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SHORT REVIEW

Plant-based Natural Remedies for Surgical Wound Healing: An *Ayurvedic* and Ethnopharmacological Narrative Review

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Abstract

Background: Surgical wound healing is a complex issue, often challenged by infection, inflammation, and abnormal tissue repair. Even with modern wound care, conventional treatment may not always result in optimal outcomes, especially in immunocompromised patients. The traditional *Ayurvedic* system of medicine offers vegetable-based drugs that are believed to induce balance within the body, thus enhancing healing. The time-tested drugs may be a useful addition to existing wound care protocols. **Aim:** This review assesses the efficacy of *Ayurvedic* plant drugs *Curcuma longa* (Turmeric), *Centella asiatica (Gotu kola), Azadirachta indica* (*Neem*), and *Aloe vera* in speeding up surgical wound healing. It also attempts to integrate traditional *Ayurvedic* principles with modern scientific understanding of wound healing mechanisms. **Methodology:** A Narrative literature review was conducted on PubMed, Scopus, and Google Scholar to identify articles describing the pharmacological activity of *Ayurvedic* herbs in wound healing. Articles on the anti-inflammatory, antimicrobial, and regenerative activity of these herbs were reviewed. **Results:** *Ayurvedic* drugs like *C. longa* and *C. asiatica* have been reported to enhance wound healing by enhancing collagen synthesis, regulating inflammation, and stimulating tissue regeneration. The findings are in accord with *Ayurvedic* principles, which hypothesise that these herbs restore the Dosha balance of the body, *i.e.*, Pitta (inflammation) and Kapha (moisture), and facilitate tissue repair. **Conclusion:** Addition of *Ayurvedic* plant drugs to existing wound care strategies promises promising therapeutic benefits. However, additional clinical trials, *i.e.*, randomised controlled trials and standardised preparations, are necessary to establish their efficacy and inclusion in existing surgical practice.

Major Findings: *C. longa, C. asiatica,* and *A. indica* have strong anti-inflammatory, antimicrobial, and regenerative activity, opening the door to their efficacy in speeding up surgical wound healing.

Keywords: Antioxidants, Collagen, Herbal Medicine, Inflammation, Tissue Regeneration, Wound Healing

1. Introduction

Surgical wounds, big or small, are common after invasive procedures, yet healing is still complex. This biological process involves inflammation, tissue regeneration, collagen synthesis, and remodelling. Infection, impaired immunity, poor perfusion, and chronic diseases (e.g., diabetes and obesity) can complicate healing[1]. Infection and delayed healing are complications that prolong hospitalisation, healthcare expenses, and morbidity and mortality. Surgical site infections can worsen recovery, leading to extended healing periods, scarring, or permanent disability. Despite enhanced surgical skills, wound care devices, and antimicrobial prophylaxis, SSIs remain a problem,

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and the use of complementary therapies to ensure faster healing is warranted[2].

Traditional therapies such as antibiotics and wound dressing are needed but fail to address all the biological intricacies of wound healing. Antimicrobial resistance makes Wound infection control difficult, as most pathogens are resistant to most antibiotics. Moreover, inflammation, oxidative stress, and collagen degradation can slow tissue regeneration and cause increased scar tissue[3]. Synthetic therapies are side-effect prone and fail to maximise tissue regeneration, particularly in chronic wounds. Further, they will likely fail to address concerns such as an impaired immune system or circulatory deficiency. This has increased interest in complementary therapy, especially plant-based therapy, to achieve more holistic wound healing[4].

Traditional systems of medicine, such as *Ayurveda*, Traditional Chinese Medicine (TCM), and *Siddha,* have understood the medicinal value of plants for centuries. *Ayurveda*, an ancient tradition, utilises plants to restore balance to the body's energies (*Doshas*) and heal wounds, both cause and symptoms. In *Ayurveda*, wound healing is called *Vrana Ropana,* where *Pitta* (inflammation) and *Kapha* (moisture), *Doshas* balance is restored, and tissue regeneration is stimulated[5]. Plants such as *C. longa (*Turmeric*), C. asiatica (Gotu Kola), A. indica (Neem),* and *A. vera* are utilised because of their anti-inflammatory, antimicrobial, and regenerative properties. As fear of synthetic drugs and antimicrobial resistance grows, modern science has increasingly investigated plant medicines. These plants contain bioactive compounds, flavonoids, terpenoids, alkaloids, and phenolics, which reduce oxidative stress, prevent infection, and stimulate tissue regeneration, thus facilitating wound healing[6].

