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Review Article

Changing trends in implant designs: A review

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ABSTRACT

Implantology is an ever-evolving scientific field that undergoes continuous refinement and innovation. Dedicated research and development efforts are focused on consistently improving the success rates of implants through innovative redesign and advancements. The introduction of advanced technologies has revolutionized the evaluation of patients in three dimensions, enabling clinicians to utilize precise and predictable approaches for diagnosis, planning, and treatment. This multidisciplinary patient-centric framework has opened new avenues for providing tailored and effective healthcare solutions. Therefore, it is of utmost importance for clinicians to conduct a comprehensive analysis of each patient's condition, ensuring meticulous selection of the suitable implant design and material, and making informed decisions regarding the most appropriate technique to be employed.

1. Introduction

Dental implants are widely recognized as one of the most promising and effective solutions for replacing missing teeth. With long-term success rates surpassing 90%, they have proven to be highly effective in restoring oral function and aesthetics in both partially and fully edentulous patients.[1] Thanks to the current availability of advanced diagnostic tools that assist in treatment planning, along with the ongoing research leading to improved implant designs, materials, and techniques, a wide range of challenging clinical situations can now be effectively managed with a high level of predictability and success.[2] Implant design features are vital factors that have a significant impact on the initial stability of implants and their ability to endure loading throughout the osseointegration process and beyond. These design elements play a fundamental role in ensuring the long-term stability and durability of dental implants. Furthermore, dental implants are engineered with specific textures and shapes that can promote cellular activity and facilitate direct bone apposition, facilitating successful integration with the surrounding tissues.[3]

Dental implant design has undergone significant advancements in recent years. In the past, primitive dental implants such as blade, staple, and periosteal types were used, but they had inherent biomechanical limitations, leading to high failure rates.[4] Recent advancements have brought about significant improvements in the morphology, structure, and design of dental implants, aimed at enhancing their biomechanical properties, stability, and long-term success. These developments reflect the ongoing commitment to innovation and the continuous pursuit of excellence in the field of dental implantology.

Implant design encompasses the comprehensive three-dimensional structure of the implant, including its various elements and characteristics. It encompasses factors such as form, shape, configuration, as well as the surface macrostructure and macro irregularities, all of which

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contribute to the overall attributes of the implant's three-dimensional structure.

2. Implant Shape

Implant shape directly influences the surface area available for stress transfer, playing a critical role in determining the implant's initial stability. The predominating macro structure for root-form endosseous implants is the screw shape, which consists of parallel-sided screw and the tapered screw.[2] Smooth-sided cylindrical implants offer a convenient advantage when it comes to surgical placement.[4] A tapered implant with smooth sides enables the transfer of a comprehensive load to the interface between the bone and the implant, the extent of which depends on the taper's degree. Implants with threaded design and circular cross sections facilitate easy surgical placement and enable enhanced optimization of the functional surface area to effectively transmit compressive loads to the bone-to-implant interface.[2]

3. Implant Geometry

The primary criterion for developing the treatment plan is still the size of the implant, including its diameter and length, primarily determined by the amount of available alveolar bone. For a given implant length, increasing the implant diameter will increase the implant surface area that is available for force transfer to the bone.[5] Provided there is sufficient bone volume, a larger diameter implant is better able to resist occlusal forces, particularly in the molar region. When designing the treatment plan, it is important to consider the drawbacks associated with bone augmentation, which used to be considered the "gold standard" in severe atrophy cases. These drawbacks include morbidity at the donor site, elevated risks of complications, extended time and increased costs, as well as potential resorption of the bone graft. Additionally, the advancing capabilities of smaller-sized implants should be considered when formulating the treatment approach.[6]

Several new concepts may provide other options for implantation, aiming to reduce treatment duration, minimize complication rates, and simplify the overall treatment procedure, such as:

4. One-piece Implant

In a one-piece implant the endosseous and abutment portions form a single unit. By eliminating the abutment interface, the one-piece implant enhances the strength and stability of the prosthesis. It is a suitable option for patients or surgical sites with insufficient bone to adequately support a prosthesis. In spite of these advantages, one-piece dental implants do have a limitation in terms of flexibility compared to two-piece implants. Their single-unit construction restricts the ability to make precise adjustments once placed.

