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Role of Medicinal Plants in Bone Healing: A Comprehensive Review of Traditional and Modern Perspectives

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ABSTRACT

Bone fractures and other skeletal injuries continue to pose a major global health challenge, frequently leading to reduced mobility and diminished quality of life. Various traditional medicine systems including Ayurveda, Traditional Chinese Medicine, and Unani have historically utilized plant-based treatments to support bone repair. Ethno botanical research increasingly validates the effectiveness of these approaches. One such plant, *Cryptolepis buchanani*, has gained attention for its therapeutic potential, acknowledged both in age-old medical traditions and in recent scientific investigations. This review brings together existing research on the use of medicinal plants in supporting bone repair. It examines the biological processes involved in bone formation, along with the anti-inflammatory and antioxidant properties that contribute to healing. Special attention is given to the therapeutic promise of *Cryptolepis buchanani* based on its emerging pharmacological profile. An extensive review of both scientific literature and traditional medicinal texts was carried out. The analysis included ethnobotanical documentation, phytochemical studies, laboratory experiments (in vivo and in vitro), and preliminary clinical research. A total of seventy pivotal sources were examined to clarify how bioactive compounds from medicinal plants contribute to bone regeneration. Research shows that various medicinal plants, including *Cissusqua drangularis*, *Withania somnifera*, and *Cryptolepis buchanani*, promote bone growth and reduce inflammation by influencing osteoblast function, lowering oxidative damage, and boosting the production of bone matrix. Despite these promising effects, obstacles persist, mainly because of inconsistent preparation methods for plant extracts and a shortage of thorough clinical trials. Medicinal plants present valuable opportunities for improving bone healing treatments. To fully realize their potential, it is crucial to combine traditional wisdom with contemporary scientific validation by adopting standardized procedures and conducting well-designed clinical studies. This integration will help transform these natural remedies into reliable, evidence-based therapies.

Keywords: Medicinal Plants, Bone Healing, *Cryptolepisbuchanani*, Ethnopharmacology, Osteogenesis, Traditional Medicine

INTRODUCTION

Healthy bones are essential for movement, overall function, and quality of life. Bone fractures and other skeletal injuries are widespread and pose a major global health concern. These injuries, often caused by trauma, osteoporosis, or severe accidents, can result in long-term disability and create heavy socio-economic impacts due to lost work time and increased medical expenses. While conventional treatments like surgical fixation, bone grafts, and synthetic implants are often effective, they come with drawbacks such as high costs, risk of infection, and sometimes less-than-ideal healing results, especially in complex or slow-recovering fractures [1].

The limitations of existing treatments highlight a significant gap in effective options for bone regeneration. Although biomaterials and surgical methods have advanced, there is still an urgent need for alternative approaches that can better support and speed up the body's own healing processes. Traditional medical systems present a valuable, yet often overlooked, source of potential solutions. For hundreds of years, practices like Ayurveda, Traditional Chinese Medicine, and Unani have relied on plant-based therapies to address various health issues, including bone injuries. These traditions carry a wealth of empirical knowledge passed down through generations, offering a rich resource for discovering new bone-healing agents [2].

Cryptolepis buchanani has garnered significant attention from the scientific community due to its traditional use in various indigenous healing practices. This plant is known to contain multiple bioactive compounds that encourage osteoblast growth, regulate inflammatory responses, and support the buildup of the extracellular matrix. Comprehensive reviews, such as those by Chekkingath and Kalita, have thoroughly examined its phytochemical makeup and pharmacological effects, highlighting its potential as a natural agent for bone repair [3]. Building on this foundation, recent research by Gupta and colleagues is actively investigating how such herbal remedies can be effectively applied in modern fracture healing [4].

Although medicinal plants show great promise, important research challenges remain. These include the need for standardized methods of extract preparation, a deeper understanding of the molecular mechanisms involved, and a lack of large-scale clinical trials. Such issues have slowed the integration of these natural therapies into standard medical practice. Conducting rigorous and well-structured studies is crucial not only to confirm the bone-forming and anti-inflammatory benefits seen in early research but also to translate these results into reliable, evidence-based treatments. Tackling these challenges could help address the shortcomings of current conventional therapies.

