thousands of vertical microchannels at controllable depths up to 2.5 mm. This mechanical precision allows automated pens to target deep scar tissue and promote dermal remodelling more efficiently than manual rollers **(4)**. Fractional radiofrequency microneedling (FRMN) devices combine mechanical needling with radiofrequency energy delivery providing additional thermal stimulation of collagen synthesis **(10)**.

Clinical Evidence for Atrophic Acne Scars

Multiple clinical studies have demonstrated the efficacy of microneedling for atrophic acne scars. Comparative studies have demonstrated that microneedling produces results comparable to non-ablative fractional lasers. **Cachafeiro et al. (11)** randomised 46 patients with atrophic facial acne scars to receive either microneedling with 2 mm needles or 1,340 nm non-ablative fractional laser finding significant but statistically equivalent improvements in both groups on the Quantitative Global Grading System for Postacne Scarring.

The response to microneedling varies according to scar morphology with rolling scars demonstrating the most favourable response due to their relatively superficial dermal tethering whilst boxcar scars show moderate improvement. Icepick scars being narrow and extending deep into the dermis respond poorly to microneedling monotherapy and typically require adjunctive treatments such as TCA CROSS or punch excision **(12)**.

Microneedling as a Platform for Transdermal Drug Delivery

A critical advantage of microneedling is its capacity to enhance transdermal drug delivery through the creation of temporary microchannels that bypass the stratum corneum, the principal barrier to percutaneous absorption. These microchannels measuring 50–200 micrometres in diameter remain patent for approximately 15–60 minutes following the procedure providing a window for enhanced penetration of topically applied therapeutic agents **(2)**.

The microchannels created by microneedling facilitate drug delivery through multiple mechanisms. First, they eliminate the rate-limiting barrier of the stratum corneum allowing direct access to the viable epidermis and dermis. Second, the increased surface area created by the micropores enhances passive diffusion. Third, the inflammatory response and increased local blood flow may accelerate drug absorption and distribution **(13)**.

This drug delivery enhancement is particularly relevant for biologic agents that would otherwise exhibit negligible percutaneous absorption due to their high molecular weight and hydrophilic nature. When applied immediately following microneedling, these agents can penetrate directly to the dermal compartment where they exert their regenerative effects. The combination of microneedling-induced growth factor release with the additional growth factors supplied by PRP creates a synergistic therapeutic effect that exceeds the outcomes achievable with either modality alone **(14)**.

Safety Profile Across Skin Phototypes and Adverse Effects

Dogra et al. (2014) evaluated 36 patients with Fitzpatrick skin types IV and V who underwent five microneedling sessions and reported a decrease in mean acne scar assessment scores from 11.73 to 6.5 with 50–75% improvement observed in the majority of patients. Importantly, no cases of PIH were reported highlighting the safety of the procedure in darker skin types.

This favourable safety profile of microneedling in patients with Fitzpatrick phototypes IV–VI makes it a preferred treatment option for acne scarring in Asian, Middle Eastern, African, and other populations with darker skin pigmentation where laser-based therapies carry unacceptable risks of pigmentary **complications (15)**.

Common adverse effects are mild and transient typically comprising erythema lasting 24–72 hours, mild oedema, pinpoint bleeding during the procedure, and occasional petechiae. These effects resolve spontaneously without intervention. Rare complications include infection which is preventable through appropriate sterile technique and track marks from improper needle insertion angles **(3)**.

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