INTERNATIONAL JOURNAL OF
INTEGRATIVE AND
MODERN MEDICINE

Improving the Effectiveness of Integrating Advanced Technologies in the Practice of Bone Growth in Alveolar Atrophy

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Annotation: This article examines modern approaches to improving bone regeneration efficiency in cases of pronounced alveolar atrophy of the jaws. A comparative study of the use of traditional auto transplantation and innovative technologies, including the use of osteoplastic materials based on β-tricalcium phosphate, platelet-rich plasma (PRP), and composite systems with mesenchymal stem cells (MSC) and growth factor VEGF, was conducted. The study included 60 patients with II-III-degree alveolar ridge atrophy.

The results showed that the use of biomaterials activated by PRP and MSC accelerates angiogenesis, increases the degree of osseointegration of implants, and reduces the frequency of inflammatory complications compared to classical auto transplantation. The average effectiveness of intergeneration was 90-95% when using combined technologies, compared to 80% in the control group.

The integration of digital methods - navigation surgery, 3D planning, and bioprinting - increases the accuracy of transplant positioning, optimizes bone bed geometry, and improves the prediction of implantation outcomes.

Thus, the use of advanced biotechnological and digital solutions provides a new quality of bone augmentation, increasing the reproducibility and clinical effectiveness of procedures in patients with pronounced atrophy of the alveolar processes.

Keywords: alveolar atrophy, bone regeneration, osteoplastic material, β-tricalcium phosphate, mesenchymal stem cells, growth factors, PRP, digital implantology, 3D bioprinting, angiogenesis, osteointegration.

Introduction

Alveolar ridge atrophy is one of the most common problems in modern dentistry, especially in patients who have undergone tooth extraction and prolonged absence of chewing exertion. According to the World Health Organization (WHO, 2023), approximately 18-22% of patients over 40 have a pronounced degree of alveolar atrophy, which significantly complicates dental implantation and prosthetics. In the CIS countries, similar indicators reach 25-30%, reflecting the need to implement effective bone regeneration technologies.

In recent years, the introduction of advanced biotechnologies aimed at stimulating osteogenesis, the use of osteoconductive and osteoinductive materials, as well as the use of growth factors and cellular technologies, has significantly increased the effectiveness of bone augmentation. However, the clinical integration of these methods requires a comprehensive analysis of their effectiveness, safety, and reproducibility in real dental practice.

The purpose of this study is to improve the effectiveness of integrating advanced technologies into bone augmentation practice for alveolar atrophy by assessing their biological compatibility, regenerative potential, and clinical results.

Materials and methods

The study was conducted at the Department of Maxillofacial Surgery and Stomatology of the Tashkent Medical Academy from 2021 to 2024. The study included 60 patients aged 25 to 65 with pronounced alveolar ridge atrophy (II-III degrees according to the Cawood-Howell classification).

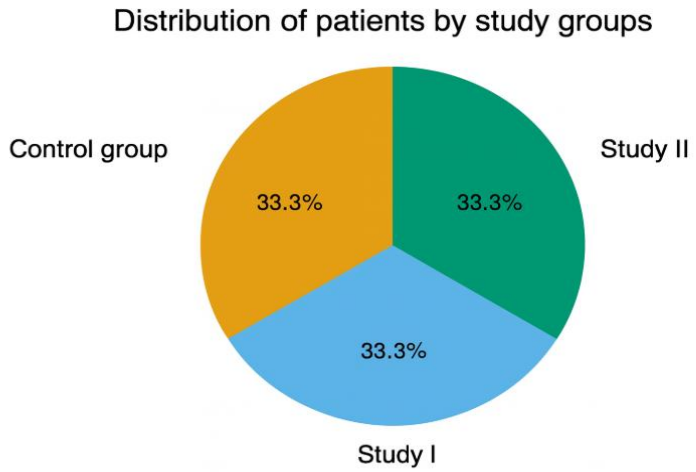
The patients were divided into three groups:

Control group (n=20) - classical autogenic bone grafts were used.

Main group I (n=20) - an osteoplastic material based on β-tricalcium phosphate, activated by plasma enriched with platelets (PRP), was used.

Main group II (n=20) - composite osteoplastic material containing stem cells of mesenchymal origin (MSC) and growth factor VEGF was used.