Although there is a history of herbal therapy used to treat wounds, it has a minimal role in contemporary surgical practice. Cumulative scientific data provide evidence to support the use of phytotherapy in wound healing. The addition of *Ayurvedic* therapy to conventional practice is likely to supplement contemporary wound therapy[7]. For example, *A. indica (Neem)* and *C. longa (*Turmeric*)* have extensively shown antimicrobial and anti-inflammatory activities and might prevent *SSIs* and reduce recovery time. *C. asiatica (gotu kola)* also possesses collagen synthesis and tissue repair activity and might be beneficial in preventing scarring and reducing recovery time[8].

In this review, we try to bridge the gap between conventional *Ayurvedic* principles and contemporary scientific knowledge of wound healing. *Ayurvedic* medicine is concerned with the restoration of internal body forces (*Doshas*) equilibrium by the use of plant medicines with active action on inflammation, moisture, and tissue formation. Contemporary science of wound healing is concerned with mechanisms like collagen synthesis, regulation of inflammation, and antimicrobial action. By looking at how *Ayurvedic* herbs, like *C. longa* (Turmeric) and *C. asiatica* (*Gotu kola*), correspond to these contemporary principles, we see the promise of incorporating these conventional medicines into present-day clinical practice to optimise the results of wound healing.

This narrative review considers using plant therapies in *Ayurvedic* practice for healing surgical wounds. The review considers the pharmacological activity of the most commonly used plants, pharmacological mechanisms, and evidence-based efficacy. The review aims to bridge traditional *Ayurvedic* practice and modern wound care, considering how the remedies can be integrated into modern surgical practice to improve patient outcomes.

The benefits are significant in association with modern treatment and Ayurvedic herbal medications. *C. longa, C. asiatica, A. indica,* and *A. vera* can be utilised to manage inflammation, infection, and collagen synthesis. However, clinical trials and standardisation must be conducted to include such treatments in mainstream medical practice.

2. Review of Literature

Several studies have investigated the capacity of plant remedies and Ayurvedic preparations to treat wounds. Anyiam *et al.*, centred on the phytochemical composition of plants such as *A. vera* and Turmeric with anti-inflammatory and antimicrobial effects[9]. However, one of the biggest challenges is bringing these remedies into clinical use through standardisation. Dhama *et al.*,

examined the antibacterial activity of medicinal plants, especially against drug-resistant organisms. However, the lack of clinical trials of particular herbal treatments raises doubts about their effectiveness and reliability in the clinical context[10]. Soni *et al.*, reviewed nascent herbal medicine delivery systems for wound healing and reported challenges to incorporating these treatments into modern medical practice[11]. Shah *et al.*, highlighted the antimicrobial and anti-inflammatory effects of *Ropana Taila* but called for clinical evidence to support its effectiveness[12]. Wayal and Gurav tested the *Bhallatakadi Ghrita* preparation and established its efficacy, although they cited the need for standardised dosing to provide replicable results[13]. Hrynyshyn *et al.*, reviewed biofilm-targeting strategies. They recommended further research to assess the potential of herbal remedies to prevent biofilm formation and enhance wound healing outcomes, as shown in Table 1[14].

3. Materials and Methods

3.1 Locating Data

Data for this review were retrieved from prominent electronic databases, including PubMed, Scopus, and Google Scholar, focusing on studies published in the last 20 years. The search terms used were "plant-based remedies," "Ayurvedic wound healing," and single herbs such as *C. longa (*Turmeric*), C. asiatica (Gotu Kola), A. indica (Neem),* and *A. vera.*

3.2 Data Collection

Original research papers, review papers, and ethnopharmacological research on wound healing and plant remedies were chosen. Preclinical (animal models, *in vitro*) and clinical studies were addressed in the research studies. Information relating to phytochemical characteristics, action mechanisms, and wound healing effects of plant remedies was acquired from research studies specifically aimed at them.

3.3 Eligibility Criteria

Review studies must examine the effect of *Ayurvedic* plant drugs, *e.g., C. longa (*Turmeric*), C. asiatica (Gotu kola), A. indica (Neem),* and *A. vera* on wound healing outcome measures like collagen synthesis, tissue repair, anti-inflammatory, or antimicrobial activity. Randomised controlled trials, observational studies, and preclinical studies published in English alone in the last 20 years will be considered.

