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REVIEW ARTICALE

EVOLUTION OF DENTAL IMPLANT AND IMPLANT SURFACE TREATMENTS- A NARRATIVE REVIEW

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ABSTRACT

Dental implants have undergone remarkable evolution over the past decades, transforming from simple experimental devices to highly predictable treatment modalities in modern dentistry. The earliest concepts of implantology were rooted in the search for biocompatible materials and mechanical stability, eventually leading to the revolutionary discovery of osseointegration. Since then, continuous advancements in implant design, surface morphology, and surface treatments have greatly enhanced clinical success rates. Early implants relied on smooth, machined surfaces, but clinical limitations such as longer healing times and unpredictable outcomes drove the development of modified surfaces. Techniques including sandblasting, acid etching, anodization, plasma spraying, and bioactive coatings have been introduced to improve bone–implant contact, accelerate osseointegration, and increase long-term stability. Recent innovations focus on nanostructured modifications, biomimetic approaches, and surface functionalization with growth factors, aiming to integrate biological and technological principles for superior clinical performance. This review highlights the historical progression of dental implants, the scientific rationale behind different surface treatments, and their clinical implications. Understanding these developments provides valuable insight into current trends and future directions in implant dentistry, emphasizing the role of surface engineering in optimizing osseointegration and enhancing patient outcomes.

***Keywords**:* Dental implants, Osseointegration, Surface modification, Nanotechnology, Implantology

INTRODUCTION

Tooth loss has long been a challenge for humans, inspiring restorative attempts across civilizations. From ancient prosthetic practices using shells and ivory to today's sophisticated titanium implants, the pursuit of stable, functional tooth replacement reflects centuries of innovation [1,2].

A crucial turning point occurred with the discovery of osseointegration, establishing dental implants as a predictable therapeutic option. The role of implant surface design and modification has since become central to enhancing bone-implant interaction, reducing healing times, and improving long-term clinical performance. This review traces the historical development of dental implants, with emphasis on the evolution of surface treatments and their clinical significance. [3,4]

Historical Background

Early Civilizations and Primitive Restorations:

Archaeological evidence shows that Egyptians, Etruscans, and Mayans experimented with tooth replacement. Seashells, ivory, and stones were placed in alveolar sockets, while gold wires stabilized mobile teeth. The Mayans, around 600 AD, are credited with some of the earliest functional dental implants using carved shell fragments [5, 6].

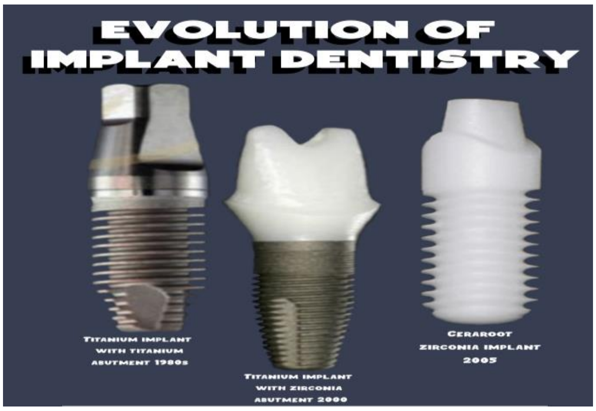
Early Scientific Attempts (16th–19th Century): During the Renaissance, attempts to transplant cadaveric teeth became common. In 1809, Maggiolo reported placing a gold tube into an extraction site, though it resulted in severe inflammation. Later efforts included implants made of porcelain, silver, and iridium, reflecting ongoing trials with material compatibility [7, 8].

20th Century Innovations: Significant progress occurred in the early 1900s. In 1913, Dr. EJ Greenfield introduced a lattice-style iridio-platinum implant. The Strock brothers later tested Vitallium screw-type implants in both animals and humans. The mid-20th century saw the introduction of subperiosteal implants and early endosseous designs such as spiral and screw-shaped implants, laying the foundation for modern systems. [9, 10]

The Branemark Revolution: The defining milestone came in the 1950s when Per-Ingvar Brånemark discovered osseointegration while studying bone healing in rabbit models. By the 1960s, he successfully applied titanium screw implants in humans, establishing a long-lasting and predictable solution. His work formalized osseointegration as a direct structural and functional connection between living bone and titanium, revolutionizing implant dentistry [11, 12].