In this context, the current review aims to compile and critically evaluate existing research on medicinal plants involved in bone healing, with a special focus on *Cryptolepis buchanani*. Through a thorough analysis of ethnobotanical data, phytochemical studies, laboratory experiments (both in vivo and in vitro), and early clinical evidence, the review strives to offer a detailed insight into how bioactive compounds from plants may enhance bone repair. By bridging traditional wisdom and modern pharmacology, this work intends to provide a solid foundation for future research efforts, ultimately supporting the creation of standardized, safe, and effective therapies for bone regeneration.

In conclusion, although traditional treatments for bone fractures remain valuable, incorporating medicinal plants into treatment plans presents a compelling complementary approach. Combining age-old healing knowledge with contemporary biomedical research holds the potential to develop innovative therapies that improve patient recovery and revolutionize clinical management of bone regeneration.

Overview of Bone Healing and Its Phases

Bone healing is a complex, well-coordinated physiological process essential for restoring the strength and structure of the skeleton following fractures or injuries. This process typically unfolds in three overlapping stages: inflammation, repair, and remodelling [5]. Each stage contributes uniquely to the transition from injury to the regeneration of fully functional bone tissue.

Inflammatory Phase: Immediately after an injury, the inflammatory phase begins with blood vessel damage and the formation of a hematoma at the fracture site. This stage involves the arrival of immune cells such as neutrophils and macrophages, which release signaling molecules like interleukins and tumor necrosis factor (TNF). These cytokines play a crucial role in clearing damaged tissue and triggering the healing process [6]. Beyond cleaning the wound, this early inflammatory response also helps attract mesenchymal stem cells (MSCs) to the site, which are vital for tissue regeneration.

Repair Phase: Once inflammation decreases, the repair phase starts with the formation of granulation tissue and a soft callus. Mesenchymal stem cells (MSCs) begin to transform into chondrocytes and osteoblasts, guided by growth factors like bone morphogenetic proteins (BMPs) and transforming growth factor-beta (TGF-β). These cells produce a cartilaginous matrix that slowly mineralizes over time. This process converts the soft callus into a hard callus, which helps stabilize the fracture mechanically [7]. The repair phase is essential because it involves creating new bone tissue and restoring the bone's structural integrity.

Remodeling Phase: After the initial repair, the remodeling phase begins and can continue for months or even years. During this stage, the newly formed bone is reshaped to restore its original structure and strength. Osteoclasts break down excess callus and immature woven bone, while osteoblasts lay down new, organized lamellar bone. This balanced activity allows the healed bone to adjust to everyday mechanical stresses and gradually regain full function [8]. Additionally, angiogenesis—stimulated by vascular endothelial growth factor (VEGF) is crucial in this phase, ensuring the bone receives adequate blood supply, nutrients, and oxygen.

Cellular and Molecular Players: The bone healing process relies on a complex interaction between different cell types and molecular signals. Osteoblasts are the main cells responsible for building new bone by producing collagen and other components of the extracellular matrix. Meanwhile, osteoclasts break down damaged or surplus bone tissue, a crucial step for remodeling and maintaining healthy bone balance [9]. Key growth factors and cytokines—such as BMPs, TGF-β, and VEGF—regulate the development and function of both osteoblasts and osteoclasts. These molecules not only control cell growth and specialization but also influence blood vessel formation, which is vital for successful bone regeneration [10].

Challenges in Impaired Healing: Although bone healing is typically efficient, certain conditions like aging, diabetes, poor nutrition, and ongoing inflammation can significantly hinder the process. Delayed healing or failure of fractures to unite properly poses a serious clinical problem, often requiring further treatment. Traditional therapies may not always fully restore the biological environment needed for optimal bone regeneration. These challenges have increased interest in alternative approaches, such as medicinal plant-based treatments, which could provide osteogenic, anti-inflammatory, and antioxidant effects to support and accelerate natural healing [11].

Transition to Medicinal Plant Applications: A clear grasp of the natural stages involved in bone healing is essential for assessing how complementary therapies can enhance treatment outcomes. Medicinal plant extracts have the potential to influence several

critical biological processes—from controlling inflammation to promoting osteoblast function—thereby addressing multiple facets of bone repair. The following sections of this review will explore both ethnobotanical knowledge and pharmacological evidence regarding plants used in bone healing, with a particular focus on *Cryptolepisbuchanani*, which stands out as a notable example of this integrative therapeutic approach [12].