Table 1. Previous work on plant-based remedies and wound healing

Key finding	Research focus	Challenges/ limitations	Future scope	References
Phytochemical properties in injury management.	Phytochemicals in wound healing	Standardisation of herbal remedies.	Explore plant combinations for wound care.	9
Antibacterial properties against drug-resistant bacteria.	Antimicrobial activity of plants	Lack of clinical trials on herbal treatments.	Clinical studies on plant antimicrobials.	10
New herbal medicine delivery systems for wound healing.	Herbal delivery systems	Integration with modern drug delivery systems.	Develop more efficient drug delivery systems.	11
Ropana Taila's antimicrobial, anti-inflammatory effects.	Ayurvedic wound healing formulations	Need for clinical trials on efficacy.	Trials on *Ropana Taila*'s safety and efficacy.	12
Bhallatakadi Ghrita promotes wound healing in animal models.	Polyherbal formulations	Need for standardisation of formulations.	Study dosage forms and clinical applications.	13
Biofilm prevention in surgical site infections.	Biofilm prevention and wound healing	Limited clinical testing of biofilm-targeting herbs.	Develop biofilm-targeting herbal treatments.	14

Note: Summary of key research on plant-based therapies for wound healing, focusing on findings, emphasis, limitations, and prospects.

Exclusion criteria for trials are trials that are non-Ayurvedic interventions described, do not measure wound healing, are of poor methodology, or are not English with a valid translation.

3.4 Data Extraction

The most critical data were gathered for plant species, formulation type, phytochemical profile, and reported effect on wound healing. The study designs, sample sizes, and outcomes were evaluated, focusing on those of clinical relevance and high quality.

3.5 Synthesising Data

Results were categorised based on plant species and their activity towards wound healing, *i.e.*, anti-inflammatory, antimicrobial, and collagen-synthesising activity. The review integrates the ancient *Ayurvedic* information with the current scientific data to provide a complete picture of plant-derived drugs for surgical wound healing.

4. Result

4.1 Phytochemical Profiles of Useful Herbs Employed in Wound Healing

Herbs such as *C. longa* (Turmeric), *C. asiatica (Gotu kola)*, *A. indica (Neem)*, and *A. vera* contain bioactive molecules responsible for wound healing. *C. longa* contains curcumin, a flavonoid, which is anti-inflammatory and antioxidant in nature and decreases the level of oxidative stress and inflammation. *C. asiatica* contains asiaticoside, a triterpenoid that induces collagen synthesis, fibroblast proliferation, and angiogenesis, which increases tissue regeneration. *A. indica (Neem)* contains an alkaloid and flavonoid with antimicrobial activity that decreases bacterial load and infection. *A. vera* contains anthraquinones and saponins that induce collagen synthesis and wound contraction and are antibacterial in nature. Coordination of these bioactive molecules controls inflammation, prevention of infection, and repair of tissue, and hence the herbs are useful in wound healing, as shown in Table 2. nimbidin.

4.2 Anti-inflammatory Activities of Plant Therapeutics

Plant medicines such as *C. longa* (Turmeric), *C. asiatica (Gotu kola)*, *A. indica (Neem)*, and *A. vera* possess strong anti-inflammatory activities that are crucial in healing surgical wounds[20,21]. In Ayurveda, inflammation is traditionally caused by an excess of the Pitta dosha, leading to heat and inflammation in

Table 2. Phytochemical profiles of key herbs used in wound healing

Plant	Bioactive compounds	Healing mechanism	Key effects	References
Various Herbs	Flavonoids, terpenoids, alkaloids	Modulates inflammation, promotes collagen synthesis, enhances tissue regeneration	Reduces inflammation, accelerates healing, and improves scar formation.	15
Oroxylum indicum	Flavonoids, phenolic acids, tannins, saponins	Promotes collagen production, enhances tissue repair, and antimicrobial activity	Prevents infection, accelerates wound healing, and improves tissue regeneration	16
Artemisia absinthium	Flavonoids, terpenes, essential oils	Anti-inflammatory, antimicrobial, stimulates wound closure	Reduces swelling, inhibits bacterial growth, promotes tissue regeneration	17
Marrubium vulgare	Flavonoids, terpenoids, phenolic compounds	Antioxidant properties promote fibroblast activity and collagen production	Enhances wound contraction, reduces oxidative stress, and promotes healing	18
Calotropis gigantea	Alkaloids, flavonoids, terpenoids	Reduces inflammation, increases collagen synthesis, antimicrobial	Promotes wound closure, accelerates healing, and prevents infection	19

