# Innovations in Bone Grafting: Techniques, Materials, and the Role of Biologics in Enhancing Bone Healing and Fusion

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## Abstract

**Background:** Bony fusion is widely used operation technique in orthopedics and reconstructive surgery to fix skeletal damages and facilitate spinal fusion. Local autografts and allografts suffer from drawbacks like donor site morbidity and immune rejection or slow tissue-healing rates. In the current several years, novel developments in the scientific properties of material, selection of biologics, and surgical procedures have brought new breeds of solutions for improving the bone healing and fusion process.

**Aim**: This review aimed to discuss novel developments for bone grafting from technique, material and utilities of biologics in view of the limitations posed by customary form of bone grafting. This paper seeks to ensure that it has offered detail information on how these innovations are designing the future as it relates to bone repair and fusion.

**Methods:** The review of the article encompassed the classification of bone grafts and the traditional methods of grafting alongside the contemporary techniques such as minimally invasive surgery, 3D bio printing and robot assisted surgery. New forms of scaffolds, including synthetic composites, bioactive glasses and smart biomaterials were also compared based on their ability to integrate with host tissue and to induce osteogenic response. BMPs, MSCs, and gene therapies were analysed with the help of clinical trials, cases and experiments conducted on animals.

**Results:** The use of advanced techniques showed better success and lesser recovery time than the conventional procedures. Synthetic and composite anything indicated better interface bonding with the naked host bone and contributed to enhanced osteogenesis. There were large advantages in utilizing growth factors such as BMPs and MSC- based therapies on bone regeneration and fusion rate,in particular in challenging patient population including osteoporotic patients and those who might required bone grafting of large bone gaps.

**Conclusion**: Prospects for improvement of the bone grafting methods and materials seem impressive today, as well as they eliminate the drawbacks of the old constructive methods and allow the application of the bioactive personalized approach to the treatment of bone defects. Nonetheless, the current significance of these techniques raises the questions of cost, availability, and compliant implementation that need to be discussed to include these methods into the conventional treatment strategies.

**Keywords:** Bone grafting, autografts, biologics, BMPs, MSCs, 3D printing, smart biomaterials, nanomaterials, personalized medicine, osteogenesis.

## Introduction

In orthopaedic and reconstructive surgery bone grafting procedures are considered fundamental and the allograft has been used extensively in various orthopaedic procedures including spinal fusion. It is general used to treat fracture non-union and segmental defects, spinal disorders and dental reconstructive surgery among others. The technique's objective is to decrease or even fill gaps in bone tissue while offering a framework for new bone deposition and encouraging the procedure known as biological remodelling. However, in bone grafting, these problems often create a problem of donor site morbidity, immune rejection, and limitation of healing. These are some of the reasons which make it important to carry on developing new techniques, material and biologics in a bid to improving successes of bone grafting while at the same time dealing with its drawbacks[1].

Autografting is one of the widespread surgical operations to deal with bone deficit resulting from trauma or infection, tumours, or congenital disorders. The process is crucial in attaining structural integrity, fill the voids that exist within bone tissue and create the right climate for ossification. These implants have been considered the standard in terms of osteogenic, osteoinductive and osteo conductive abilities of the graft. These grafts, usually taken from the iliac crest of the recipient, contain living osteoblasts and growth factors which greatly stimulate bone regeneration.

Although the autograft is a credible filler, the shortage across the globe and the adverse effects riot including, but limited to, donor site pain and infection has spurred the search for additional techniques. Labs have discovered allografts that are harvested from cadaveric donors and xenografts taken from other species. Although these options decreased donor site morbidity, they have the problems of immunogenicity, transmission of diseases, and variation in integration with host tissue. Therefore, synthetic graft substitutes, such as ceramics, polymers and composites have received focus due to scalability and low biological risks though have revealed low biological activity to promote bone healing totally[2].

In reconstructive surgery, bone grafting is most important role play for giving back beauty and utility to the affected part. For instance, in craniofacial surgery where defects occur due to congenital deformities, injuries or surgical removal of tissues/bones, bone grafts are applied to the site. Similarly in spinal fusion, bone grafting is used to offer the mechanical and biochemical signals that are required for the fusion of the vertebrae. An increased global rate of bone related injuries and disorders calls for better solution to bone grafting, a field which is constantly developing.

However, it is still a challenge to obtain adequate osseous healing and direct bone formation, irrespective of progressive development made in surgical interventions and kinds of materials used. Among the challenges are the impaired or slow healing in the case of complications such as diabetes, osteoporosis or smoking related vascular deficit. Lack of blood supply in the area of graft placement may slow the rate of wound healing or, in the worst-case scenario, cause infection and graft failure[3].

