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Carbopol-Based Curcumin Topical Gel for Wound Care: A Comprehensive Review

Mansi G. Raut, Komal A. Raut, Komal V. Dandge, Nidhi D. Mhasaye, Poonam R. More
Under the guidance of Prof. P. D. Ghube
PRMSS Anuradha College of Pharmacy, Chikhli, Buldhana, Maharashtra, India
Sant Gadge Baba Amravati University, Amravati

Abstract: *Wound healing is a complex biological process involving haemostasis, inflammation, proliferation and tissue remodelling. Delayed healing, particularly in chronic wounds, is associated with persistent inflammation, oxidative stress, microbial colonisation and impaired tissue regeneration. Curcumin, the principal curcuminoid of Curcuma longa, has attracted considerable interest as a topical wound-care candidate because of its anti-inflammatory, antioxidant, antimicrobial and pro-healing activities. However, poor aqueous solubility, limited skin permeation, chemical instability and rapid systemic metabolism restrict its conventional pharmaceutical use. Topical delivery through a hydrogel can improve local retention and provide a suitable moist environment for wound repair. Carbopol-940 is a widely used acrylic-acid-based gelling polymer that can produce clear, bioadhesive and shear-thinning gels at relatively low concentrations. This review examines the physiological basis of wound healing, the pharmacological actions of curcumin relevant to tissue repair, and the formulation rationale for Carbopol-based topical gels. Published evidence on conventional gels, nanoemulgels and curcumin-loaded hydrogel systems is critically considered, with emphasis on solubility enhancement, skin permeation, drug release, rheology, antimicrobial activity and wound-healing outcomes. Recent studies indicate that incorporation of curcumin into advanced delivery systems, including nanoemulsions, micelles and other hydrogel platforms, can improve its biopharmaceutical performance compared with unformulated curcumin. Nevertheless, evidence remains heterogeneous and is dominated by in-vitro and animal studies. Further standardized formulation studies, long-term safety assessments and well-designed clinical trials are required before Carbopol-based curcumin gels can be considered established wound-care therapies.*

Keywords: Curcumin; Curcuma longa; Carbopol-940; topical gel; hydrogel; wound healing; nanoemulgel; drug delivery.

I. INTRODUCTION

Wounds are disruptions of the normal anatomical structure and function of skin or underlying tissue caused by physical, chemical, thermal, microbial or other insults. Acute wounds generally progress through an orderly sequence of repair, whereas chronic wounds may remain in a prolonged inflammatory state and show impaired proliferation, angiogenesis and remodelling. The biological complexity of wound repair creates a need for therapies that address several pathological processes simultaneously rather than targeting a single event.

Curcumin is a polyphenolic compound derived from the rhizomes of Curcuma longa. Its pharmacological profile includes anti-inflammatory, antioxidant and antimicrobial effects, together with reported effects on collagen deposition, fibroblast activity, epithelialisation and angiogenesis. These properties make curcumin an attractive candidate for wound management. Reviews of topical curcumin have nevertheless identified poor aqueous solubility and limited tissue absorption as major barriers to effective delivery [1–3].

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Topical semisolid systems can address some of these limitations by placing the active compound close to the site of injury. Hydrogels contain a three-dimensional polymeric network capable of retaining substantial amounts of water and can provide cooling, spreadability and controlled release. Carbopol-940 is particularly useful as a gelling polymer because neutralisation of its carboxylic groups produces chain expansion and increased viscosity. Its shear-thinning behaviour can facilitate spreading while allowing the formulation to remain at the application site [4,5].

The objective of this review is to critically discuss the rationale, evidence and formulation considerations for Carbopol-based curcumin topical gels for wound care. The review also identifies limitations in the current evidence and directions for future formulation and clinical research.

II. METHODOLOGY

A literature-based review was undertaken using PubMed, ScienceDirect, Google Scholar and Scopus as the principal electronic sources. Search terms included combinations of “curcumin”, “Curcuma longa”, “Carbopol”, “carbomer”, “topical gel”, “hydrogel”, “nanoemulgel”, “wound healing”, “anti-inflammatory”, “antioxidant”, “antimicrobial” and “drug delivery”. Priority was given to peer-reviewed original research articles and relevant review articles describing curcumin pharmacology, wound-healing mechanisms, topical delivery systems and Carbopol-based formulations.

Studies were considered relevant when they addressed at least one of the following: biological mechanisms of curcumin in wound repair; formulation or evaluation of curcumin-containing topical gels or hydrogels; Carbopol-based delivery of curcumin or related phytoconstituents; or formulation strategies intended to overcome curcumin's poor solubility and skin permeation. Studies unrelated to dermal or wound applications and publications for which the available information was insufficient to assess relevance were not prioritised. The selected literature was organised thematically rather than treated as a formal systematic review. No new experimental work was performed in preparation of this article.