Note: This table highlights the bioactive compounds in key herbs used for wound healing. These compounds act through anti-inflammatory, antimicrobial, and regenerative mechanisms to promote wound healing, reduce infection risk, and improve tissue regeneration.

the body. These medicinal plants regulate Pitta by suppressing inflammation and reducing excess heat in the wound region. *C. longa* contains curcumin, which regulates pro-inflammatory cytokines (*e.g.*, TNF-α, IL-1β) and suppresses the NF-kB pathway, a key regulator of inflammation[22]. *C. asiatica* suppresses pro-inflammatory cytokines and promotes the synthesis of collagen, allowing tissue repair to occur at an increased rate. *A. indica (Neem)* suppresses prostaglandin and cytokine production, and thus, inflammation is prevented. *A. vera* contains anthraquinones, which reduce inflammatory markers and enhance healing[23,24]. These findings link *Ayurvedic* principles to modern pharmacological understanding of the regulation of inflammation during wound healing, as shown in Table 3.

4.3 Antimicrobial Properties and their Function in Preventing Infection

Plant antimicrobial compounds, especially in *A. indica (Neem)* and *C. longa* (Turmeric), are of great importance in the management of Surgical Site Infections (SSI) due to their ability to fight microbial pathogens at the site of the wound[25,26]. *A. indica* has nimbidin, a flavonoid with broad-spectrum antifungal and antibacterial activity. It inhibits bacterial cell membranes and prevents the growth of pathogens like Staphylococcus aureus and Pseudomonas aeruginosa, which are responsible for most SSI[27]. *C. longa* (Turmeric), especially its active component curcumin, has antimicrobial activity against gram-positive and gram-negative bacteria and fungi. Curcumin inhibits the replication of microbial DNA and protein synthesis, thereby preventing pathogen growth. Synergism of terpenoids, flavonoids, and alkaloids found in these plants not only prevents microbial growth but also activates the immune system, preventing infection and enhancing wound healing[28,29] as shown in Table 4.

4.4 Collagen Synthesis and Tissue Regeneration

Centella asiatica (Gotu kola) is renowned for its ability to stimulate collagen production and tissue repair and is thus an excellent herb for wound healing[30]. It contains triterpenoids, particularly asiaticoside, which induces the proliferation of fibroblasts, a crucial event in collagen production and repair of tissue. Asiaticoside triggers collagen production by inducing collagenase and lysyl oxidase, enzymes responsible for the maturation of collagen[31,32]. *C. asiatica* also triggers angiogenesis, which enables the formation of new blood vessels that increase the delivery of nutrients and oxygen

Table 3. Anti-inflammatory effects of plant-based remedies

Plant	Active compound	Anti-inflammatory mechanism	Impact on wound healing	References
Various plants	Flavonoids, terpenoids, phenolic compounds	Modulates cytokine production and inhibits the NF-kB pathway	Reduces inflammation and accelerates healing by modulating the inflammatory response	20
Various plants	Flavonoids, alkaloids	Inhibits COX-2, reduces prostaglandin production, modulates TNF-α levels	Controls inflammation, enhances tissue regeneration, reduces scarring	21
Various plants	Phenolic compounds, essential oils	Suppresses pro-inflammatory cytokines and enzymes like COX-2	Helps in faster recovery and reduces pain and swelling	22
Various Italian Folk plants	Essential oils, flavonoids	Inhibits inflammatory mediators and modulates the immune response	Reduces inflammation and promotes wound healing and comfort	23
Various plants	Flavonoids, alkaloids, essential oils	Reduces TNF-α, IL-1β, and other pro-inflammatory cytokines	Alleviates swelling and supports effective wound healing by controlling inflammation	24

Note: This table summarises the anti-inflammatory effects of various plant-based remedies. Active compounds like flavonoids and essential oils modulate the immune response, reduce inflammation, and promote faster wound healing.