Milestone era of Dental implants

A two-stage threaded titanium root-form implant was introduced by Dr. P. Branemark in 1978. He also created and tested a method using pure titanium screws, which he referred to as fixtures.[13] These were the earliest, best-documented, and longest-lasting dental implants to date when they were originally implanted in his patients in 1965. Severe chin and jaw abnormalities, congenitally absent teeth, and misaligned teeth were present in Branemark's first case. The mandible underwent four implants. These implants took six months to integrate and stayed in place for the following 40 years. [13,14] When he implanted titanium chambers in rabbit femurs to study blood flow, he made this discovery by accident in 1952; over time, the chamber became firmly affixed to the bone and could not be removed.[12] In fact, the titanium surface connected with the bone. In reality, if a fracture did take place, it always happened between bones rather than between the bone and the implant. He used this concept to the field of dentistry. With the help of his implant, the term "osseointegration" and the belief that dental implant education may be added to dentistry school curricula were created. Branemark clarified and extended this phrase further, defining it as "a direct structural and functional relationship between organized, living bone and the surface of a load-bearing implant." The Branemark implant was first designed as a cylindrical one; later variations took on tapered shapes. After the Branemark implant, numerous other implant types were developed, such as the IMZ implant, the Stryker implant, the CoreVent implant. [14, 15] and the ITI-sprayed implant.



Trending of titanium implants

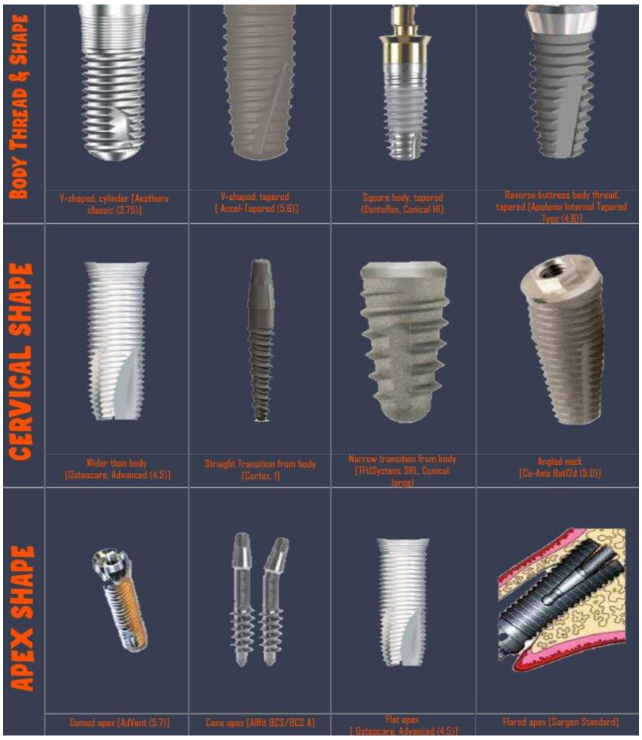
The endosseous root form implant was the type of implant that many dental professionals employed in the middle of the 1980s. In the early 1980s, Dr. Tatum developed the omni-R implant, which has horizontal titanium alloy fins. [16] Core-Vent Hollow Threaded Implant and Screw-Vent Implant with Hydroxyapatite Coating were both developed by Dr. Niznick. He began adding new technologies, such as Micro-Vent and Bio-Vent. [17] The root form endosseous implant was soon after introduced by Dr. Driskell in the 1980s in two variations: one coated with titanium alloy and the other with hydroxyapatite. Early in the 1980s, the calcite firm began producing calcitite, a synthetic polycrystalline ceramic hydroxyapatite. [18] The Straumman Company first offered an integral ITI implant system in 1985. The device comprises of plasma sprayed cylinders and screws which are designed to be placed in one stage procedure.

The use of titanium (Ti) dental implants and the procera (Nobel Biocare, Zurich, Switzerland) computer-aided design and computer-aided manufacture (CAD/CAM) method of high precession were both approved by the US Food and Drug Administration in 1982 and 1983, respectively. The development of materials and methods to increase quality and anchoring has made remarkable progress. In order to improve osseointegration, ceramic surface treatments have been integrated by manufacturer companies since the advent of contemporary ceramics in 1992. [19,20]

Evolution of Dental implant Surface coatings

The nature of the implant surface determines the response and has an impact on the mechanical strength of the implant tissue interface since the surface of dental implants is the only component that comes into contact with the bio-environment. The first osseointegrated dental implants had a machined or smooth machined surface.

