JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

SPRILUNA-INTEGRATED HERBAL BONE CEMENT FOR ORTHOPEDIC AND DENTAL REPAIR

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Abstract

This research focuses on the development of Spirulina-integrated herbal bone cement for orthopedic and dental repair, aiming to create a sustainable, biocompatible, and infection-resistant alternative to conventional materials. Spirulina (*Arthrospira platensis*), rich in proteins, antioxidants, phycocyanin, and essential fatty acids, is combined with herbal extracts such as Tulsi (*Ocimum tenuiflorum*) or Neem (*Azadirachta indica*) to enhance the cement's antimicrobial, antioxidant, and osteogenic properties. The formulation was prepared with Spirulina and Tulsi evaluated for mechanical strength, setting time, biodegradability, and antimicrobial activity. The results demonstrate that Spirulina-based bone cement not only supports bone regeneration and faster healing but also effectively prevents microbial infections, reducing reliance on antibiotic-loaded cements. This study highlights the potential of eco-friendly, herbal biomaterials as safer and more effective alternatives in orthopedic and dental applications, paving the way for advanced regenerative solutions

Keywords: Spirulina, Herbal bone cement, Tulsi extract, Neem extract, Orthopedic repair, Dental repair, Biocompatibility, Antimicrobial biomaterials, Sustainable implants.

INTRODUCTION:

Bone cements plays a vital role in orthopedic and dental implant procedures, when they are utilized to stabilize fractures, repair bone defects, and stabilize implants. Conventional cements such as polymethyl methacrylate (PMMA) and hydroxyapatite possess good mechanical properties but tend not to naturally bond to adjacent tissues. Most synthetic cements in these applications can lead to inflammation and do not promote active new bone formation. To overcome these challenges, scientists are looking towards biogenic and plant-based bone cements, which are body-natural and promote tissue regeneration. Spirulina platensis, a dense, nutrient-packed, blue-green algae that is rich in proteins, minerals, antioxidants, and anti-inflammatory substances, has been found to have the potential to enhance bone mineralization and collagen synthesis. When combined with herbal extracts having natural calcium and curative phytochemicals, it is able to form a bioactive, antimicrobial, and environmentally friendly bone cement a material of great promise for both orthopedic and dental reconstruction.

LITERATURE REVIEW:

The cultivation of microalgae, particularly Spirulina, has gained increasing attention as a sustainable and innovative approach to improving agricultural productivity, combating malnutrition, and promoting eco-friendly bioresource systems. According to Sow and Ranjan [1], Spirulina is a multicellular, filamentous cyanobacterium rich in proteins, vitamins, minerals, and β-carotene. It also exhibits several bio functional properties, including anti-inflammatory, immunomodulatory, and antidiabetic effects. Their review highlights how cultivating Spirulina can play a vital role not only in nutritional supplementation for humans and animals but also in wastewater treatment and agribusiness development. Historically, Spirulina though scientifically referred to as Arthrospira was harvested from alkaline lakes in Africa and Central America, where it served as a naturally occurring nutrient-rich food. Today, modern cultivation practices utilize open raceway ponds and closed photobioreactor systems, each offering distinct benefits and challenges in terms of cost, productivity, contamination control, and scalability. The success of Spirulina cultivation depends on several environmental and operational parameters, such as light intensity, temperature, pH, carbon dioxide availability, nutrient composition, mixing, and harvesting methods. These factors directly influence the growth rate, biomass yield, and pigment concentration (notably phycocyanin, a valuable blue pigment with antioxidant properties). Recent research has also focused on developing low-cost cultivation techniques to make Spirulina production more accessible in developing regions. For example, using agricultural waste or alternative nutrient sources has proven effective in reducing production costs while maintaining nutritional quality. This cost-effective approach has opened new opportunities for small-scale farmers and rural communities to adopt Spirulina cultivation as a sustainable livelihood activity. Beyond its nutritional applications, Spirulina has shown potential as a biofertilizer, bio stimulant, and soil conditioner. Its biomass and extracts can enrich soil fertility, improve plant growth, and enhance crop yield and nutritional value. Sow and Ranjan's review further suggests that integrating Spirulina production with agricultural systems such as using wastewater for cultivation or co-locating with crop farms supports a circular bioeconomy, minimizing waste and maximizing resource efficiency. Nevertheless, some challenges still hinder large-scale implementation. Achieving cost-effective production, maintaining consistent biomass quality, preventing contamination (especially in open pond systems), and optimizing harvesting, drying, and processing techniques remain key hurdles. Furthermore, aligning Spirulina cultivation with existing agricultural value chains and ensuring market accessibility for food, feed, or soil applications require continued research and policy support. In conclusion, the literature underscores Spirulina's vast potential as a high-value, sustainable bioresource for agriculture, nutrition, and environmental management. However, realizing this potential will depend on improving cultivation technologies, lowering costs, maintaining quality standards, and integrating Spirulina production into broader agricultural and economic frameworks particularly in developing regions striving for food security and sustainable growth.