Table 4. Antimicrobial properties and their role in preventing infections

Plant	Active Compound	Antimicrobial Action	Target Pathogens	Healing Impact	References
Various plants	Antimicrobial peptides	Disrupts bacterial membranes, inhibits growth	*S. aureus, P. aeruginosa, E. coli*	Reduces infection, accelerates healing	25
Chitosan	Chitosan derivatives	Disrupts cell walls, prevents biofilm	*S. enterica, S. dysenteriae, E. coli*	Prevents infection, speeds healing	26
Various plants	Alkaloids, flavonoids, terpenoids	Inhibits growth, disrupts DNA/protein synthesis	*S. aureus, P. aeruginosa, B. subtilis*	Enhances healing, accelerates regeneration	27
Honey	Bioactive compounds	Disrupts membranes, inhibits biofilm	*S. aureus, E. coli, P. aeruginosa*	Reduces infection, promotes regeneration	28
Various plants	Essential oils, flavonoids, terpenoids	Inhibits growth, prevents biofilm	*E. coli, S. aureus, P. aeruginosa*	Prevents infection, speeds healing	29

Note: This table summarises the antimicrobial properties of plant-based remedies. Active compounds like antimicrobial peptides, flavonoids, and honey compounds inhibit microbial growth, reduce the risk of infections, and promote wound healing by targeting common pathogens.

to the wound site, thereby accelerating recovery[33,34]. The herb also inhibits scarring because it increases the structural integrity and quality of the skin, and as a result, it is a must-have for wound healing and scarring prevention, as shown in Table 5.

4.5 Mechanisms of Action in Classical *Ayurvedic* Preparations

Ropana Taila is a classical *Ayurvedic* formulation for wound healing, with principles adhering to *Vrana Ropana*, the *Ayurvedic* science of wound healing. The formulation is Dosha-balancing, with Pitta representing inflammation and heat, and Kapha controlling moisture and tissue formation[35]. *Ropana Taila*, a filtrate of herbal extracts and oils, includes *C. longa (*Turmeric), *A. indica (Neem),* and *Bacopa monnieri (Brahmi)* because these have anti-inflammatory, antimicrobial, and tissue-regenerating activities[36]. Turmeric is active against inflammation and stimulates collagen formation, and *Neem* provides antimicrobial activity. The oil phase provides maximum moisture, stimulates epithelialisation, and supports tissue

Table 5. Collagen synthesis and tissue regeneration

Plant	Active compound	Mechanism of action	Effects on wound healing	References
Collagen	Collagen and its derivatives	Stimulates collagen synthesis, enhances tissue regeneration	Promotes bone tissue regeneration and accelerates wound healing	30
Collagen	Collagen I, Collagen III	Regulates the synthesis of collagen I and III in response to tissue injury	Improves wound healing by supporting collagen synthesis and tissue repair	31
Pullulan gel	Pullulan	Enhances collagen synthesis, promotes fibroblast activity	Accelerates wound closure, reduces scar formation, and enhances tissue regeneration	32
Collagen	Collagen peptides	Enhances collagen synthesis in musculoskeletal tissues	Improves tissue regeneration, promotes wound healing and repair	33
Collagen peptides	Collagen peptides	Stimulates collagen synthesis, supports joint and skin regeneration	Enhances recovery, promotes skin regeneration, and reduces scarring	34

Note: This table highlights the bioactive compounds that influence collagen synthesis and tissue regeneration, which are critical for wound healing. Collagen derivatives and peptides stimulate collagen production, enhance fibroblast activity, and accelerate tissue regeneration, leading to faster recovery and reduced scarring.

regeneration. Through *Pitta-Kapha* balance, *Ropana Taila* promotes a holistic healing process of tissue repair and regeneration[37].

4.6 Integrating Recent Scientific Discoveries with *Ayurvedic* Wisdom

Recent scientific studies have initiated the verification of *Ayurvedic* claims about the wound-healing activity of plants like *A. vera* and Turmeric. *A. vera (Kumari)* enhances the production of collagen and exhibits anti-inflammatory as well as antimicrobial activity, promoting the process of wound healing[38]. Preclinical as well as clinical evidence support its activity in the healing of burns and skin wounds through increased epithelialisation and formation of granulation tissue. Turmeric *(C. longa)*, having anti-inflammatory activity, curcumin suppresses pro-inflammatory cytokines and the NF-kB signalling pathway. Studies substantiate curcumin's anti-inflammatory and antioxidant activities, leading to a reduction in wound size and improved recovery, as per *Ayurvedic* concepts and verifying the application of traditional plants in modern wound healing[39].