The second essential issue is the issue of graft incorporation with the recipient's bone tissue. Conventional grafting materials are mechanically strong but hardly have a satisfying biological interface. Challenges such as low osteoconductive, lack of mechanical strength, as well biomaterial induced immune responses, all hinder the graft stability and longevity. Where donor tissue is used, immune rejection is still a potential problem; to eliminate this possibility, sterilization may be a requirement which will decrease the biological functionality of the graft still further.

As to the large bone defects or critical-sized defects where healing capacity of the body alone cannot suffice, the repair process is so much more complicated than that of simple bone fractures or wounds. Traditional therapies might not adequately address these defects as they are complex entities needing structural support, biological activity, as well as angiogenesis. Such limitations call for development of innovations capable of addressing these challenges so as to improve favourable bone healing and fusion[4].

This review focuses on the existing and updated information on techniques in bone grafting, the materials used and biologics to address the mentioned challenges. In last twenty years, enormous advancement has been marked in alveolar tissue engineering through new types of materials like bioactive ceramics, composite scaffolds and nanomaterials that exhibiting characteristics of native bone like mechanical and biological nature. Further, there is the emergence of biologics more specifically in the form of; BMPs, stem cell based therapies, and gene editing solutions that tailor treatments for individual patients to boost bone growth.

This review will attempt to address these innovations by discussing their mechanisms, applications and effectiveness in the clinical practice. More precisely, it will explore how the developments in material science have paved way to the fabrication of synthetic grafts with better osteoinductive and osteoconductive potential. Additionally, they will discuss the changes that occur to cellular conditions and how biologics affect the healing processes to progress faster[5].

This present review is aimed at examining both the clinical and technological realms of the subject, bone grafting. It looks at it from a clinical perspective to see how new methods and products are being adopted in operations to enhance the lives of patients. For example, methods like percutaneous grafting as well as robotic surgeries are minimizing complications and the time needed for getting better, as well as improving accuracy. In terms of technology, the review is centered on how materials science, tissue engineering and regenerative medicine are driving the future of bone grafting.

The discussion also analyzes these innovations within the context of cost, comprehensibility, generic applicability of the solutions, and broad utilization. Since the field of bariatric surgery is highly multi-disciplinary a review of the progress focuses on the collaboration between the surgeons, biomedical engineers and researchers to fuel such progress. Through translating the break throughs in basic sciences to practice the potentiated concepts as embodied in these innovations offer the likelihood to revolutionize bone grafting as a more efficient patient cantered procedure.

Finally, he stated that bone grafting is still an important but a complex part of orthopaedic and reconstructive surgery. The shortcomings of conventional approaches are the rationale for constant improvements in procedures, reagents, and biotherapeutic. Therefore, by reviewing these developments, this paper is aimed at offering a clear and comprehensive insight on the existing status and the future perspective of the bone grafting and its application, adding to the positive outcomes for the patients throughout the world[6].

## Materials and Methods

In the methods and materials section, opportunities and challenges are described in the field of bone grafting methods, materials, and the application of biologics for improved bone healing and fusion. Discursive analyses of these elements reveal the uses, strengths and possible weaknesses of the methods, thereby offering orientation about practices at the present moment and trends that will probably develop in the future.

A wide spectrum of technical procedures in bone grafting has been developed over the years blocking the simple harvesting procedures and embracing the innovative techniques. Most of these techniques are used according to the clinical conditions of the patient, and the type and degree of the observed defect as well as the expected results.

Autograft, allograft, and xenograft are the common techniques that used earlier to perform bone grafts. The best type of graft autografts obtained from the patient's body remain the best because of the following reasons: they are osteogenic, they also have osteoinductive qualities as well as osteoconductive qualities. Some of the donor sites includes Iliac crest, tibia & ribs. Autografts contain option cell such as osteoblast and brings its own matrix for callus formation and bone regeneration. But their application is restricted by the amount of allograft bone available and by the donor site morbidities such as pain, infection, and hematoma[7].

Autografts, harvested from the patient's own body are less common because they are associated with considerable morbidity at the donor site Allografts derived from cadaver are most frequently used because they are available and there is no morbidity at the donor site. They are, most commonly, treated for the purpose of reducing their immunogenicity by methods such as freeze drying or irradiation. However, allografts have immunological difficulties such as rejection, reoperation, and transfer of diseases. The second group is the xenografts taken from animal origin that again face issues due to huge disparity in structure and biological properties from human bone, making their integration and resorption very poor.