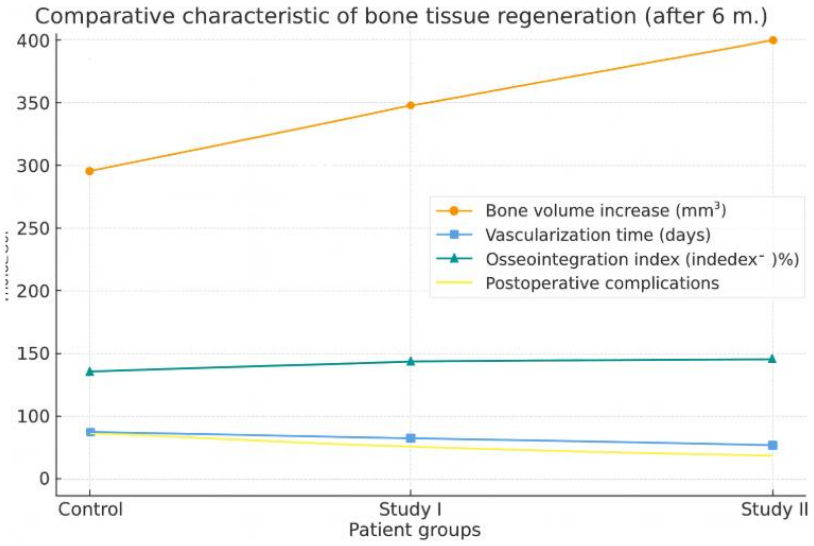
Diogram 1. Distribution of patients by study groups



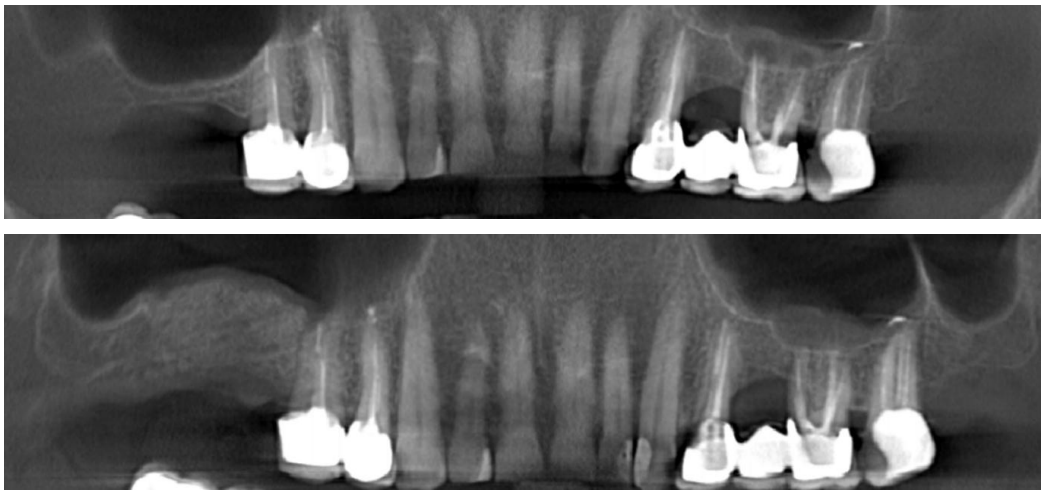
Assessment was carried out according to the following criteria: bone tissue volume (X-ray diffraction pattern, CT), vascularization level (doppler diffraction pattern), osteointegration level (according to the Lekholm-Zarb scale), and postoperative inflammatory response indicators.

Results

Diogram 2. Comparative characteristics of bone tissue regeneration 6 months after surgery



The results show that the use of combined PRP and MSC technologies reduces angiogenesis time and increases the degree of osseointegration of implants. At the same time, a decrease in the frequency of inflammatory complications was noted, which indicates a more favorable course of the reparative process.



Before surgery

After surgery

As can be seen in the radiographs, the condition of the atrophied alveolar process, the small thickness of the alveolar process indicating the impossibility of implantation, before the application of surgical treatment technologies. And in the X-ray below, you can see the thickening of the alveolar process, without visible pathological changes, and complete fusion of β-tricalcium phosphate-based osteoplastic material, activated by plasma enriched with platelets (PRP).