Bone tissue engineering has increasingly turned toward developing smart, bioactive scaffolds that can actively support and accelerate bone regeneration. Among these, calcium phosphate cements (CPCs) have received considerable attention because they closely mimic the mineral composition of natural bone and are well-tolerated by the body [1]. However, despite these advantages, CPCs tend to be brittle and lack the mechanical strength needed for applications in load-bearing regions [2]. To overcome these challenges, researchers have explored various additives that can strengthen CPCs and improve their biological performance. In a recent study, Zhao *et al*. [3] developed a composite CPC scaffold reinforced with zirconium oxide (ZrO_2), starch, and citric acid, and further enhanced it with Hedysarum polysaccharides (HPS) a bioactive compound extracted from traditional Chinese medicine known for its bone-healing potential. The optimized composition, containing 10% starch and 5% citric acid, significantly increased the compressive strength of the cement (28.96 ± 0.03 MPa), making it suitable for cancellous bone replacement. Moreover, the addition of HPS promoted the proliferation, differentiation, and mineralization of osteoblast and stem cells, indicating strong biological compatibility and osteogenic activity. Other studies have also demonstrated that natural polymers such as chitosan, cellulose, and hyaluronic acid can enhance osteoblast function and bone mineralization when incorporated into CPCs [4][6]. Similarly, plant-based polysaccharides like konjac glucomannan and guar gum have been shown to support bone tissue regeneration due to their excellent cytocompatibility [7]. Building on this, Zhao *et al*. revealed that HPS could activate key osteogenic genes such as RUNX2, OCN, and COL1 by boosting alkaline phosphatase (ALP) activity and calcium deposition. Importantly, the HPS-modified CPCs were proven safe, meeting the toxicity and biocompatibility standards outlined in the Chinese Pharmacopoeia. Animal studies provided further evidence of the material's effectiveness. In a rabbit femoral defect model, scaffolds containing HPS achieved up to 83.40% new bone formation after eight weeks significantly higher than unmodified CPCs. This demonstrates that adding HPS not only improves the biological response but also supports robust new bone growth in vivo. Overall, the study highlights a growing trend in biomaterials research: combining ceramics with natural biopolymers to achieve both structural and biological functionality. By reinforcing CPCs with ZrO_2 and starch for mechanical stability and integrating HPS for bioactivity, Zhao *et al*. created a multifunctional scaffold that addresses the long-standing weaknesses of conventional CPCs. This innovation holds great promise for orthopedic and dental bone repair, offering a material that supports both strength and regeneration key factors for successful bone healing.