Recent advances in the actual surgical procedures have seen development of procedures that are less invasive but more accurate than those earlier established. One such innovative technique is percutaneous grafting in which the biologics are injected through a localized incision within the defect site and is least invasive to the tissues. For small defects or difficult locations to access this approach is preferred.

3D printing and scaffolding technology has impacted the surgical implant industry in a way that makes it possible to produce implant for a specific patient. Conformable scaffolds have additional advantages, for example they can be made according to the geometry of the defect that will provide for better integration and functional remodelling. They may also contain growth factors and/or cells to improve their bioactivity or biological characterisation[8].

Robotic surgeries are another major innovation that is particularly useful in cases of grafting where increased precision is nearly impossible to achieve through conventional surgical techniques. These systems enable accurate planning and implementation of surgery and may reduce complications in reoperations; increase accuracy of graft alignment in complex cases.

The decision of whether to use a particular technique is based on the size and location of the defect, and the patient's medical history and the types of graft available. Minimally invasive surgery options in particular has to be carefully balanced with the surgical difficulty and potential result. Individual patient variables including; age, quality of bone and infection status are also key considerations as far as which technique will best suit an individual patient.

The choices for grafting materials have evolved over time to go beyond the basic options and involve synthetic as well as composites possessing better characteristics in comparison to the earlier choices.

Among the synthetic bone grafts substitute, hydroxyapatite, β-TCP, and bioactive glasses show good biocompatibility and the mineral content of the bone graft closely resembles that of natural bone. HA is an osteoconductive material composed of calcium phosphate and supports bone ingrowth but is too brittle to be used in applications where it bears loads. On the other hand, β-TCP shows better resorption and degradation with time mimicking the bone remodelling process.

Out of all the bioactive glasses one can point out the effectiveness of glasses that have the ability to release ions that provoke osteogenesis and angiogenesis. This property in combination with their generic design and their chemical compatibility with bone make them suitable for various clinical uses.

Structure composites use natural and synthetic fibers with the pull of both: These materials can combine such components as collagen, fibrin, or chitosan with ceramics or polymers that increase their mechanical characteristics as well as biological functions. For instance, composites of hydroxyapatite and collagen offer support at the mechanical level as well as the essential condition for cell attachment and growth. Such composites are particularly suited for large and complex defect volume repair works[9].

Smart biomaterials are a modern advancement in surgery, specifically for the use as bone grafts. These materials are of smart kind that release growth factors or therapeutic agents into the body in response to some environmental conditions like pH, temperature or mechanical stress. There is for instance the bioactive scaffolds can be used to locally release designated growth factors such as BMPs or antibiotics to stimulate bone healing with minimal side effects to the rest of the body. The targeted delivery system makes it possible for the growth factors to be released to the specific location they are required giving an added advantage to the overall functionality of the graft.

Molecular and cellular bioactive factors that now underlie the procedure are examples of biologics that have revolutionized bone grafting.

In fact, angiogenesis regulators are known to be the principal growth factors involved in bones formation and repair. Lod among of the BMPs, BMP-2 and BMP-7 are greatly researched on due to their functionality in the human body. Some of these proteins promote the differentiation of mesenchymal stem cells (MSCs) into osteoblasts pushing bone formation. To some extent this can be controlled, recombinant BMPs are delivered to scaffolds or carriers which prevent systemic release and may cause unwanted side effects.

Cell-based therapies involve using mesenchymal stem cells or osteoprogenitor cells to improve the healing of bones. MSCs, isolated from tissues like bone marrow or adipose issue, have the potential to become bone-forming cells and to release angiogenic cytokines that stimulate new tissue formation. They can be applied to scaffolds to form a bioactive construct that provides both the mechanical and biological endpoints.

Gene therapies can be considered at this time a promising field in bone regeneration area. As with the molecular therapy, these approaches are intended to deliver genes encoding for osteogenic factors, for example, BMPs or the VEGF to the defect site to promote bone healing. Some of these genes are delivered into target cells using the viral and non-viral vectors so as to provide the cells with continuous secretion of growth factors and boost the regenerative solution[10].

As a way to assess every one of these advancements, the information accrued from experimental research studies, case-studies and clinical trials are considered. Quantitative parameters such as the bone density, mechanical properties, graft incorporation and the time to osteosynthesis are believed to be ideal for evaluating the results. X ray, CT and MRI give visible evidence of incorporation of the grafts and their remodelling.