4.7 Healing Efficacy of Topical Versus Oral Plant-based Treatments

The mode of action of plant remedies in healing wounds may differ based on the mode of delivery, which may either be topical or oral. Topical formulations, such as ointments or gels, deliver high concentrations of active ingredients such as curcumin of Turmeric or saponins of *A. vera*, with localised anti-inflammatory, antioxidant, and collagen-stimulating effects to promote wound healing and reduce scar formation[40]. However, the bioavailability of such drugs may be limited by skin absorption. Oral plant remedies, however, such as *C. asiatica (Gotu kola)* in powdered or capsule form, have systemic action by stimulating collagen synthesis and fibroblast proliferation in the entire body. Although oral preparations are less bioavailable due to digestion, they have more widespread regenerative effects, while topical preparations are more beneficial in focal wound healing[41].

4.8 Comparative Analysis of Herbal and Conventional Wound Treatments

Herbal treatments, particularly *Ayurvedic*, offer a natural, holistic approach to wound healing through the inhibition of inflammation, stimulation of tissue regeneration, and inhibition of infection. Herbs like *C. asiatica* and *C. longa (*Turmeric*)* contain bioactive molecules like asiaticoside and curcumin that stimulate collagen biosynthesis, modulate the immune responses, and exert antimicrobial properties[42]. These are less side-effect-prone and less toxic when compared to conventional modalities, particularly with long-term use. Conventional wound care, however, utilises antibiotics, corticosteroids, and synthetic dressings, which are geared towards the prevention of infection and inflammation[43].

Effective as they are, they are side-effect-prone, like antimicrobial resistance, tissue healing delay, and skin irritation due to dressings. Antibiotic resistance is particularly a problem in chronic wound care. Herbal remedies also have the added benefit of encouraging tissue regeneration, improving skin integrity, and minimising scarring[44]. *C. asiatica*, for instance, speeds up the healing process with the encouragement of collagen production and the prevention of scars. Conventional treatment is more likely to give quick results in acute infections and deep wounds. An integrative process incorporating herbal remedies and conventional treatment might improve wound care with the combined benefits of both accelerating faster healing, minimising complications, and optimising long-term results. Further clinical trials are needed to confirm this integrative process[45].

4.9 Clinical Evidence in Support of *Ayurvedic* Plant Therapies

Clinical trials validate the efficacy of *Ayurvedic* drugs like *C. asiatica (Gotu kola)* and *Bhallatakadi Ghrita* in wound healing, particularly in surgical cases. A trial confirmed topical *C. asiatica* to enhance collagen production, wound contraction, and scar tissue formation. Asiaticoside, the active constituent, induces fibroblast growth and angiogenesis, modulating the inflammatory process for faster recovery and minimal scarring[46]. In a trial, *Bhallatakadi Ghrita*, a polyherbal ghee preparation, promoted wound healing, suppressed inflammation, and facilitated epithelialisation. Its synergistic effect of herbs like Turmeric and *Neem* balances Pitta dosha, disperses excess heat and inflammation. These trials validate the therapeutic use

of *Ayurvedic* medicine in modern clinical practice but need larger-scale clinical trials to standardise their use and establish long-term safety and efficacy[47].

4.10 Plant Medicines Toxicology and Safety for Wound Healing

Although herbal wound-healing remedies are of great utility, safety issues have to be addressed. Topical application of Turmeric and *A. vera* can be responsible for sensitivity, allergy, or dermatitis in sensitive skin patients. Oral administration of *Neem* and *C. asiatica* with high doses can be responsible for gastrointestinal disturbance, hepatotoxicity, or hypoglycemia[48]. Some of the bioactive molecules, such as alkaloids and saponins, are also toxic at certain dosages. For clinical safety, standardised formulations with controlled active material are advisable, and further clinical studies on toxicity and long-term safety are needed for these remedies to be used more extensively[49].

4.11 Research Gaps and Directions in Plant Wound Healing

Although promising outcomes, there are glaring gaps in the evidence supporting plant-based wound-healing therapies. The biggest gap is the absence of well-conducted large human clinical trials. The majority of studies are preclinical or small-scale trials, and it is not appropriate to make general inferences. Standardised preparations, dosage, and delivery forms are necessary to ensure homogeneity in clinical practice. Future work must emphasise the development of biofilm-targeting herbal drugs, as biofilms make chronic wound infections difficult. Researching advanced drug delivery systems, like nanoformulations or hydrogels, may improve the bioavailability and efficacy of herbal agents. Ongoing work in synergy of plant-based therapies with conventional treatments and long-term toxicity will make these treatments a part of mainstream wound care.