These implants have surface markings from the devices used in their development and were cleaned and decontaminated. These surface flaws aid in the bonding of bone cells to the metal. Dental implants with machined surfaces have the drawback that bone-forming cells frequently migrate to the surface grooves. [21-23] The major goal of modifying dental implant surfaces is to speed up osseointegration healing. The surface treatment increases the functional surface area of the implant bone interface so that the stress is effectively distributed. Moreover, the surface treatment promotes bone apposition and influences the cytokine and growth factor production. [24,25] Various surface treatments include mechanical treatments; that is machining and grit blasting, acid etched chemical treatments, anodic oxidation through electrochemical treatments, thermal treatments and laser treatments.[26]



Hydroxyapatite coating and titanium plasma sprayed coatings

Hydroxyapatite (HA) has the ability to create robust connections between the implant and the bone. Recent research suggests that nano-hydroxyapatite-coated surfaces in the transmucosal area are just as compatible as pure titanium surfaces. [27,28] However, the possibility that the hydroxyapatite may experience resorption and additional deterioration, ultimately leading to the loosening of the titanium particles, has been documented in situations with plasma sprayed coatings. Composite coatings, titanium nitride coatings, carbon, glass, and ceramic coatings are examples of additional coating surfaces.

The thickness of the coating on the implant can be controlled to be between 40 and 50 micrometres using plasma spraying coating, which includes injecting powdered forms of titanium into the plasma torch at high temperatures. On the implant surface, this particle subsequently condenses and fuses together, increasing the production of TGF-beta 1 and inducing mineralization nodule. However, the plasma sprayed approach has a number of disadvantages, including irregular layer thickness and poor long-term coating adhesion.

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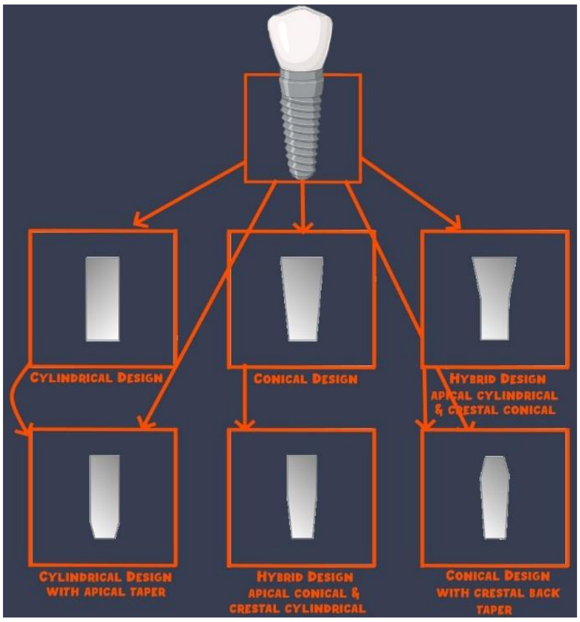
Sandblasted and etched implants

The formation of sandblasted and acid-etched implants involves a protracted blasting procedure, followed by etching with sulfuric and hydrochloric acids. For the blasting process, large grit titanium or alumina particles are utilized. This leads to surface abrasion with excellent bone integration. Compared to machined implants, titanium implants with alumina and titanium particles of 25 micrometre and 75 micrometre diameter promoted superior bone growth. [31-34]

Electrochemical dental implant surface treatment

Electrochemical anodic oxidation works first began in the 1950s. Using anodic oxidation, ceramic TiO_2 layers with thicknesses ranging from hundreds of nanometers to hundreds of micrometres can be formed on titanium substrates. Currently, titanium-based devices that have calcium phosphate molecules added to them have been used in clinical settings. Due to its many benefits, including its ease of use and low cost, ability to improve coating adhesion, interfacial bonding, and corrosion resistance, and ability to increase mechanical compatibility of the coating by creating porous structures with excellent cell colonization potential, anodic oxidation has gained popularity in recent years in the surface modification of titanium. [35,36]



Laser and growth factor treatments

Another technique to improve bone-to-metal interactions is surface preparation by laser ablation of dental implants. This process produces titanium microstructure surfaces that are extremely hard, highly resistant to weakening, have exceptional roughness, and have an enhanced oxide layer.[37] According to biological studies, there are grooved surfaces that facilitate cell adhesion and control how they grow [38].