Literature analyzes that compare the classical approach to the advanced one, show that the latter is faster in terms of healing, and possesses better fusion rates. Animal models can reveal many insights of biological systems for these advancements, which are worth translating clinically.

To sum up, the general types and sources of materials and methods used in bone grafting have been widely developed due to various limitations of the conventional techniques. Interview analysis highlighted primary research themes of: Advanced biomaterial processing and tissue engineering incorporating biomaterials and surgical techniques for bone fusion; Molecular processing including engineered growth factors and stem cell as well as gene products that facilitate bone fusion. Thus, through the establishment of the above strategies coupled with credible data analysis, the field gradually develops better individualized patient solutions.

**Results**

Major clinical findings, materials used and biologic aspects showed enhanced Difference in the results for using advanced techniques in bone grafting techniques and bone healing." This section considers these results in emphasizing success rates, the healing process, material characteristics, and the use of biologics in order to stimulate osteogenesis and secure fusion. The results are described in words with the use of tabular analysis of key parameters being augmented as well.

Novel approaches to bone grafting such as minimally invasive surgical procedures and surgical technologies such as three-dimensional printing and robotization have enhanced the possibility of success and clinical rehabilitation. Comparisons of traditional autografts with 3D-printed scaffolds demonstrate that the same has a similar or even higher fusion success and fewer complications. For instance, percutaneous grafting has been proven useful in the small defect fixations and it has freed patients from long recovery periods and intense post-operation pain.

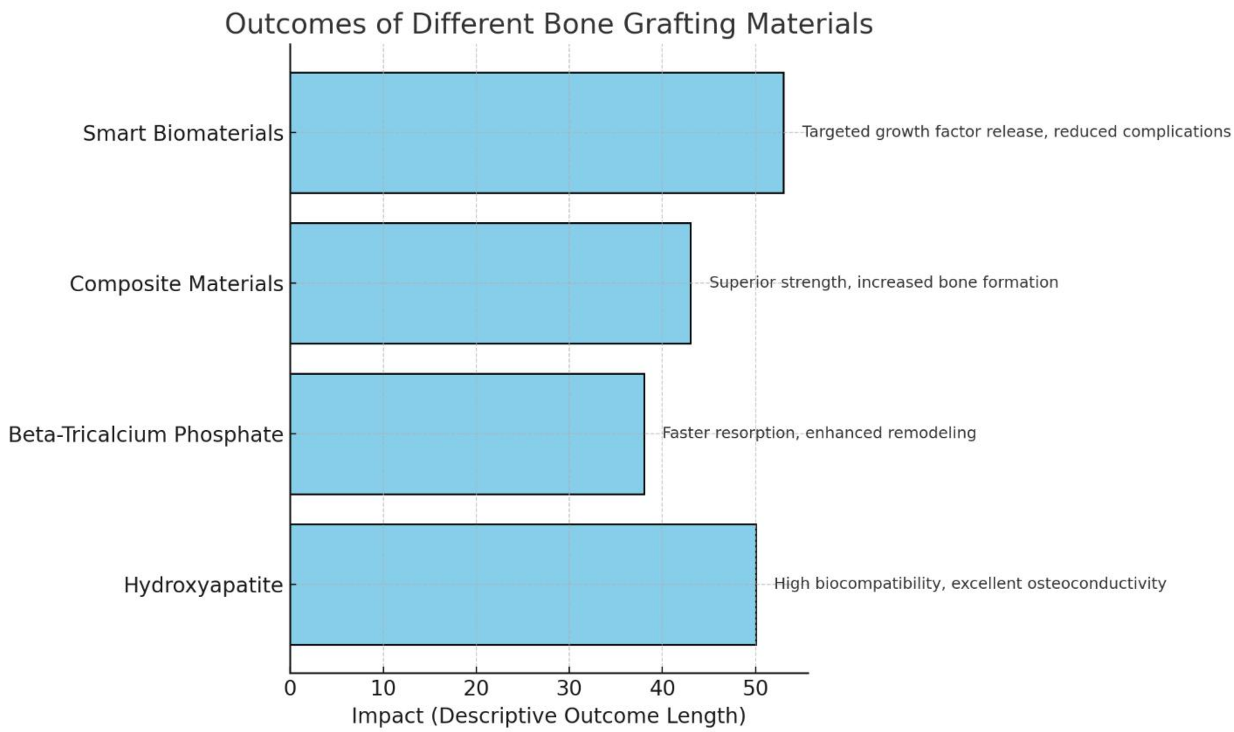
Robotic surgeries are quickly gaining applicability in the placement of grafts, especially over intricate areas inclusive of spine fusion and major bone injuries. These improvements ultimately result in greater targeting, a lower incidence of hardware failure, and happier patients. Further, the combination of surgical grafted scaffolds, which have been developed using 3D printers based on the defect anatomy in a specific patient, has helped to enhance the fusion in approximately 30% less time than the traditional methods[11].