The design of one-piece implants allows for uninterrupted healing of the soft tissues surrounding the implant and avoids any disruption to the soft tissue seal when placing the final prosthetic restoration.[7]

5. Mini-Implants

Compared to standard dental implants, mini-implants are characterized by their reduced diameter, typically less than 3 mm, and shorter length. Despite their smaller size, they are typically made from the same biocompatible materials as standard implants. These implants are particularly useful when achieving acceptable and satisfactory function with conventional prostheses is challenging. Clinical situations like flabby ridges, atrophic ridges, or inadequate residual bone where denture retention is less, are likely to do well with mini-implants.[8]

6. Short Implants

Placing conventional implants can be challenging in cases of atrophic alveolar ridges due to various anatomical restrictions. These include the presence of the maxillary sinus, nasal floor, nasopalatine canal, and inferior alveolar canal. These structures can limit the available bone volume and affect the feasibility of conventional implant placement. To address these and other vertical bone deficits, additional surgical procedures are often employed to facilitate the placement of standard implants. These may include guided bone regeneration, block bone grafting, maxillary sinus lift, distraction osteogenesis, and nerve repositioning. These techniques aim to augment the available bone volume, create a favorable environment for implant placement, and overcome the challenges presented by the anatomical restrictions.

Short implants are often regarded as a simpler and more effective solution for rehabilitating the atrophic alveolar ridge. By minimizing the likelihood of complications, patient discomfort, procedure costs, and overall treatment time, they offer several advantages. In this context, however, it is worth mentioning that the categorization of a dental implant as "short" is subjective, and there are no universally defined criteria for determining the specific length that qualifies as a short dental implant. Recently, less than 8 mm- long short implants have been offered by implant companies.[9]

7. Tilted and Zygomatic Implants

The utilization of a tilted or angulated implant in the posterior maxilla has been suggested as a potential alternative to sinus augmentation procedures. In the All-on-4 concept (a theory that uses four implants to restore total edentulism) for completely edentulous maxilla patients trans-sinus tilted implants are employed.

Zygomatic implants present an alternative to sinus augmentation procedures. They are lengthy implants travelling through the sinus or laterally into the sinus and are almost identical to trans-sinus tilting implants.[10]

8. Pterygoid implants

Pterygoid implants were introduced as another method of increasing the amount of bone that can be used for placement of implants in posterior maxillary region. The typical implant size for this method is between 15 and 20 mm. The implant enters the maxilla in the first or second molar region, following an oblique mesio-cranial direction. From there, the implant trajectory proceeds posteriorly toward the pyramidal process. Thereafter, it ascends between wings of the pterygoid processes and continues its course in the sphenoid bone to find anchorage in pterygoido scaphoid fossa.

The presence of dense cortical bone provides excellent engagement and stability for the pterygoid implants. That and an opportunity to obviate the requirement for maxillary sinus augmentation and other grafting procedures are two benefits of employing these implants.[11]

9. Tuberosity implants

Tuberosity implants are designed to be placed at the most distal aspect of the maxillary alveolar process, specifically targeting the tuberosity region. They are positioned to potentially engage the pyramidal process of the maxilla. Because of the dense bone present in this region, the difference in bony support for a pterygoid implant and a tuberosity implant can be significant.[11]

10. Utilizing three-dimensional printing for customized implants

The initial adoption of three-dimensional printing (3DP) for custom implants took place in the domains of rapid tooling and rapid prototyping. Digital scanning was combined with a CAD/CAM design and using 3DP, dental labs produced dental prostheses and patient models in significantly less time and with a precision that was unmatched by most traditional procedures. The combination of cone beam computed tomography (CBCT) and CAD/CAM was proposed to generate a surgical guide for precise implant placement.[12]

11. Transitional Implant

Their length varies from 7 to 14 mm, and diameter is between 1.8 and 2.8 mm. Transitional implants are manufactured using pure titanium and consist of a single-body design with a treated surface. They play an important role by absorbing the masticatory stress during the healing phase. This stress absorption helps promote a stress-free environment for the maturation of bone around the submerged implants, allowing them to heal smoothly and without complications.

