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Review of Current and Future Methods for Fracture Repair

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ABSTRACT

One special kind of tissue found in bones is that it may regrow after injury. Nonetheless, for correct alignment and healing, there are some fractures and abnormalities that call for professional intervention. As with any implant, the material chosen to make the implants to treat these issues needs to be carefully considered. The implants themselves may cause bone fractures or abnormalities, or there may be no bone healing at all, if the wrong material is selected. Metals, ceramics, and polymers are the three types of biomaterials that have been employed in the treatment of bone abnormalities as well as fractures. Each class of biomaterial has certain advantages and restrictions related to its uses. In an effort to capitalize on the many advantages that each of these materials has to offer, composites of these various materials have also been developed. This study outlines the many materials that have been developed to treat fractures and bone deformities in place of bone grafts, as well as their drawbacks and the need for more research.

KEYWORDS: Fracture, tissue, future directions.

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INTRODUCTION

As a dynamic tissue that is constantly remodeling, bone has the capacity to heal from injuries and regain its pre-damage mechanical and biological characteristics. However, the skeletal system can get damaged as a result of certain illnesses, conditions, and trauma. Increased mortality may occur from the associated skeletal system abnormalities and fractures, with the strength of the mortality relationship varying depending on the specific bone. Although the exact cause is uncertain, the related comorbidities of the fractures or abnormalities are probably to blame. Defects and fractures may be the result of something else entirely, or they may be brought on by an implant itself. In addition, after blood, bone is the tissue that is transplanted into humans the most. As a result, it's critical to give considerable thought to treating skeletal system stress without endangering patients while designing orthopaedic equipment [1, 2].

When bone completely fails to regenerate, leading to abnormalities in the bone, or when serious fractures require realignment and fixation for optimum healing, orthopedic implants become required. In order to create an implant that closely resembles the biomechanical properties of bone and integrates with the surrounding tissue while preserving its integrity for the necessary amount of time, the design of these implants must take into account the material's chemical properties, failure properties, mechanical properties, and biocompatibility. The diamond idea, which outlines four essential components required for effective bone healing using bone tissue engineering, can be used to highlight the cardinal needs of bone tissue engineering: An osteoconductive scaffold that facilitates bone growth, growth factors that trigger cellular events to promote healing, a healthy population of osteogenic cells to allow for bone regrowth, and a mechanical environment that is both sufficient to provide stability for healing and mimic the mechanical properties of the native tissue. Furthermore, the patient and their medical history must be taken into account, as the patient's medical history may contain risk factors that raise the possibility of fractures, nonunions of fractures, or abnormalities of the bones. For instance, a patient's age can have a significant impact on their skeletal system because aging is linked to illnesses like osteoporosis and osteoarthritis as well as increased fracture rates and decreased fracture recovery [3, 4].

FRACTURE FIXATION MATERIALS AND DEVICES

Reduction of the fracture, or alignment of the shattered pieces, and preservation of the reduction by immobilization are the objectives of fracture therapy. Reduction can be accomplished surgically or by externally manipulating the bone, and immobilization can be accomplished by internal or external fixation. The fracture heals in a different way depending on the type of therapy. Treatments that tightly close fractures and cause direct contact with the vascular bone surfaces cure initial fractures, and treatments that close fractures so that the bone may still move somewhat heal secondary fractures [5, 6].

Orthopedic surgeons employ external fixation, which involves the percutaneous implantation of pins or wires, to support a bone or joint during repair. External fixation is less intrusive and causes less damage to soft tissue than internal fixation, which is advantageous in cases of acute trauma. Additionally, external fixators' placement may be readily modified after fixation, which internal fixators cannot accomplish. Nevertheless, there are restrictions on the use of external fixators, such as restricted limb mobility. Furthermore, compared to internal fixation, external fixation procedures for fractures have worse outcomes and a greater incidence of nonunions and malunions. For this reason, external fixators are reserved for individuals who cannot or will not undergo surgery as a temporary measure [7, 8].