5. Discussion

The newly developed problem of antimicrobial resistance (AMR) seriously compromises wound healing, especially the treatment of postsurgical and chronic infections. AMR infections, for example, infections caused by multi-drug-resistant organisms like MRSA and VRE, require the application of alternative therapeutic regimens[50]. Chronic wounds like venous leg ulcers and diabetic foot ulcers are susceptible to such infections and have resulted in delayed healing, which causes healthcare costs and morbidity. Herbal drugs, and more specifically *Ayurvedic* drugs, have been seen to be suitable alternatives since they exhibit broad-spectrum antimicrobial, anti-inflammatory, and regenerative activities[51].

5.1 The Rising Need for Plant-based Wound Treatments

Because AMR has lowered the effectiveness of conventional antibiotic medicines, plant medicines offer a natural, promising solution. *Neem* and Turmeric have broad-spectrum antimicrobial properties, preventing bacterial growth and infection[52]. Turmeric's active component, curcumin, not only prevents inflammation but also prevents microbial growth, while *Neem*, with its nimbidin compounds, prevents biofilm formation, a major issue in chronic wound healing. With their multi-action advantages, plant medicines offer a cost-effective and less invasive solution compared to man-made antibiotics, addressing the worldwide medical crisis of AMR[53].

5.2 Mechanism of Action: *C. longa*, *C. asiatica*, *A. indica* and *A. vera*

The therapeutic action of these plants lies in their unique mechanisms of action. *C. longa* (Turmeric) has curcumin, which acts on the NF-kB pathway, inhibiting inflammation and stimulating collagen synthesis. *A. indica (Neem)* has broad-spectrum antimicrobial action against bacteria, destroying bacterial cell membranes and inhibiting the formation of biofilm[54]. *C. asiatica (Gotu kola)* stimulates collagen synthesis and fibroblast proliferation and also stimulates angiogenesis for increased blood supply to healing tissue. *A. vera* has substances that inhibit inflammation, stimulate collagen synthesis, and have antimicrobial action, leading to increased wound closure and decreased scarring[55].

5.3 Inflammation Treatment and Collagen Synthesis

Excessive scarring and inflammation are prevalent wound healing complications, especially of surgical wounds. *C. asiatica* and turmeric regulate inflammation by suppressing pro-inflammatory cytokines, allowing

smoother healing to the proliferative phase[56]. *C. asiatica* and turmeric also enhance collagen synthesis. *C. asiatica* stimulates the synthesis of both Type I and Type III collagen, resulting in stronger, functional wound healing, whereas Turmeric allows collagen synthesis to fortify the wound and minimise scarring[57].

5.4 Drug Delivery Systems and Bioavailability

One of the primary challenges faced in plant therapy is maintaining the bioavailability of the active ingredients. The low bioavailability of curcumin restricts its therapeutic activity, but the development of drug delivery systems such as liposomal curcumin and nanoemulsions is enhancing its absorption and targeting at the wound site[58]. Likewise, hydrogel-based systems are being developed to improve the delivery of ingredients such as *C. asiatica* and *A. vera,* providing a slow release and appropriate moisture equilibrium for wound healing. These technologies enhance the efficacy of plant therapies by providing the right concentration to the injured site[59].

5.5 Synthesising Traditional and Contemporary Approaches

Introduction of *Ayurvedic* medicine into modern clinical practice is not without problems. Standardisation and regulatory approval are two of them. Formulations like *Ropana Taila* and *Bhallatakadi Ghrita* have been used in effective manners in classical practice, but rigorous clinical trials need to be carried out to have well-defined dosing regimens and long-term safety profiles[60]. An interdisciplinary exchange between *Ayurvedic* doctors and biomedical scientists needs to occur to overcome these challenges. Modern clinical trials for formulations like *C. asiatica* and *Bhallatakadi Ghrita* are leading the way to evidence-based recommendations for the use of these medicines in modern wound care[61].

5.6 Challenges

Although it has the potential to cure wounds, there are several issues and limitations in employing Ayurvedic herbal drugs that restrict their application in everyday clinical practice. One of the major complaints is that there are not sufficient numbers of well-designed clinical trials to establish their safety and efficacy. Most are either small or preclinical and therefore not readily extrapolable for general use.