Some commercially available Transitional Implant System include the Immediate Provisional Implant System–IPI by Nobel Biocare; Modular Transitional Implant System -MTI by Dentatus; and TRN/ TRI Implants by Hi Tec implants.[13]

12. Ligaplant

This technology involves the integration of periodontal ligament (PDL) cells with implant biomaterial. Research is currently being done to make this implant honourable. In Ligaplant, the PDL cells serve as a soft, vascular tissue that distributes forces, absorbs shocks, and provides proprioception for the tooth within its socket.[14]

13. Design Variables in Surface Area Optimization Thread Geometry

The market today offers a variety of implant systems with different implant thread configurations (Figure 1). The number of threads, width of the thread, depth of the thread, face angle of the thread and its pitch are among the various geometric combinations that affect final bone-implant contact (BIC) and distribution of load. A greater number of threads and increased thread depth provides greater available surface area for load distribution.[15]

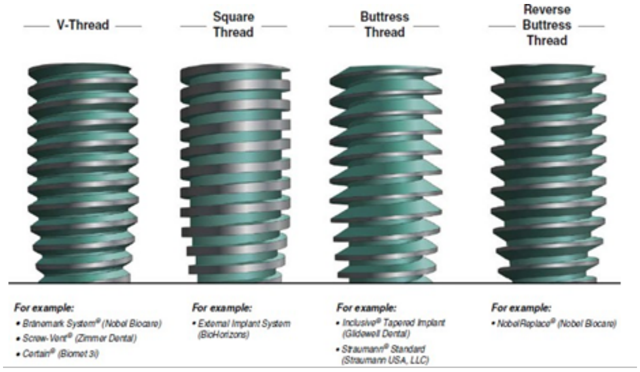

Fig. 1: Thread shapes of dental implants (V-thread, square, buttress, and reverse buttress).

Source: Grant Bullis .Functional Basis for Dental Implant Design. In: Misch,s Contemporary Implant Dentistry .4th ed. St Louis, USA: Mosby.;2021. p.48-68.

Implant threads are crucial for achieving primary stability, particularly in areas where bone quality is not good and for dissipating stresses at the bone-implant interface. This aids in minimizing the risk of complications and supports successful healing and integration of the implant with the bone.

The implant apical region should be tapered to assist insertion into the osteotomy and initial engagement of threads of the implant. It should be either rounded or flattened to reduce the probability of perforating membranes during placement. It will have flat regions or grooves circumferentially arranged on the implant body to stabilize the implant against rotation after healing and to aid in insertion.[16]

14. Implant Crest Module and Abutment (Figures 2 and 3)

Current knowledge of prosthetic connections suggests that an internal prosthetic connection offers the best functionality. Of the internal prosthetic connection types in use today, the conical prosthetic connection have the best feature set, also conical prosthetic connections provide a stable abutment connection, lower peak bone stresses when positioned level to the marginal bone, and have a high resistance to axial loads. The Morse taper implant abutment connection features a tapered projection on the abutment that fits into a tapered recess in the implant. This creates a friction fit and cold welding to prevent rotation, providing stability during function. Taper angles vary, such as 8° in ITI Straumann or Ankylos, or 11° in Astra. The Bicon implant system has rounded channels with a 1.5 degree taper. When the cross section of the implant permits, platform shifting should be used to redistribute the stress away from the bone-implant interface. Platform shifting or using abutments with a diameter less than the implant collar is thought to be advantageous to maintain marginal bone levels while providing a biomechanical advantage in osseointegrated implants as it redirects the concentration of stress, taking it away from the cervical region of bone-implant interface; with an inverse relationship between the amount of implant-abutment diameter mismatch and cortical bone stress concentration.

Angled abutments, UCLA Abutment, Ceramic abutments, CERADAPT Abutment, and Multi- Unit abutment are recent advancements in implant abutments.[17]

Fig. 2: a): CAD/ CAM custom abutments. Left to right, posterior milled titanium abutment, anterior milled titanium abutment, and hybrid milled zirconia bonded to titanium abutment base. **b):** Multiunit abutments with screws.