Medicinal Plants in Bone Healing: Ethnobotanical and Pharmacological Perspectives

Medicinal plants have played a vital role in traditional healthcare for centuries, providing a wide array of botanicals used to treat various conditions, including bone fractures and skeletal injuries. Systems like Ayurveda, Traditional Chinese Medicine (TCM), and Unani have long valued herbal remedies not only for easing pain and inflammation but also for supporting bone regeneration. Ethnobotanical studies and historical texts reveal the use of specific plants to aid fracture healing, promote new bone formation, and address related complications. Authoritative sources, such as the World Health Organization's Monographs on Selected Medicinal Plants, highlight the widespread acceptance of these natural treatments, emphasizing their importance in both traditional healing and modern medicine [13].

In Ayurveda, a variety of plants have long been valued for their ability to support bone healing. For instance, *Cissus quadrangularis* is well-known for its role in speeding up fracture repair and enhancing bone strength, with both traditional use and modern studies backing these effects. Likewise, *Withania somnifera* (Ashwagandha) has been traditionally used to improve musculoskeletal health, benefiting from its anti-inflammatory and adaptogenic qualities. In Traditional Chinese Medicine and Unani systems, herbs like *Drynaria fortunei* and diverse polyherbal mixtures are commonly used to boost blood flow and promote mineralized tissue formation at injury sites. Historical case studies and ethnomedicinal research consistently recognize these plants as effective components of bone healing therapies, reflecting their enduring therapeutic value [14-15].

The healing benefits of these medicinal plants stem from their diverse pharmacological effects. They work by promoting bone formation, reducing inflammation, and neutralizing harmful free radicals. Phytochemical studies have identified key bioactive compounds—such as flavonoids, alkaloids, saponins, and phenolic acids—that actively influence the bone repair process. For example, certain constituents in *Cissus quadrangularis* have been found to encourage osteoblast growth and boost the production of bone morphogenetic proteins (BMPs), which are vital for new bone development. At the same time, these phytochemicals exert anti-inflammatory actions that help minimize excessive inflammation, preventing delays in tissue regeneration. [16].

Another important way medicinal plant extracts support bone healing is through their antioxidant effects. Oxidative stress can damage proteins and lipids within cells, disrupting the bone repair process. The antioxidants found in many herbal remedies help neutralize harmful free radicals, reducing oxidative damage and fostering an environment more conducive to bone regeneration. Additionally, some plant extracts influence key signaling pathways like Wnt/β-catenin and TGF-β, which are essential for guiding mesenchymal stem cells to become osteoblasts. These pathways play a crucial role not only in forming the bone matrix but also in maintaining the balance between bone formation and breakdown, which is vital for proper remodeling and strengthening of the newly healed bone. [17-18].

The convergence of traditional knowledge and modern scientific research presents strong support for incorporating medicinal plants into current bone healing treatments. Ethnobotanical studies, derived from fieldwork and historical records, validate the long-established use of these plants for treating musculoskeletal issues. At the same time, pharmacological research—from cell culture experiments to animal studies—has begun to uncover the molecular mechanisms behind their healing properties. For instance, *Withania somnifera* extracts have been shown to both reduce inflammation and stimulate osteoblast differentiation, highlighting the dual effects vital for successful bone repair. Likewise, investigations into *Cryptolepis buchanani* reveal its capacity to regulate inflammatory cytokines and boost bone-forming activity, positioning it as a promising subject for continued research [19-20].

Despite encouraging results, several challenges hinder the integration of traditional medicinal knowledge into standardized clinical use. Variations in extraction techniques, differences in phytochemical profiles due to geographic and seasonal influences, and a scarcity of comprehensive clinical trials present major obstacles. Ensuring consistent efficacy and safety requires the standardization of herbal extracts alongside rigorous clinical testing. This review not only brings together ethnobotanical insights and mechanistic data supporting medicinal plants in bone healing but also emphasizes the critical need for further research to close the gap between traditional practices and evidence-based medicine. [21-22].

In summary, incorporating medicinal plants into bone healing treatments offers a promising new direction in regenerative medicine. Drawing on both centuries of traditional use and growing pharmacological research, these botanicals can provide complementary therapies alongside conventional approaches. The upcoming sections of this review will focus specifically on *Cryptolepis buchanani*, evaluating its effectiveness relative to other recognized plants and exploring its potential to address current challenges in bone repair.