5.7 Future Directions

Subsequent research will need to overcome these challenges through conducting large-scale, randomised controlled clinical trials to determine the safety and effectiveness of *Ayurvedic* plant-based remedies for wound healing. Standardised herbal preparations and clearly defined dosing regimens will be needed to gain clinical acceptance. Furthermore, the application of novel drug delivery systems, such as nanoformulations and hydrogel-based systems, will enhance the bioavailability and site-specific delivery of active plant molecules. Long-term toxicity studies will also be needed to determine the safety of these remedies for extended periods of use. With the convergence of the holistic philosophy of *Ayurvedic* medicine and advanced scientific technology, the integration of these remedies into mainstream wound care has the potential to offer safer, more effective, and sustainable wound healing solutions.

5.8 Limitations

Even though the *Ayurvedic* herbal drugs have vast therapeutic potential in wound healing, several limitations need to be overcome before their widespread clinical use. The largest limitation, perhaps, is the lack of large-scale, randomised controlled trials to define the safety and efficacy of the therapy. The majority of the available studies are preclinical or small-scale, limiting the scope of generalisability of the findings. Variability in plant quality, preparation, and dosage also makes the process of standardisation harder. Bioavailability of the active molecules, for instance, curcumin from *C. longa*, remains unaddressed since it is poorly absorbed when administered orally. Regulatory issues also remain, with *Ayurvedic* preparations not officially approved within different healthcare systems, thus making it difficult to include them in mainstream medicine. These issues underscore the need for rigorous scientific examination and standardisation of these drugs.

6. Conclusion

In summary, *Ayurvedic* herbal drugs, in this case, *C. asiatica (Gotu kola)* and *Bhallatakadi Ghrita*, are of high value in accelerating the healing of wounds and postoperative recovery. The herbs show therapeutic action through anti-inflammatory, antimicrobial, and

collagen-stimulating activity, as borne out by clinical trials as well as Ayurvedic principles. *C. asiatica* stimulates collagen production, fibroblast proliferation, and angiogenesis, while *Bhallatakadi Ghrita* is a synergistic combination of anti-inflammatory and antimicrobial activities. In summary, the results show that *Ayurvedic* drugs can complement the current wound care practice, offering a holistic and sustainable approach.

But challenges like standardisation of the formulation, low bioavailability of the active ingredients, and the need for prolonged clinical trials to determine uniform therapeutic regimens need to be overcome. Future studies need to focus on enhancing drug delivery systems, such as nanoformulations and liposomal encapsulation, to increase bioavailability and targeted delivery. Exploring biofilm-guided therapy and interdisciplinary research between *Ayurvedic* practitioners and biomedical scientists will become the need of the hour in bringing traditional knowledge and modern clinical practice together. With increasing studies, *Ayurvedic* plant-based drugs can become part of modern wound care, providing a safe and effective option in the battle against chronic wound infections and antimicrobial resistance.

7. Key Takeaways

Plant therapies, particularly *Ayurvedic* therapies, provide a promising solution to wound healing. *C. asiatica* and *Bhallatakadi Ghrita* exhibit synergistic action in promoting collagen growth, suppressing inflammation, and accelerating tissue repair. Modern studies validate these traditional therapies with proof of their efficacy in accelerating recovery and minimising scarring in surgical wounds. Despite being promising, problems of bioavailability, standardisation, and clinical evidence must be addressed. Standardisation of preparations and novel drug delivery systems must be explored in future studies to maximise therapeutic efficacy. Ultimately, using these plant therapies in clinical practice can provide effective and holistic solutions to traditional wound care, resulting in faster healing and better patient outcomes.

8. Ethical Consideration

This narrative review follows ethical practices for conducting research and publication. Since this study is a review of published literature, it does not entail the collection of primary data from human or animal participants. The articles used in this review had been reviewed ethically by their respective institutions and complied with ethical human and animal experimentation practices as defined by institutional review boards. The authors ensured that all studies quoted in this review were carried out with adequate ethical clearances, informed consent, and confidentiality of patient data where necessary. No identifiable or personal data had been included in this review.

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10. Author Contribution

Dr. Shrinivas Ramrao Ballore designed the study and helped prepare the manuscript. Dr. Sanjay Chandrakant Babar made critical revisions and helped in the research direction. Dr Amit Ashok Paliwal, Dr Mahesh Pandurang Jadhav, and Dr Priyanka Dushyant Patil helped with data acquisition and analysis. In contrast, Dr Vinod Bharat Hendawale helped with manuscript review and scientific validity. In contrast, Dr. Shalini U.A. helped in formatting the final revisions. All authors have read and agreed to the published version of the manuscript.

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