III. PHYSIOLOGY OF WOUND HEALING

3.1 Haemostasis

Haemostasis begins immediately after tissue injury. Vasoconstriction and platelet aggregation lead to formation of a fibrin-rich clot that limits blood loss and provides a provisional matrix for cell migration. Activated platelets release mediators and growth factors that initiate subsequent inflammatory and reparative events.

3.2 Inflammation

Neutrophils and macrophages migrate into the wound and remove microorganisms and cellular debris. Macrophages also release cytokines and growth factors that coordinate progression to the proliferative phase. Inflammation is therefore necessary for normal repair, but persistent inflammatory signalling and excessive reactive oxygen species can damage viable tissue and contribute to chronic non-healing wounds.

3.3 Proliferation

The proliferative phase includes re-epithelialisation, fibroblast activity, extracellular-matrix deposition, angiogenesis and wound contraction. Keratinocyte migration restores epithelial continuity, fibroblasts synthesise extracellular matrix and new blood vessels improve oxygen and nutrient delivery. Collagen deposition gradually fills the wound bed with granulation tissue.

3.4 Remodelling

During remodelling, the extracellular matrix is reorganised and relatively weaker early collagen is progressively replaced and rearranged into a stronger network. The tensile strength of healed tissue increases over time but generally remains below that of uninjured skin. An effective wound-care strategy should therefore support appropriate inflammation, control excessive oxidative and microbial stress, and promote organised tissue regeneration.

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IV. CURCUMIN: PHARMACOLOGY RELEVANT TO WOUND HEALING

4.1 Anti-inflammatory activity

Curcumin has been widely investigated for its ability to modulate inflammatory signalling. Reported effects include suppression of nuclear factor-κB-associated inflammatory pathways and reduction of mediators such as TNF-α, IL-1 and IL-6. Because excessive or prolonged inflammation can delay wound progression, this activity provides a mechanistic rationale for investigating curcumin in chronic or inflamed wounds [2,3].

4.2 Antioxidant activity

Oxidative stress is an important component of tissue injury. Curcumin can interact with reactive oxygen species and has also been associated with enhancement of endogenous antioxidant defence. Reducing excessive oxidative stress may help protect cells and extracellular matrix components during wound repair. However, antioxidant activity demonstrated in chemical assays should not automatically be equated with clinical efficacy [2,3].

4.3 Antimicrobial activity

Curcumin has demonstrated antimicrobial effects against several microorganisms in experimental studies, including organisms relevant to wound infection. Its reported ability to interfere with microbial growth and biofilm-associated processes is potentially useful because infection can prolong inflammation and delay closure. Nevertheless, antimicrobial findings are strongly dependent on concentration, organism, experimental conditions and formulation, and should not be interpreted as evidence that curcumin can replace clinically indicated antimicrobial treatment [5,6].

4.4 Effects on proliferation, collagen and angiogenesis

Experimental studies have reported effects of curcumin on fibroblast migration, collagen deposition, extracellular-matrix remodelling and angiogenic signalling. These effects may support progression through the proliferative and remodelling stages. Curcumin-loaded hydrogel and nanocarrier studies have also reported improved wound closure and histological outcomes in animal models [5,9].

4.5 Major biopharmaceutical limitations

Despite its pharmacological potential, curcumin has poor aqueous solubility and limited dermal delivery. Its chemical stability is also influenced by environmental conditions such as light and pH. These limitations make formulation design central to its topical development. The objective is not simply to place curcumin in a gel, but to maintain adequate drug solubilisation or dispersion, stability, release and deposition at the wound site [1,6].

V. CARBOPOL-940 AS A TOPICAL GEL BASE

Carbopol-940, also referred to as Carbomer 940, is a cross-linked poly(acrylic acid)-type polymer used as a thickening and gelling agent in pharmaceutical and cosmetic preparations. When dispersed in water and subsequently neutralised, ionisation of its carboxylic groups promotes polymer-chain expansion and formation of a viscous three-dimensional network [4,7].

At appropriate concentrations, Carbopol can produce clear or translucent gels with useful rheological properties. Its shear-thinning behaviour means viscosity decreases under the shear associated with spreading and recovers when the applied stress is removed. This behaviour can be advantageous for topical application because the formulation spreads readily but can remain on the treated surface.