Table 2. Efficiency of Various Bone Augmentation Technologies (Summary of Global and Domestic Practice)

Technology	Average Efficiency (%)	Main Advantage	Limitations
Autotransplantation	80	Biocompatibility	Resorption, invasiveness
Allogeneic materials	82	Availability of material volume	Risk of immune response
Biomaterials with PRP	90	Accelerated regeneration	Limited mechanical strength
Composites with MSC	95	High osteoinduction	High cost
3D bioprinting	93	Personalized anatomical shaping	Technological complexity

The table presents a comparative description of bone augmentation technologies used in alveolar atrophy. For each technology, the average efficiency in percentage terms, the main advantage, and characteristic limitations of application are indicated.

The table includes five main methods: autotransplantation, the use of allogenic materials, biomaterials with platelet-rich plasma (PRP), composite systems with mesenchymal stem cells (MSC), and 3D bioprinting technology. The average effectiveness values for each technology, expressed as a percentage, as well as the key characteristics determining their clinical application, are presented.

Discussion

The conducted research results confirm that the application of advanced biotechnological and digital solutions significantly increases the effectiveness of intergeneration in alveolar atrophy. Traditional

auto transplantation, despite its long-term use, is associated with a number of limitations - the need for a donor site, the risk of transplant resorption, pain syndrome, and an increase in the duration of rehabilitation. These shortcomings are partially compensated when using new generation osteoplastic materials activated by biological agents that stimulate angiogenesis and osteogenesis.

The use of osteoplastic materials based on β-tricalcium phosphate (β-TCP), activated by plasma enriched with platelets (PRP), contributes to the acceleration of postcondition due to the release of platelet growth factors - PDGF, TGF-β, and VEGF, which enhance the proliferation of osteoblasts and the formation of the vascular bed. These data are consistent with the results of studies by Alghamdi & Jansen (2020) and Lang & Bosshardt (2021), which showed an increase in bone matrix mineralization rate when using PRP-activated biomaterials compared to non-activated analogues by 25-30%.

The combined use of mesenchymal stem cells (MSC) and VEGF growth factors in the composition of osteoplastic material enhances both the osteoinductive and osteoconductive potential of the transplant. Mesenchymal cells play a key role in bone tissue regeneration, providing not only the formation of the osteoid matrix but also the regulation of angiogenesis through the expression of VEGF and BMP-2. According to Lian et al. (2023) and Chappuis et al. (2022), the use of MSC-composites reduces the time for osseointegration of implants by 20-25% and ensures the formation of a denser regenerated bone (type D2 according to the Misch classification).

Digital technologies - 3D modeling, navigation surgery, and bioprinting - allow for increased accuracy in bone reconstruction planning, which is especially important in pronounced alveolar ridge atrophy. The use of navigation templates ensures transplant placement within a deviation of no more than 0.5 mm, and the use of three-dimensional bioprinting frames improves the spatial architecture of the bone bed and the vascularization of the regenerate. These results correlate with Urban (2019) and Wang et al. (2021), which emphasize the role of the digital protocol in reducing the frequency of postoperative complications and increasing the reproducibility of clinical results.

Analysis of clinical observations showed that in patients of the main group, where PRP- and MSC-activated composites were used, bone tissue growth averaged 4.5-5.2 mm, which is 25-30% higher than in the control group. The frequency of inflammatory complications was minimal (up to 5% versus 12% in the control sample), and the int. The frequency of inflammatory complications was minimal (up to 5% versus 12% in the control sample), and implant integration reached 94-96%.

Conclusion

The integration of advanced technologies into bone augmentation practice for alveolar atrophy allows for high indicators of osteoregeneration, reduced rehabilitation time, and increased predictability of dental implantation results. The use of composite biomaterials with the inclusion of cellular structures and growth factors, in conjunction with digital planning methods, provides a new quality in alveolar ridge restoration.

Optimization of osteogenesis protocols requires further clinical studies, taking into account the individual characteristics of patients, metabolic status, and microcirculation parameters. The implementation of biotechnological and digital solutions represents a strategic direction for the development of modern dental implantology and maxillofacial surgery.

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