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ROLE OF STEM CELLS IN DENTAL IMPLANTS: A REVIEW OF CURRENT TRENDS AND FUTURE PERSPECTIVES

Dentistry

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ABSTRACT

Stem cell-based dental implants represent a transformative advancement in regenerative dentistry. By integrating stem cells with scaffolds and implant surfaces, researchers aim to enhance osseointegration, regenerate alveolar bone and potentially replace lost periodontal tissues. This review explores the current landscape of stem cell dental implants, focusing on cell sources, scaffold technologies, clinical and preclinical studies and challenges toward clinical translation.

KEYWORDS

Stem cells; Dental implant; Osseointegration; Osteogenesis; Peri-implantitis

INTRODUCTION

Dental implants are widely used for tooth replacement, yet conventional titanium implants rely on sufficient bone quantity and quality. In cases of bone loss or systemic conditions, outcomes may be compromised. Guided bone regeneration (GBR) is one technique that is commonly used to enhance osseointegration of the surrounding alveolar bone[1,2]. Stem cell-based therapies offer an innovative solution by harnessing the body's regenerative potential to enhance bone integration and implant stability. Stem cell therapy aims to limit or reverse the failure associated with disease, trauma or treatment. Minimal donor site complications make it one of the ideal methods of reconstruction of both soft and hard tissues[3].

2. Stem Cell Sources For Dental Applications

2.1 Mesenchymal Stem Cells (MSCs): Derived from bone marrow, adipose tissue, umbilical cord. These cells possess multilineage differentiation potential and immunomodulatory properties, making them ideal for bone regeneration[4].

Various mesenchymal stem cell populations exist in the tooth. According to their position in the tooth they can be grouped as[5]:
- Dental pulp stem cells, DPSCs
- Stem cells from human exfoliated deciduous teeth, SHEDs
- Periodontal ligament stem cells, PDLSCs
- Dental follicle stem cells, DFSCs
- Stem cells from the dental apical papilla, SCAPs

3. Scaffold And Carrier Systems

Scaffolds provide structural support and a microenvironment conducive to cell adhesion and differentiation. Commonly used scaffolds include:
- **Natural Materials**: Collagen, fibrin, platelet-rich plasma (PRP)[6]
- **Ceramics**: Hydroxyapatite (HA), β-tricalcium phosphate (β-TCP)[7]
- **Synthetic Polymers**: PLGA (poly(lactic-co-glycolic acid)) , PCL Polycaprolactone[8].
- **Composite Scaffolds**: Combining biological and synthetic elements for enhanced bioactivity. Advanced scaffolds may also be functionalized with growth factors (e.g., BMP-2) or fabricated using 3D printing technologies[9].

4. Implant Surface Modification

Implant surfaces can be modified to support stem cell adhesion and differentiation. Surface modification of Ti and its alloys can greatly improve the osseointegration and antibacterial properties of biomedical implants. A variety of modification techniques can contribute to modulating the implant–bone interface and lead to better outcomes of osseointegration and/or osteogenesis. Various techniques include:
- Plasma spraying technology
- Plasma immersion ion implantation (PIII)
- Laser cladding
- Sandblasting and acid etching (SLA)
- Thermal oxidation
- Hydrothermal treatment
- Anodic oxidation (AO)
- Micro arc oxidation
- Layer by layer self-assembly
- Tremella-like ZnO

These modifications aim to improve cellular interactions and accelerate healing. The concept of "osteo-immunomodulation" has gained increasing understanding and recognition of its importance in bone healing, with emerging strategies aimed at biomaterial modifications that modulate the host immune environment to provide anti-inflammatory and anti-infective properties[10].

5. Preclinical And Clinical Evidence

5.1 Animal Studies

Numerous preclinical studies have shown enhanced osseointegration and bone regeneration when implants are combined with stem cells. Studies in canine, rabbit, and rodent models have confirmed the safety and efficacy of these methods. Many of the animal models used dogs in the studies. Dogs are a reliable model for periodontal and peri-implant research. They have tooth sizes that are comparable to humans, and they show a similar history of progression of periodontitis. Dogs have been used to examine the use of bone grafts and barrier materials in peri-implant regeneration[8].