The process of internal fixing involves the surgical insertion of fasteners to stabilize the fracture pieces. Depending on the nature and location of the fracture, various techniques and internal fixators are employed. These include plates, screws, nails, rods, wires, and pins. The most popular internal fixing implant used to treat fractures is a bone plate. They serve to lessen the fracture and stop any movement, as well as protect the fracture site from stress to promote healing. They are screwed onto broken bone pieces. To lessen the fracture and stabilize the fracture pieces, screws can also be individually placed into the bone fragments. Bioinert materials, including titanium and stainless steel, are typically used to make bone plates and screws instead of bioactive ones since it is not desired for the bone to bind with the plate during plate removal or corrective surgery. Since bone is often subjected to cyclic loading conditions, bone plates should be both very rigid and have a high enough fatigue resistance to prevent tension at the fracture site. After one to two years, plates can either be taken out or kept in the body to aid in bone mending [9, 10].

Only biomaterials that can sustain cyclic loads—thereby maintaining the skeletal system's inherent functionality—are suitable for use in internal fracture fixation. Orthopedic biomaterials have been made using metals, polymers, and ceramics; nevertheless, metals offer the most desired qualities required. Furthermore, because of their mechanical qualities, which provide the necessary stability, metals are the most often utilized class of biomaterials for fracture repair; nevertheless, ceramics and polymers have also been used [11, 12].

BIOACTIVE IMPLANTS

Significant medical interest exists in bioactive materials with antibacterial characteristics. Simple combinations of antibacterial compounds with hydrogels, ceramics, metals, and polymers in various forms—such as fibers, foams, films, or gels—can be used to create antibacterial bioactive materials. Bacteria will be killed as a result of the antibiotic molecules' delivery. An alternative strategy would be to include antibacterial qualities into the material's design, particularly on its surface. Applications to lower the risk of infection have been identified in cardiovascular grafts and orthopaedics. The first line of therapy for wounds in the wound care sector is always the use of antibacterial bioactive materials to control infection. Still, there are a number of significant obstacles to overcome, such as the challenge of treating infections at a deep level, managing the growth of biofilms, and creating both broad-spectrum and targeted antibacterial bioactive materials. To reduce the harmful effects on human health, bioactive materials based on biomimetic materials with antibacterial qualities will be created in the future from natural resources [13].

Perspectives and future directions

The best materials for fracture fixation devices are biodegradable ones since they eliminate the need to remove implants and the risks involved in doing so. Although degradable polymer fixation devices are presently available, their use is limited to non-load-bearing craniofacial applications. Furthermore, because they would need to be built significantly thicker to have the necessary strength, these biodegradable polymeric fixation devices are not ideal choices for load-bearing fixing [14].

Biodegradable polymer fixation devices present a promising avenue in medical implant technology, particularly in eliminating the need for implant removal and associated risks. However, their suitability for load-bearing applications is limited by certain factors. The mechanical properties of biodegradable polymers, including strength and stiffness, often fall short of the requirements for load-bearing implants. To achieve the necessary mechanical robustness, these polymers would need to be constructed significantly thicker, affecting their practicality and functionality. Additionally, the rate of degradation must align precisely with the healing process; if too rapid, the implant may fail to provide sufficient support during critical early healing stages, and if too slow, complications may arise. Biocompatibility is another concern, as inflammatory responses to degradation byproducts could compromise healing, especially in weight-bearing areas. Lastly, the complexity of load-bearing requirements often exceeds the capabilities of current biodegradable polymers in terms of customization. While these materials have found success in non-load-bearing craniofacial applications, addressing these limitations is crucial for their broader application in load-bearing fixation devices. Ongoing research aims to overcome these challenges and expand the utility of biodegradable materials in more demanding medical scenarios [14].

The retirement or removal of bioactive implants, such as those utilized in medical devices or prosthetics, is not without inherent risks and considerations. Typically necessitating surgical intervention, the removal process carries the standard surgical risks, including infection, bleeding, and anesthesia-related complications. Moreover, the extraction of implants may pose risks such as potential damage to surrounding tissues, particularly if the implant has integrated with the body or bone. Infections are an added concern, especially if the implant has been in place for an extended duration, fostering biofilm formation and bacterial colonization. Additionally, implants anchored in bone, common in orthopedic procedures, may lead to bone loss upon removal or require additional interventions to address resulting defects. Foreign body reactions, inflammatory responses, and potential functional implications are all factors that patients and healthcare professionals must consider. Recovery time varies based on the complexity of the removal procedure and the patient's overall health. The decision to retire a bioactive implant should be made in consultation with healthcare professionals, taking into account the specific circumstances of the patient, the type of implant, and the reasons for removal [15].