Fig. 3: a): Stock/standardized healing abutments **b):** Custom healing abutment with ideal contours.
Source: Park NI, and Kerr M. Terminology in Implant Dentistry. In: Misch,s Contemporary Implant Dentistry .4th ed. St Louis, USA: Mosby.;2021.p.20-4

15. Implant Materials

Dental implants have been tested using various materials, including metals, alloys, ceramics, polymers, glasses, and carbon. Biocompatibility, bio functionality, availability, and the ability to Osseo integrate are specific characteristics needed for their manufacturing.

Materials for dental implants and the prosthetic components they support must adhere to several strict requirements. For dental implants, titanium alloys continue to have the finest mechanical and biocompatibility qualities, and their usage is recommended. Currently, commercially pure titanium, titanium alloys, and zirconia (zirconium dioxide, ZrO_2), ceramic implants are the representative biomaterials in wide use for dental implant applications. Additional other advanced material are Zirconia Toughened Alumina (ZTA) and Alumina Toughened Zirconia (AZT), Poly-Ether-Ether-Ketone (PEEK), Powder Injection Molding (PIM), Tantalum Implants, Porous Tantalum Trabecular Metal (PTTM), LASER- LOK Technology.[18]

16. Surface Modification of Implants

Research has shown that microrough surfaces had higher degrees of bone-to-implant contact or BIC. These modifications can be divided into subtractive and additive processes, depending on whether material is removed or deposited on the implant surface in the development of the surface.[19] Plasma arc is an additive process that involves depositing a bioactive hydroxyapatite (HA) material onto the implant surface. Polishing, machining, and acid etching are subtractive procedures used for implant surface treatment. These treatments can be classified into various methods, including mechanical, chemical, electrochemical, electropolishing, vacuum, thermal, and laser techniques (Figure 4). Various modifications have been implemented to enhance the biological surface of dental implants, aiming to achieve optimal bone-to-implant contact.[20]

Surface treatments involving calcium deposition have shown increasing bioactivity over time, with the highest deposition observed in the sandblasted, acid-etched, and thermally oxidized group. This is in lieu of greater surface roughness that promotes cell adhesion, proliferation, and differentiation.[20]

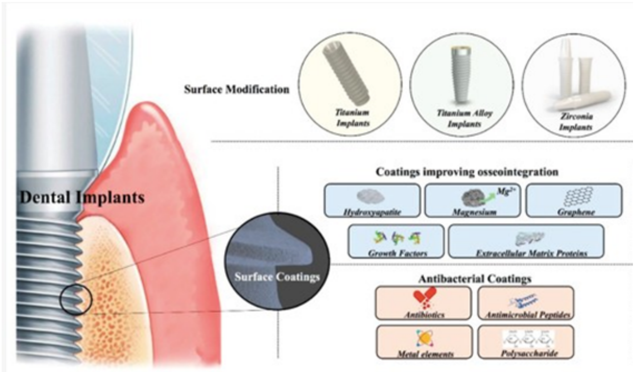

Fig. 4: Schematic illustration depicting surface modification and coatings of dental implants Source: Dong H, Liu H, Zhou N, Li Q, Yang G, Chen L, MouY. Surface Modified techniques & Emerging Functional Coating of Dental Implants. Coatings 2020, 10(11),1012:3-25

Recent studies have explored bioactive surface modifications of dental implants using inorganic materials (e.g., HA, calcium phosphate), growth factors, peptides, and extracellular matrix components. These approaches aim to enhance implant osseointegration and improve biological responses.[20] Research has shown the potential of utilizing stem cell-mediated bone regeneration for the treatment of peri-implant defects. However, stem cell implant technology is still in its early stages and is not currently a viable option for replacing missing teeth. Ongoing research hopes to enhance these techniques and develop more cost-effective procedures involving stem cells.[21]