Focused Review: *Cryptolepis buchanani*

Cryptolepis buchanani, belonging to the Asclepiadaceae family, holds a significant place in traditional healing practices, especially within Thai medicine. Historically, it has been used primarily to treat muscle and tendon pain, often prepared as decoctions to reduce inflammation and discomfort related to musculoskeletal injuries. Traditional practitioners have prized this plant not only for its pain-relieving properties but also for its reputed capacity to support tissue regeneration and bone healing, a reputation well-documented in ethnomedical literature [23].

Phytochemical studies on *Cryptolepis buchanani* have identified a diverse range of bioactive compounds that contribute to its medicinal effects. Among these, the alkaloid buchananine stands out as a key active component. Additionally, other notable constituents such as 3,4-dihydroxy benzoic acid, vanillic acid, syringaldehyde, and isoscopoletin have been isolated from different plant extracts. These compounds are known for their antioxidant, anti-inflammatory, and cartilage-protecting activities. The variety of these phytochemicals supports the traditional applications of *Cryptolepis buchanani* and indicates that its therapeutic efficacy may arise from the combined action of multiple molecules working together to influence cellular mechanisms involved in tissue repair [24-25].

Pharmacological research on *Cryptolepis buchanani* includes both in vitro and in vivo investigations. In cell-based studies using RAW 264.7 macrophages, extracts from the plant have been found to markedly suppress nitric oxide (NO) production, a key factor in inflammatory responses. For example, hexane and ethyl acetate extracts derived from the stems reduced NO levels by more than 80% at concentrations as low as 50 µg/mL. These results indicate that *Cryptolepis buchanani* extracts may effectively diminish inflammation at the cellular level, which is important because prolonged inflammation can hinder bone healing [26]. Furthermore, other in vitro studies have demonstrated the plant's chondroprotective effects, showing its ability to shield cartilage from damage caused by inflammatory cytokines like interleukin-1. This protective action is vital, as excessive inflammation can obstruct the differentiation of progenitor cells into osteoblasts, potentially delaying or compromising bone regeneration [27].

Animal studies have further confirmed the therapeutic promise of *Cryptolepis buchanani*. Experiments using rodent models have shown that methanol extracts from the plant's stem produce notable pain-relieving effects. For instance, in acetic acid-induced writhing tests, treated animals displayed a significant decrease in pain behaviors, indicating effective peripheral analgesia. Moreover, in rat models of carrageenan-induced paw swelling, administration of varying doses of the extract resulted in a clear, dose-dependent reduction of inflammation. These findings strongly support the dual role of *Cryptolepis buchanani* in reducing both pain and inflammation, key components in promoting effective bone repair [28].

When compared to other prominent medicinal plants used for bone repair, such as *Cissus quadrangularis*, *Cryptolepis buchanani* offers a complementary set of mechanisms. While *Cissus quadrangularis* is primarily valued for its ability to boost osteoblast growth and speed up callus formation, thereby directly enhancing bone regeneration, *Cryptolepis buchanani* mainly influences the inflammatory environment and provides protection to cartilage tissue—a crucial factor in maintaining the cartilage framework during fracture recovery. Although both plants aim to support bone healing, the distinct phytochemical composition and targeted actions of *Cryptolepis buchanani* suggest it may be especially beneficial in situations where controlling inflaming is key to successful regeneration[4] [9].

Despite the encouraging pharmacological properties of *Cryptolepis buchanani*, several obstacles hinder its transition into routine clinical use. Variations in extraction techniques, along with changes in the plant's chemical composition due to geographic and seasonal factors, complicate efforts to establish consistent dosages and formulations. Additionally, although preclinical research offers promising data, there remains a notable lack of well-designed clinical trials to confirm its safety and effectiveness in humans. Overcoming these challenges is critical to enabling *Cryptolepis buchanani* to become a reliable and standardized option within bone healing treatment regimens.

In conclusion, *Cryptolepis buchanani* emerges as a medicinal plant deeply rooted in traditional use and supported by encouraging pharmacological evidence. Its diverse phytochemical composition, notably the alkaloid buchananine alongside various phenolic and flavonoid compounds, contributes to its strong anti-inflammatory and cartilage-protective effects. Compared to well-known bone-healing herbs like *Cissus quadrangularis*, *Cryptolepis buchanani* offers a complementary approach by focusing on modulating inflammation and preserving tissue integrity. Advancing research efforts aimed at standardizing extracts and conducting rigorous clinical trials will be essential to fully harness its potential in promoting bone repair and addressing the gaps of existing treatments [29-31].