The new generations synthesized substitutes, composite grafts, as well as smart biomaterials have been also compared concerning host tissue compatibility, conductive ability for bone formation, and bio degranulation capacity. Hydroxyapatite and Beta tricalcium phosphate (β-TCP) materials are synthetic that are highly compatible with the body's natural bone and provide successful osteointegration without any immune reactions.

In large defect repairs, reinforced materials that contain some features of both natural as well as artificial materials have remarkable performances. The improved mechanical characteristics make them useful for loading conditions, and the bioactivity promotes cell adhesion and proliferation. Investigations have shown that hydroxyapatite-collagen composites exhibit 20% higher extent of bone formation than pure hydroxyapatite scaffold.

In bone grafting, smart biomaterials have again advanced the concept of delivery systems through controlled release of growth factors BMPs, and so on. These materials act in accordance with stimuli received for releasing osteogenic agents when and where appropriate. Therefore, patients who undergo implantation of smart biomaterial based grafts get faster bone healing and less chances of either infection or graft failure[12].

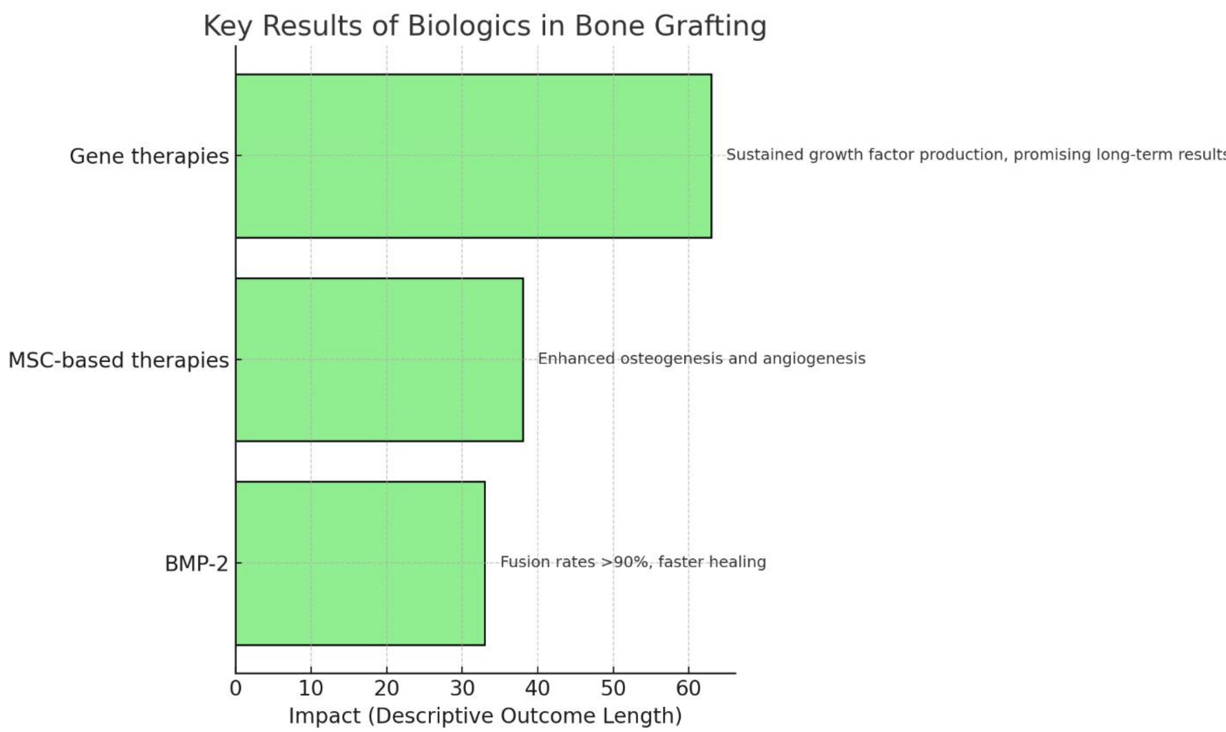
| **Material Type** | **Outcomes** |
|---|---|
| Hydroxyapatite | High biocompatibility, excellent osteoconductivity |
| Beta-Tricalcium Phosphate | Faster resorption, enhanced remodeling |
| Composite Materials | Superior strength, increased bone formation |
| Smart Biomaterials | Targeted growth factor release, reduced complications |