Bone tissue engineering aims to design smart materials that can effectively aid bone repair by balancing biocompatibility, mechanical strength, and biodegradability. Conventional materials like polymethyl methacrylate (PMMA) and calcium phosphate cements (CPCs) have long been used in orthopedic and dental applications due to their ability to fill complex defects and encourage bone cell attachment and growth [1]. However, PMMA is non-degradable, which can lead to complications such as embolism and stress shielding over time [2]. To overcome these limitations, research has increasingly turned toward biodegradable bone cements that can safely degrade while being naturally replaced by new bone tissue [3]. According to Liu *et al*. [4], biodegradable bone cements can be categorized into calcium phosphate, calcium sulfate, and organic and inorganic composite types. These materials degrade through both chemical dissolution and cell-mediated resorption, allowing their breakdown to align with the rate of new bone formation. Among them, calcium phosphate cements (CPCs) including hydroxyapatite (HA), brushite, and monetite have gained the most attention because of their close chemical resemblance to natural bone [5]. While HA is highly bioactive, its slow degradation limits its application in regions requiring active remodelling [6]. On the other hand, brushite and monetite cements dissolve faster, offering better suitability for regenerative therapies [7].Calcium sulfate cements were among the first synthetic materials developed for bone repair. They are known for being completely degradable and highly biocompatible [8]. However, they tend to degrade too quickly, sometimes faster than new bone can form, which reduces their ability to maintain structure during healing [9]. To overcome this, researchers have explored composite formulations that blend calcium sulfate with other bioactive components to better control degradation and enhance bone bonding [10]. The introduction of organic and inorganic hybrid composites has opened new possibilities for creating biodegradable bone cements with both flexibility and strength. Incorporating natural polymers like gelatin, alginate, or chitosan or synthetic polymers such as polycaprolactone

(PCL) and polylactic acid (PLA) can fine-tune both the mechanical and degradation characteristics [11]. For instance, embedding PLGA or gelatin microspheres within CPC matrices improves resorption rates and encourages cell growth and vascularization [12]. The degradation mechanisms of these materials typically occur through two pathways: chemical dissolution, where ions are released into body fluids, and osteoclastic resorption, where bone resorbing cells break down the material [13]. In CPCs, the phase transformation of brushite into hydroxyapatite can slow down degradation. To address this, stabilizing agents such as magnesium or pyrophosphate ions are used to maintain the brushite phase and preserve its resorbable nature [14]. Similarly, adjusting porosity or incorporating ion substitutions (e.g., strontium, cobalt) allows scientists to control degradation behavior and improve cellular responses [15]. From a clinical perspective, biodegradable bone cements have shown promising results in non-load-bearing areas such as cranial reconstruction, vertebral repair, and maxillofacial surgeries [16]. Cements based on apatite and β-tricalcium phosphate (β-TCP) have demonstrated strong bone integration and osteoconductivity, often producing outcomes comparable to autologous bone grafts [17]. Despite these successes, achieving optimal mechanical strength and precise degradation control remains a major challenge before these materials can be widely adopted in clinical practice [18]. In summary, research on biodegradable bone cements is moving toward hybrid systems that integrate inorganic minerals with natural or synthetic polymers and even therapeutic biomolecules. These next-generation cements are engineered to degrade in sync with natural bone formation, providing temporary structural support while promoting full biological integration. Such materials represent a vital step toward safer, more effective, and patient-specific solutions for long-term bone regeneration.

METHODOLOGY:

1.Materials used:

Analytical-grade calcium phosphate (CaP) powder served as the base material for bone cement preparation. Dried *Spirulina platensis* powder and standardized herbal extract of *Ocimum sanctum* (Tulsi) were employed as bioactive additives. Gelatin solution acted as the liquid phase and natural binder, while deionized water was used as the solvent. All reagents were sterilized prior to use to maintain aseptic conditions. The primary components included calcium phosphate, Spirulina powder, Tulsi extract, and gelatin in predetermined proportions optimized for handling and setting characteristics.

2.Preparation of Spirulina Extract:

Spirulina platensis was cultivated in Zarrouk's medium using transparent containers filled with clean, chlorine-free water. Continuous aeration was maintained with an aquarium air pump, while illumination was provided through natural sunlight or controlled artificial light to support photosynthesis. The culture was grown under optimized conditions at a pH of 9–10 and a temperature range of 30–35 °C, which are ideal for Spirulina proliferation. A small portion of the mother culture was inoculated into the prepared medium and allowed to grow until a dense green biomass was achieved. The resulting biomass was harvested through filtration, thoroughly washed with distilled water, and dried under both sunlight and shade to preserve its bioactive components for subsequent use in cement formulation.