5.2 Human Trials

Limited but promising clinical studies suggest that autologous MSCs can support alveolar bone regeneration and improve implant success rates. However, standardized protocols and long-term data are still lacking. The selected studies showed heterogeneity in the implant site chosen. Most of the studies placed implants coated with stem cells in the mandibular canine/premolar to the molar region. A few studies used the maxillary sinus region as the site of placement. Owing to the heterogeneity of the sites, the data are not comparable, as the bone quality varies with the site of placement. The amount of cancellous bone versus cortical bone varies in the maxilla versus the mandible. The mandible presents with more cortical bone than scant cancellous bone. This can contribute to increased implant stability and enhanced osseointegration. However, since a control site with an uncoated implant was used in all of the studies, such that the bias induced by the jaw of choice and the bone quality could be eliminated.

Most studies used bone marrow MSCs for coating the implant. A few studies used amniotic fluid, umbilical cord, hematopoietic, dental pulp, SHED, adipose-derived, and periodontal ligament . Bone marrow represents a good source of MSCs, with distinct surface markers that differentiate them from hematopoietic lineage stem cells. These cells have good pluripotency and can differentiate into osteoblasts in a favorable environment of induction factors, growth factors, and biological modifiers. The regenerative and differentiation

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potential of these cells is also reflected in the recruited studies. Many studies found good regeneration and osseointegration with the bone marrow MSCs. The only demerit that can be recognized is the difficulty of harnessing these cells. Obtaining bone marrow tissue requires surgical aspiration, which is painful and can involve postoperative morbidity. MSCs prove to be a viable alternative. Stem cells with adequate regenerative potential can be harvested from the teeth pulp, periodontal ligament, and gingiva. Further research is required to ascertain the potential of using dental pulp-derived stem cells for peri-implant regeneration[8].

5. Stem Cells And Peri-implantitis

Peri-implantitis is one of the leading and frequent reasons for dental implant rejection. The main etiological factor in the development of peri-implantitis diseases is a biofilm, which is a complex microbial community of numerous microorganisms. The most important long-term outcome is bone regeneration after peri-implantitis treatment[11]. Therefore, the surface should promote cell regeneration. cell adhesion ability on various dental implant surfaces subjected to different processing methods during peri-implantitis are minimal. After the surgical access and cleaning of the implant surface from the bacterial film, it surrounds blood cells and bone marrow cells, forming a temporary bioactive layer. In the second phase, osteoclasts trigger bone tissue absorption a month later. MSCs and osteoblasts migrate to the osteogenic area on the implant's surface.

6. Challenges And Limitations[12]

- **Standardization**: Variability in stem cell types, sources, and preparation
- **Safety**: Risk of immune reactions, neoplastic transformation or ectopic tissue formation
- **Cost And Complexity**: High production and regulatory costs
- **Regulatory Barriers**: Need for rigorous clinical trials to ensure safety and efficacy

7. Future Directions

- Development of off-the-shelf, allogeneic stem cell therapies[12].
- Integration of AI and 3D bioprinting in scaffold design[13].
- Scaffold-free technologies using organoids or cell sheets.
- Personalized regenerative protocols tailored to patient genetics and health status.

8. Ethics And Regulatory Policies

These therapies have to undergo testing and trials from various regulatory authorities before they are approved to be used by clinicians. The concerns over the source of stem cells for use and possible consequences of genetic changes may lead to ethical issues. Safe implementation can only be achieved when ethical rules are followed and consent procedures are clear to the patient. Financially, such treatment procedures are costly and this factor remains a roadblock to the implementation of the treatments, mainly in developing countries. Technological developments may bring about cost reductions in the future but conscious effort must be made by researchers, clinicians and policymakers to bring about such innovations[2,14,15].

9. CONCLUSION

Stem cell-based dental implants represent a promising frontier in dental and craniofacial regeneration. While significant progress has been made in understanding their potential, clinical adoption depends on addressing safety, standardization, and scalability challenges through robust scientific and regulatory frameworks. molecular enhancement by osteoinductive materials and stem-cell-based therapies can be used to improve and expedite clinical outcomes.

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