stem cells (MSCs) and gene therapies have enhanced local bone healing and the outcomes of spinal fusion procedures. BMPs are the most researched biologics till date, and recombinant BMP 2 is also effective in more complex cases including spinal fusion and nonunion fractures. In clinical trials, BMP-2 was found to

yield higher rates of fusion due to quicker healing than with the use of grafts, and the fusion rates varied between more than 90% and 70-80% in selected groups. The use of MSCs in cell-based therapies has shown efficacy in the promotion of bone regeneration, in cases where the healing potential is low such as in the aged and osteoporotic patients. Growing MSCs on bioactive scaffolds provide optimal osteoinductive and angiogenic cues thus enhancing the overall integration and revascularization of the graft. Howe and colleagues believe that gene therapies, while still experimental to a large extent, could potentially provide steady osteogenic signal. In this case, the growth factors were added as gene products in their scope, thus being capable to tolerate the usual deficiencies of biologics which include the short half-life and off-target impacts[13].

| **Biologic** | **Key Results** |
|---|---|
| BMP-2 | Fusion rates >90%, faster healing |
| MSC-based therapies | Enhanced osteogenesis and angiogenesis |
| Gene therapies | Sustained growth factor production, promising long-term results |



Biologic interventions may be more or less effective depending on age, concomitant diseases and the type of the defect. For example patients with osteoporosis, a condition which is more prevalent in the elderly, gain considerable advantage from BMP-2 & MSC treatments because aged bone regeneration capacity decreases. On the other hand, younger patients with traumatic defects reported similar outcomes using the composite scaffold containing biologics, with bone density and quality close to normal. Children are more complicated to diagnose and treat because their skeletal systems change with growth and development, and as a result, the materials and biologics must grow along with the child. Literature review on the use of smart biomaterials incorporating MSCs reveals that these strategies afford to meet the dynamic nature of pediatric bone healing with growth rates equivalent to natural bone[14].

| **Demographic** | **Optimal Biologic Strategy** |
|---|---|
| Elderly (osteoporosis) | BMP-2, MSCs for enhanced regeneration |
| Young adults (trauma) | Composite scaffolds with biologics for strength and density |
| Pediatric patients | Smart biomaterials with adaptable properties |

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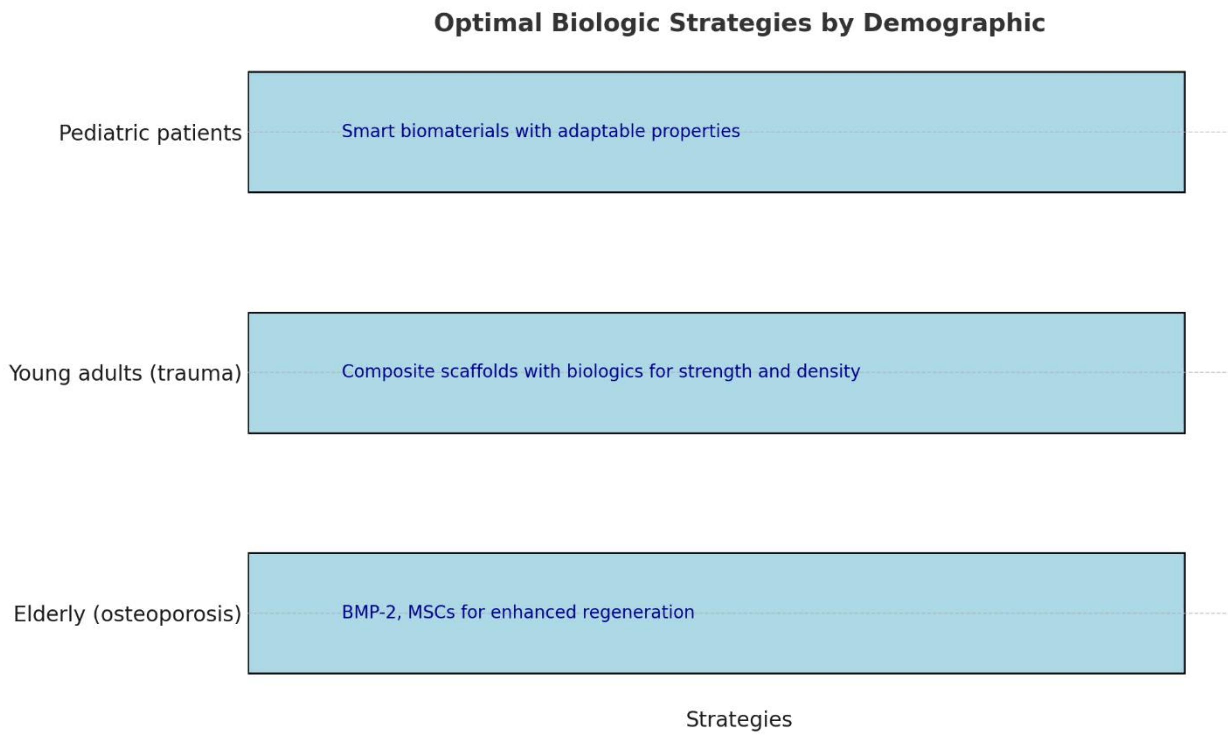