Carbopol also provides a practical platform for incorporating solubilisation strategies for hydrophobic actives. In a curcumin formulation, co-solvents, surfactants, complexing agents or nanocarriers may be used before incorporation into the polymeric gel. The final formulation must be optimised because increasing polymer concentration or adding large quantities of co-solvents can alter viscosity, spreadability, drug release and skin tolerability [7].

VI. CURCUMIN-LOADED CARBOPOL SYSTEMS: CURRENT EVIDENCE

Direct evidence supporting the specific Carbopol-curcumin combination is more limited than the broader literature on curcumin wound-healing systems. This distinction is important: evidence that curcumin promotes wound repair does not by itself prove that every Carbopol-curcumin gel will be effective.

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Song et al. reported a Carbopol-940 hydrogel containing curcumin-loaded polymeric micelles. The hybrid system showed skin deposition and permeation, sustained curcumin release and antioxidant activity. In a full-thickness wound model, the formulation promoted wound closure and improved collagen enrichment and re-epithelialisation. These findings provide particularly relevant evidence for combining a curcumin solubility-enhancing carrier with a Carbopol-940 matrix [8].

Another experimental approach incorporated a curcumin-loaded nanoemulsion into 0.5% Carbopol-940 hydrogel. The resulting nanoemulgel showed thixotropic rheology and improved skin penetrability compared with curcumin dispersed in a conventional hydrogel, with supportive wound-healing findings in Wistar rats. This illustrates an important formulation principle: Carbopol can act as the final topical vehicle while a secondary nanocarrier addresses the intrinsic delivery limitations of curcumin [9].

More recent hydrogel studies using polymers other than Carbopol also support the broader concept of curcumin-loaded hydrogels. Curcumin-containing chitosan/PVA hydrogels have demonstrated antimicrobial and sustained-release characteristics in vitro, while other curcumin-loaded hydrogel systems have shown improved wound closure or tissue responses in animal models. These studies are relevant as supporting evidence but should not be presented as direct evidence for Carbopol-940 unless Carbopol was actually used [10–12].

Table 1. Representative evidence relevant to curcumin-loaded topical wound-delivery systems.

Study	Delivery system	Model	Main observation	Relevance
Mohanty and Sahoo, 2017 [10]	Multiple topical curcumin systems	Review	Summarised films, fibres, emulsions, hydrogels and nanoformulations for wound healing.	Supports topical formulation rationale.
Gong et al., 2013 [11]	Curcumin micelles in thermosensitive hydrogel	In vitro + animal	Extended release, tissue adhesion and improved wound repair were reported.	Supports carrier-assisted topical delivery.
Song et al., 2022 [8]	Curcumin-loaded micelles in Carbopol-940 hydrogel	In vitro + mouse wound model	Sustained release, skin deposition/permeation and improved wound healing were reported.	Directly relevant to Carbopol-940.
Alam et al., 2021 [9]	Curcumin nanoemulsion in 0.5% Carbopol-940	In vitro + ex vivo + rat	Improved skin penetrability and wound-healing performance compared with conventional curcumin hydrogel.	Directly relevant to Carbopol-940 nanoemulgel.
Zamani et al., 2024 [12]	Curcumin-loaded alginate hydrogel	In vitro/animal	Wound-healing effects were associated with gene-expression changes.	Supports broader hydrogel evidence.
Fu et al., 2024 [13]	Curcumin-loaded nanocomposite hydrogel	Experimental wound model	Hydrogel design was investigated for infected wound healing and tissue regeneration.	Supports advanced hydrogel strategies.
2025 clinical scoping review [14]	Various curcumin formulations	Human clinical trials	Clinical evidence was identified but showed substantial heterogeneity.	Highlights need for standardised clinical evidence.

VII. FORMULATION DESIGN AND EVALUATION

7.1 Solubility and pre-formulation

Because curcumin is poorly water soluble, pre-formulation should establish its identity, purity, solubility profile and compatibility with the intended excipients. Common investigations include organoleptic properties, melting behaviour,

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spectroscopic identification, UV-visible calibration and Fourier-transform infrared spectroscopy for compatibility assessment. Where a co-solvent or nanocarrier is used, the formulation should also be evaluated for precipitation, phase separation and chemical stability [1,6].

7.2 Gel preparation principles

A typical Carbopol formulation involves gradual dispersion of the polymer in purified water, hydration of the polymer, incorporation of the drug or drug-loaded carrier, and controlled neutralisation to obtain the desired gel consistency and pH. Curcumin may be incorporated using an appropriate solvent or carrier system rather than simply dispersing crystalline drug into the aqueous polymer network. The exact composition should be derived from experimental optimisation and should not be presented as a universal formula [4,7].