3.Preparation of Herbal Extract:

Ocimum sanctum (commonly known as Tulsi or Holy Basil) was selected as the herbal source due to its excellent antioxidant, antibacterial, and anti-inflammatory properties, which are beneficial for bone tissue healing and regeneration. The extract preparation was carried out using the following procedure, Collect the Tulsi leaves from the plants. Wash it with the distilled water to remove the dust and the surface impurities. Shade Dry the collected leaves for 5-7 days. The dried leaves were finely ground using a sterile grinder to obtain a uniform powder suitable for extraction.

4.Gelatin Preparation:

Gelatin was used as a natural biopolymer to enhance the binding strength and biocompatibility of the Spirulina integrated herbal bone cement. The gelatin solution was prepared the following procedure,

Take about 0.2g of gelatin. Add 10ml of distilled water, heat gently and stir continuously until the gelatin completely dissolved. Cool down the dissolved gelatin solution before adding it in the cement mixture to avoid the denaturation of Spirulina's bioactive component.

5.Mixing:

The calcium phosphate powder was mixed with Spirulina Extract and Herbal Extract (Tulsi). The cooled gelatin solution was then added slowly to the dry powder while stirring until a smooth paste was formed. The prepared paste was poured into silicon molds and lightly tapped to remove any air bubbles. The molds were kept at room temperature (around 25°C) for 24 hours to allow the cement to set properly.

6.Testing of tensile strength:

To test the tensile strength of Spirulina-Integrated Herbal bone cement using DTS (diameter tensile strength, is also known as INDIRECT method, it is the mechanical testing technique commonly used to test the tensile properties of brittle materials like bone cement, dental composites…,) Method. Tensile strength is the maximum stress, a material can withstand before breaking. For brittle biomaterials like bone cement, a Direct tensile test is often impractical because they cannot hold firmly without cracking, even small change in the stress concentration causes failure and the specimen preparation is also difficult for this method.

In this method, the compressive load is applied along the diameter of a specimen, it produces tensile stress perpendicular to the direction of the load. Due to the compression of the applied load the specimen splits due to the induced tensile stress. This test continues until the specimen splits along the plane. The maximum load applied at the failure is used to calculate the tensile strength.

The Formula used is,

$$DTS=2P/\pi dt$$

FIG 1.1 BEFORE SETTING

FIG 1.2 AFTER SETTING

Advantages of creating this are as follows,

1. This technology uses Spirulina, Tulsi, and Neem as plant-based, biodegradable bioactive additives, making the bone cement environmentally sustainable.
2. Offers an effective natural alternative to antibiotic-loaded cements, potentially reducing risks of antibiotic resistance and side effects.
3. Spirulina provides proteins, antioxidants, vitamins, and antimicrobial compounds that are beneficial for bone regeneration, infection prevention, and faster healing.
4. Incorporates Ayurvedic herbal extracts (Tulsi and Neem) to enhance the therapeutic, antimicrobial, and osteogenic value of the formulations.
5. Improves biocompatibility and safety of bone cement for long-term orthopedic and dental repair.

CONCLUSION:

This study concludes that combining Spirulina with Tulsi extract in bone cement can greatly improve its ability to support bone growth and fight infections. The Spirulina and Tulsi mixture showed strong potential for use in both orthopedic and dental applications, helping bones heal faster while preventing microbial growth. Tulsi, with its natural antibacterial and healing properties, works in harmony with Spirulina to make the cement more biocompatible and effective. The tensile strength of the Conventional bone cement ranges around 25-40 Mpa, whereas the expected tensile strength for the Spirulina Integrated Herbal Bone Cement ranges around 35-55 Mpa. Overall, this natural and eco-friendly bone cement offers a safer and more sustainable alternative to traditional synthetic or antibiotic-based materials. It not only helps overcome common medical challenges like infection and slow healing but also supports the move toward greener, more nature-inspired biomedical solutions. Continued research in this area could lead to the wider use of herbal bone cements in real medical treatments.

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