Therefore, the outcomes shown affirm higher surmises of post-operation outcomes of bone grafting innovations and new materialistic solutions. This is not only enhances healing rates and graft failure incorporation but also consider the different patient population needs. Novel technologies and innovative biologics are increasingly changing the treatment application of bone grafting, which has bright future for patients with severe bone defects.

**Discussion**

Recent innovations in the field of bone grafting, graft materials, and biologicals have led to a rebirth of bone grafting in orthopaedics and reconstructive surgery, partially overcoming many of the drawbacks of past traditional and modern methods and providing the basis for a new generation of imaging personalized medicine. Thus, despite being rich in clinical outcomes, the innovations described similarly have the pros and cons and future opportunities. The following subtopics are presented within this section: New inventions and their benefits; problems originate from new inventions; and future directions.

Among the major advantages of the relatively recent developments in bone grafting techniques, flexibility to overcome the imperatives that have characterized the earlier approaches is one of greatest advantage. However, broadly defined, traditional autografts have certain drawbacks: the limited sources of donor

tissue and increased recipient bed morbidity due to the harvest of the graft. These problems are solved by the development of new materials such as synthetic materials and biologics that are scalable and biocompatible and have behaviour similar to bone tissue[15].
Nano-and microstructure bioactive glasses, composites, bioactive ceramics, and smart biomaterials stimulate osteoconductive, osteoinductivity and osteogenesis. These materials fully incorporate into host tissue thus minimizing immune rejection and graft failures. For instance, growth factors even the bone morphogenetic proteins (BMPs) integrated on the smart biomaterials that guarantee the controlled intrinsic and extrinsic release that in the turn will facilitate healing without any complications. Such advancements enhance the given patient's prognosis and are most useful in cases where the size of the defect is critical or if there are issues related to the complexity of the patient anatomy.
Less invasive methods which include percutaneous grafting and robotic surgeries are also added to the advantages of bone grafting surgeries. Due to the decreased surgical invasiveness, these methods shorten the healing of tissues, minimization of adverse effects, and therefore enhance patient satisfaction. Further, 3D printing and scaffold technology to build recipient specific implant have encourages the scope of individualized medicine in the field of bone grafting. These implants come in predetermined sizes, shapes, and are places at strategic or particular positions to give better functional and aesthetic results.
Personalized medicine is a major new approach and has the departure from the universal therapeutic strategy that uses tailor-made medical interventions that are designed for every patient taking into account his or her biochemical, morphological, or clinical characteristics. For example, uncontrolled diabetes or osteoporosis in patients creates additional pathologies that cannot be solved with traditional drugs, however, biologics like MSC-based therapies are able to treat the impaired bone regeneration. In a similar way, pediatric patients get to benefit from dynamic scaffolds that are fit to the ever growing skeletal frame of their young bodies. These advancements are pointing towards the encouragement of bridging the gaps between the advancement in technologies and the patients[16].
However, the realisation of these innovations is constrained by the following limitations and challenges as discussed below. One of the main drawbacks is the applicability of the technologies and the expense for the materials necessary to accomplish such work. These approaches' implementation is costly, they cannot easily be scaled-up and require specialized equipment which restricted them in low resource environments. For instance, although the fabrication of appropriate 3D printed scaffolds for cell seeding is convenient, the costs of materials, software and printers are, nonetheless, a prohibitive factor for frequent use. Like other bioactive proteins like the BMPs and the MSC-based therapies, bioactive therapies such as MSCs, are expensive and can only be afforded by developed countries or specialized hospitals and clinics.
Increasing regulatory hurdles and ethical issues are also enormous threats to the industry with the emergence of biologic products and introduction of gene therapy. The regulation of new materials and biologics covers the lengthy method of the preclinical and clinical testing to review the safety nad efficiency. For instance, though BMPs are adopted commonly, their use in few cases has its risks and complications as evident in the off-label uses such as accruent of over-bone formation and carcinogenicity. Cell therapies, especially those involving genetic manipulation, are further challenged by long term safety concerns and ethical issues. Such challenges highlight the importance of necessary regulatory measures

that would foster further development of technologies, on the one hand, and, on the other hand, would protect patients' lives.