The most popular biomaterial utilized as alternatives to bone grafts in the treatment of bone defects is biodegradable ceramic material. Ceramics have the advantage of closely resembling the mineral component of the extracellular matrix (ECM) of bone, but they are usually not strong enough. As a result, in order to carry weights, future developments for bone graft replacements will require stronger materials. Metals such as tantalum and titanium alloys have been proposed for these uses. Due to their osseointegrative or bioactive qualities and FDA approval, these metals are an excellent choice. Degradable materials, on the other hand, are the best choice for bone graft alternatives, such as fracture fixation devices, as they enable the implant to be replaced with natural tissue [16].

Degradable metals, like zinc and magnesium, solve the mechanical strength that other degradable materials have and show a lot of promise for bone graft replacement and fracture repair. Studies have indicated that magnesium may be used in load-bearing applications, and screws made of magnesium have been certified for use in Germany and Korea for non-load-bearing purposes. The primary obstacle to magnesium's application is its rapid deterioration and the ensuing evolution of H2, yet magnesium may be coated, alloyed, or mixed with other metals to slow down its rapid deterioration. Furthermore, the byproducts of magnesium's breakdown promote the rebuilding of bone. In a similar vein, zinc's degradative byproducts promote bone growth. Zinc needs additional research because it has been examined less than magnesium. To summarize, further research is required to fully understand magnesium and zinc, as well as to maximize their mechanical strength and rates of degradation, before they may be used in therapeutic settings [17].

Implants may be designed to precisely match the anatomical characteristics of the patient and the damage thanks to computer aided design (CAD) and computer aided manufacturing (CAM) techniques. A model of the fracture or bone defect can be created using computed tomography or magnetic resonance imaging images of the bone. This model can then be used to design an implant or fracture fixation device that is appropriate for CAD or CAM bone defect repair. In order to get the required form, material would normally be removed from a block using computer numerical control (CNC) production in subtractive manufacturing, which was employed by early CAD/CAM systems. However, there is a material loss associated with subtractive manufacturing, as well as limited resolution and geometries due to the cutting tool [18, 19].

PBF or direct energy deposition (DED) have been widely employed for metal implants in particular. In order to form and melt the metal powder or to sinter and fuse the metal powder together to create the build, they both require the usage of lasers. PBF encompasses techniques like electron beam melting (EBM) and selective laser sintering (SLS), whereas DED covers techniques like direct metal deposition (DMD). With titanium constructs, these additive manufacturing techniques have proven effective and have been applied in clinical settings, resulting in faster implant creation, better fit, and faster patient recovery [20].

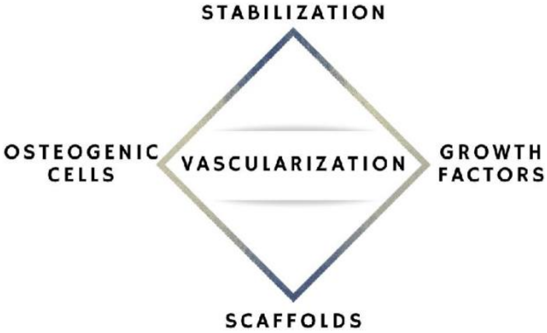

Figure 1. Diagram of 5 elements promoting successful bone tissue regeneration [21]

CONCLUSION

Orthopedic implants are used to repair bone abnormalities and fractures, and there is overlap in the materials utilized and desired qualities. This essay discussed the various materials, their advantages, and their drawbacks as they applied to various uses. The effectiveness of these various materials can be further enhanced by additions—which were not covered in this paper—to the fixators and scaffolds, such as growth factors. Still, no perfect biomaterial exists for the healing of bone defects or for the fixing of fractures.

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