17. Current Technologies for Implant Design and Placement Analysis

The success of dental implantation depends on accurate imaging. Cone Beam Computed Tomography (CBCT) utilising three-dimensional images is one of the newest technologies in dentistry imaging. This technology offers a continuous flow of data that allows dental surgeons to reconstruct images as needed, while minimizing radiation exposure for patients.[22,23]

18. Current developments in computed tomography technology include

1. (a) *Cone beam Computed Tomography:* This technology utilises a cone shaped beam of radiations. The image is reconstructed with special software. Comprehensive information like a Computed Tomography is obtained, albeit with 1/8th of radiation exposure and at minimal cost.
   (b) *Microtomograph:* This device helps in obtaining serial sections of the interface between implant and bone.
   (c) *Multislice helical CT:* This device has the advantage of providing high quality images when compared to Computed Tomography. It is referred as Dentascan Imaging.
   (d) *Interactive Computed Tomography:* This device develops image files that can be transferred from Radiologist to dentist's computer, who can work upon the case with precision and ease. Both the dentist and the radiologist work together and simulate placement of cylinders of arbitrary sizes in images, replicating root form implants, allowing for virtual surgical planning and an "Electronic Surgery".
   (e) *Magnetic resonance imaging (MRI):* This 3D non-invasive imaging method uses an electronic image acquisition process where image is produced digitally.

Better stability is made possible by the shape and configuration of implants, which is essential for the osseo-integration process. Refinement of drilling machines has led to better control over drilling speed and associated torque, which reduces risk of overheating the surrounding bone.[24] Improved control of water irrigation and the incorporation of internal implant irrigation systems also play a crucial role in minimizing the elevation of bone temperature during implant procedures. Additionally, the use of custom-made surgical splints, guided by CT data, assists in accurately defining the implant location and angulation, ensuring precise and optimal placement.[25]

Dental professionals and specifically prosthodontists have greater concern of the occlusal load on given prosthesis. Achieving precise dental implant alignment and connecting implants in a triangular configuration is crucial for the successful placement of fixed bridges in some cases. This configuration enhances stability and helps to resist lateral displacement forces.[26]

19. Peri implant surgery

It is common for tooth loss to be accompanied by the simultaneous resorption of the alveolar bone. As adequate implant width and length are crucial for long-term success of any implant, cases with insufficient remaining bone often pose a problem. The volume of the bone can be increased by varied techniques. For slight depressions, a simple onlay bone graft can be used while an inlay bone graft can be employed where a sandwich osteotomy is required. Maxillary sinus floor augmentation can be used to increase bone volume in the upper jaw. Distraction osteogenesis is also a state-of-the-art procedure used for augmenting areas of bone. Now a days, osteo-inductive and osteo-conductive substances can help accelerate the healing process. Vestibuloplasty and palatal graft transplant are getting popular in cases where ablative surgery or tissue atrophy decreases the amount of available soft tissue. Free gingival graft transplant is a simpler procedure that produces less overall patient morbidity. Thus, the issues linked to either the soft tissue or bone deficit around the implant can likely be treated by combining several peri- implant operations.[27,28]

20. Image Guided Implantology

Image-guided implant surgery has experienced remarkable advancements in recent years. It involves two main types that utilize dedicated software for precise implant planning to define implant angulation and position, while avoiding contact with the maxillary sinus or with the inferior alveolar nerve. While one procedure consists of real-time navigational implant surgery, the other inserts implants using a surgical splint created using stereo lithography.[29]

Computer-designed surgical splints significantly expedite the implant placement process. However, any errors in planning or splint fabrication cannot be easily corrected during surgery. In such cases, surgeons may need to forgo the use of the splint altogether, potentially leading to incorrect implant placement.[30]

21. Conclusion

The future of dental implantology holds immense potential through continuous innovation and progress. Areas such as biomaterials, implant design, surface modification, and functionalization are critical for improving patient care and enhancing treatment outcomes. Advancements at every stage, including diagnosis, treatment planning, surgery, grafting, and implant designs, are essential for achieving successful long-term results in restoring missing dentition. By focusing on these areas of improvement, we can strive towards better patient outcomes and advancements in dental implant technology.

22. Source of Funding

None.

23. Conflict of Interest

None.

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