7.3 Physicochemical evaluation

Important evaluation parameters include appearance, homogeneity, pH, viscosity, rheological behaviour, spreadability, extrudability and drug-content uniformity. Skin compatibility is an important consideration because a wound formulation should avoid unnecessary irritation. The target pH should be justified by the intended application and the stability characteristics of the active rather than selected solely because it is convenient for gelation.

7.4 Drug release and permeation

In-vitro release studies can be performed using an appropriate diffusion-cell method, with a validated analytical procedure for quantification. Release profiles may be analysed using kinetic models such as zero-order, first-order, Higuchi and Korsmeyer–Peppas models where their assumptions are applicable. Ex-vivo skin permeation or deposition studies can provide additional information about whether the formulation increases local delivery. Importantly, improved release through a membrane does not automatically demonstrate improved therapeutic efficacy in humans.

7.5 Biological evaluation

Antimicrobial assays, antioxidant assays and cell-based or animal wound models may provide complementary evidence. Animal studies should follow appropriate ethical approval and recognised reporting standards. Histological assessment, wound-closure measurements and relevant biochemical or molecular markers can strengthen interpretation. Clinical translation requires evidence from adequately designed human studies rather than relying solely on laboratory or animal findings [14].

VIII. ADVANTAGES AND LIMITATIONS

8.1 Advantages

Carbopol-based topical systems offer a convenient platform for local administration and can provide desirable spreadability and residence characteristics. A hydrogel can maintain a hydrated wound interface and can be engineered for controlled release. Combining this platform with curcumin's multi-target pharmacology may provide simultaneous modulation of inflammation, oxidative stress and microbial burden. Carrier-assisted formulations can additionally improve curcumin dispersion and skin delivery [8,9].

8.2 Limitations

Curcumin's poor aqueous solubility remains the central formulation challenge. The intense yellow-orange colour may also reduce cosmetic acceptability. Limited penetration through intact skin can restrict delivery to deeper tissue, while chemical instability can affect product quality during storage. High-water-content gels require an appropriate preservation strategy and packaging. Most importantly, the current evidence base is heterogeneous: formulations differ in polymer concentration, curcumin loading, carrier composition, animal model, dosing and evaluation methods. Therefore, the apparent benefit of one formulation should not be generalised to all Carbopol-curcumin gels [6,14].

IX. FUTURE PERSPECTIVES

Future work should focus first on improving the pharmaceutical performance of curcumin without making the formulation unnecessarily complex. Nanoemulsions, polymeric micelles, cyclodextrin complexes and related carrier systems may improve apparent solubility, protect curcumin and enhance skin deposition. Recent research also

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demonstrates continuing interest in curcumin-loaded hydrogels and nanocomposite dressings, indicating that hybrid delivery systems remain an active research area [12,13,15–17].

For Carbopol-based products, formulation optimisation should consider polymer concentration, neutralisation, drug loading, carrier size, release kinetics, rheology, skin deposition and stability simultaneously. Comparative studies should include an unformulated curcumin control and an appropriate conventional topical comparator so that the benefit attributable to the delivery system can be distinguished from the intrinsic activity of curcumin.

Translation into clinical wound care requires standardised in-vivo protocols followed by adequately powered clinical trials. A 2025 scoping review of clinical trials found promising but heterogeneous evidence across different curcumin formulations, reinforcing the need for standardised dose, formulation, treatment duration and outcome measures [14]. Future studies should also address long-term safety, repeated application, product stability, manufacturing scale-up and cost-effectiveness.

X. CONCLUSION

Carbopol-based curcumin topical gels represent a rational pharmaceutical approach for local wound delivery because they combine the formulation advantages of a hydrogel with the multifunctional pharmacology of curcumin. Available experimental evidence supports the potential of Carbopol-940 systems, particularly when solubility and skin-delivery limitations are addressed through micellar or nanoemulsion approaches. However, the current evidence should be interpreted cautiously because much of it remains preclinical and formulations vary substantially between studies. The most important priorities are rigorous formulation optimisation, reproducible evaluation, long-term stability and safety assessment, and well-designed clinical studies. Accordingly, Carbopol-curcumin gels should be regarded as promising investigational wound-care systems rather than established replacements for standard wound management.

DECLARATIONS

Conflict of Interest

The authors declare that there is no conflict of interest.

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Ethical Approval

Not applicable, as this article is a literature review and does not report new experiments involving humans or animals.

Author Contributions

Author contributions should be finalised by the authors according to their actual intellectual and writing contributions before submission.

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