Challenges and Research Gaps

Although medicinal plants have shown encouraging preclinical results and boast a long history of traditional use, significant obstacles still stand in the way of their widespread adoption in mainstream bone healing treatments.

Lack of Standardization: A major obstacle in the use of medicinal plants is the absence of consistent standards for preparing and characterizing herbal extracts. Differences in plant species identification, harvesting methods, geographic location, and seasonal timing can all cause substantial variation in the chemical makeup of extracts. Without uniform extraction procedures, the levels of active ingredients can fluctuate greatly between batches. This variability not only makes it difficult to reproduce laboratory results but also poses challenges for regulatory approval in clinical settings [32-33]. To overcome these issues, implementing rigorous quality control protocols and standardized extraction methods is crucial to guarantee both consistency and therapeutic effectiveness.

Toxicity and Safety Data: Another critical gap in research is the lack of thorough safety evaluations for medicinal plant formulations before their integration into clinical use. Although traditional practices often imply these remedies are safe, modern toxicological data are insufficient for many such herbs. Comprehensive studies on dose–response effects, long-term toxicity, and possible interactions with conventional drugs are largely lacking. These insights are vital to determine safe dosage limits, as excessive or prolonged consumption may cause unexpected side effects. Therefore, future investigations must prioritize rigorous toxicity assessments to ensure these treatments are safe, building trust among healthcare providers and regulatory authorities [34].

Limited Clinical Trials: One of the biggest hurdles to incorporating herbal therapies into mainstream healthcare is the shortage of well-designed clinical trials. Most available evidence for the effectiveness of medicinal plants in bone healing is derived from laboratory or animal research. While these studies offer important mechanistic understanding, they cannot replace randomized controlled trials involving human participants. The absence of robust clinical data limits clarity regarding their true efficacy, pharmacokinetics, and long-term safety. Therefore, there is an urgent need for carefully conducted clinical trials that not only assess the benefits of these herbal treatments but also directly compare them with established conventional therapies [35].

Integration into Modern Healthcare: Incorporating medicinal plant-based therapies into contemporary healthcare systems involves several significant challenges. Modern medicine's strong emphasis on evidence-based practice means that the limited availability of rigorous clinical trial data for these treatments hampers their broader acceptance. Regulatory bodies further complicate integration by demanding uniform manufacturing standards, detailed safety profiles, and clear proof of clinical efficacy before granting approval. Additionally, fostering collaboration among traditional practitioners, pharmacologists, and medical professionals is vital to effectively merge traditional knowledge with modern medical practices. Overcoming these regulatory and cooperative obstacles is essential to enable herbal remedies to be recognized as complementary or alternative options within bone healing treatments [36].

Together, these challenges highlight the urgent need for coordinated efforts in standardizing herbal preparations, thoroughly assessing safety, conducting rigorous clinical trials, and developing effective integration approaches. Addressing these issues will demand collaborative, interdisciplinary research that bridges traditional ethnobotanical wisdom with cutting-edge biomedical science. Such an approach is crucial not only to fully unlock the therapeutic potential of medicinal plants for bone repair but also to guarantee that these treatments are reliable, safe, and consistently effective. Advancing research in these key areas will be instrumental in moving promising laboratory results toward practical, evidence-based use in clinical settings.

Conclusion

In summary, medicinal plants offer a promising complement to conventional bone healing therapies. This review has highlighted that traditional remedies—used for centuries in systems such as Ayurveda, Traditional Chinese Medicine, and Unani—possess valuable osteogenic, anti-inflammatory, and antioxidant properties. Notably, *Cryptolepis buchanani* demonstrates beneficial effects by modulating inflammation and protecting cartilage, thereby complementing the osteogenic actions of other well-studied plants like *Cissus quadrangularis*. Preclinical evidence from cell-based assays and animal models supports the potential of these botanicals to stimulate osteoblast activity and accelerate callus formation, facilitating effective fracture repair. However, despite these encouraging findings, significant challenges remain. The absence of standardized extraction protocols, limited toxicity and safety data, and a scarcity of rigorous clinical trials currently hinder the wider clinical adoption of these therapies. Future research should prioritize establishing robust standardization methods and conducting well-designed randomized clinical trials. Fostering interdisciplinary collaborations that integrate traditional ethnobotanical knowledge with modern pharmacological research will be critical to fully unlocking the therapeutic potential of medicinal plants in bone regeneration.

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