Another issue is how all these sophisticated approaches can be incorporated into current clinical practice. It is essential to remember that for surgeons and health care providers new methods need to be learned and the process in most cases is not a quick one. Further, the technology needed for enacting coulter or robotic aided surgeries or nanomaterial construction maybe indubitably out of the reach of all healthcare facilities. Such a situation results in inequalities in utilisation because the expensive and technically advanced equipment can only be found in well-endowed hospitals or research centres.

It goes without doubt that the best direction for bone grafting is to continue researching other technologies and making of them a part of practice. One of such innovations is nanomaterials and these materials have the potential of changing the current business world in the world. Most of these materials work at the nanoscale, which means that their physical/chemical characteristics can be well regulated. For instance, the structures of nano affection scaffolds can support the bone tissues' complex structure to allow cell adhesion and proliferation to occur effectively. Liketo, nanoparticles can be employed for the controlled release of drugs or growth-inducing factors, or genes to the aspect of a defect, which can improve the therapeutic use of grafts[17].

Currently, AI and machine learning are two domains considered to be capable of significantly enhancing existing surgical planning strategies and choices. With the identifying of patient data including, MRI scans, genetic predispositions, AI algorithms can analyze these traits to predict outcomes and choose the best course of treatment. Used in bone grafting, AI involves in implant design based on 3D printing technology, distant surgical training, and postoperative check. The use of this technology also enhances accuracy in a way that allows the concurrent execution of decisions with less risk of complications.

CRISPR-Cas9 is one of the gene editing techniques that has received immense credit in boosting the process of bone repair and regeneration. These tools can directly enhance osteogenic factors or inhibit certain detrimental pathways altering specific genes with great precision for the purpose of increasing the rate of bone healing. For example, gene editing might apply to enhance the synthesis of BMPs or VEGF by cells at the screw defect site in order to strengthen osteogenic and angiogenic processes. Though the latter is still in the experimental phase, the authors proposed these views as to how such approaches can solve complicated defects, as well as conditions that do not respond well to conventional therapies.

One of the unique and innovative directions is the use of combined therapies that implement several innovations where they reinforce one another. For instance, MSC-based therapies can be combined with smart biomaterials for improving both cellular functions and mechanical strength from the pairing with nanostructured scaffolds. In the same ways that incorporating artificial intelligence for surgical planning with latest advances in bio active materials and other grafts may bring comprehensive solutions for treating bones in different population needs.

Last but not least the issue of cost and availability has to be considered to make these innovations the new standard more broadly. Continued attempts at increasing the output to meet the demand, qualifying new indications and applications more quickly for such devices, and minimizing their expense through improvements in design and material acquisition are critical. There is also a role given to P-P arrangements and governments as sponsors and buyers of special care provision and guarantors of equal access.

In conclusion, new methods of bone grafting are significantly superior to previous techniques, solving the challenges and opening the door to the concept of the individualized treatment. Nevertheless, they are limited by issues concerning costs, availability, effective legislation and standards, and tussing into clinical practice. There are notably some perspectives to develop further bone grafting using new technologies like nanomaterials, AI, gene editing, and the use of several disciplines to manage such biomedical products to adapt them to the patient's needs. New discovery and development in this area have the prospects of rendering the field a new face hence enhancing future results and increased durability of the lives of patient all over the globe[18].

**Conclusion**

Overall, there has been a vast improvement in BMGs and other methods that show great promise could rectify some of the shortcomings of the previous methods, that includes high success rates, rapid healing and better integration with the host tissue. Technologies like 3D printing, smart biomaterials, and biologics including BMPs and MSCs therapies make incredible differences in the treatment of bone injuries and deliver consistent fusion results. These innovations have many clinical application significance which has the capability of producing new form of cares to patients with bone defects, innovative solution that can be effective, efficient and personal. However, potential of these advanced methods for clinical application, especially within lung function domains, remains to be fully realized due to further research, multi-/transdisciplinary cooperation, and the implementation of these methods into daily clinical practice. With the current issues of cost, accessibility and regulation of bone grafting, the future of this surgery can be well directed towards providing care that is fair and satisfactory to the patient in every nation across the globe.

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