On titanium implant surfaces, growth factors include bone morphogenetic proteins (BMPs), platelet-derived growth factor (PDGF), and TGF-beta 1 promote bone repair.[39] Goats have been used to study the effects of applying TGF- beta1 to calcium-phosphate implant surfaces.[40-43] The disadvantage in the use of growth factors in treating the surfaces of implants is that the active growth factor has to be released over a period of time.[44]

Current implant design trends

1. **Analyzing with finite elements (FEA)**

In order to analyze the jaw bone and the boning-implant interface and to optimize implant design so that it functions in accordance with bone stress distribution, FEA has become a widely used technique in implant dentistry. To forecast the properties of the stress distribution in bone within physiological bounds, it comprises of three-dimensional models. [45]

2. **CAD/CAM modern dental implant technology**

Employing three-dimensional printing, a personalized implant (3DP) was initially applied to quick prototyping and tooling. In the beginning, 3DP produced unique, customized items for restorative dentistry. Dental labs can generate dental prostheses (crowns, bridges) and plaster/stone models more quickly and with good precision by integrating oral scanning with a CAD/CAM design and employing 3DP thanthe majority of traditional techniques carried out by lab staff. [46]

The use of CAD/CAM as a supportive tool to enhance the outcomes of implant therapy has increased with the development of implant dentistry. For challenging circumstances where traditional abutments might not offer a good choice for a future prosthesis, customized implant abutments have been successfully manufactured utilizing CAD/CAM

Complex shaped implants and abutments have been produced using CAD-CAM technology. The accuracy of these methods is improved. [47-48]

The use of cone beam computed tomography (CBCT) combined with CAD/CAM was suggested to produce a surgical guide for implant placement

3DP and CAD/CAM have been involved in practically every area of implant dentistry. When a patient needs an implant to replace a single tooth, the tooth must be extracted during the initial procedure, and only then may the implant be placed during a subsequent procedure. To avoid the need for a second surgery and to allow for quick implantation, it would appear more efficient to have the personalized implant ready before tooth extraction. [49]

3. Implants made with nanotechnology

For dental implants, nanotechnology-based developments include biomimetic calcium phosphate coatings, the addition of growth hormones to speed up bone repair, and surface roughness modification at the nanoscale level to improve protein adsorption and cell adhesion. [50]

Only a few research have revealed changes to the roughness as well as the chemistry at the nanoscale scale in a repeatable manner, despite the fact that most attempts to obtain Nano roughness have used processing techniques such lithography and surface laser-pitting. Another strategy is to coat Ti surfaces with nanoparticles such as biomimetic calcium phosphate, alumina, titania, zirconia, and other minerals. Additionally, to boost up the local bone-healing process, Ti dental implants can also be coated with bone-stimulating substances like growth factors (such as transforming growth factor-, bone morphogenetic proteins [BMPs], platelet-derived growth factors, and insulin-like growth factor [IGF]-1 and 2) and antiresorptive medications (bisphosphonates). [50-51]

Various nanoparticles used in dental implants and their applications are shown in table 1.

Table 1. Various Nanoparticles and its applications in Dental Implants

Nanoparticle	Utilization method	Application	References
Silver	1. A layer of 9.3, 21.3, and 98 nm thickness coated on the enamel surface 2. Coated as a colloidal. 3. Coating of Sliver and amorphous nanoparticles of the synthetic calcium phosphate. 4. Improved by chitosan with fluoride mixture, and placed as a colloidal suspension yearly one-time	Anti-bacterial treatments Antibacterial treatment Resin-composite fixatives Mouth-freshener	Espinosa-Cristóbal et al., 2013[52] Huang et al., 2011[53] Cheng et al., 2012. [54] Dos Santos et al., 2014[55]
Zirconium oxide	1. Coating material + Nano-hydroxyapatite 2. Coated with Ca/PO4 3. Inclusion into dental resins 4. Anti-bacterial agents for peri-implantitis 5. Inclusion into dental cement	Dental implant Cement sealants Resins-composite fixatives Dental cement Treatments of antibacterial implant	Memarzadeh et al., 2015 [56] Osorio et al., 2014[57] Kasraei et al., 2014[58] Vargas-Reus et al., 2012[59] Guerreiro-Tanomaru et al., 2014 [60]
Titanium dioxide	1. conjunction with bright-healing orthodontic paste 2. nanotubes integrated into ZnO NPs on Ti surfaces 3. Adhered in the same liquid to improve hydrogen peroxide bleaching performance	In Resins composites fixatives Implant. Bleaching agents	Poosti et al., 2013[61] Liu et al., 2014[62] Martín et al., 2015[63]
Cuprous oxide	1. Relative to TiO2, Ag + CuO, Ag + ZnO & also WO4 which compositions had anti-microbial impact.	Resins-composite fixatives	Vargas-Reus et al., 2012[64]
Chitosan-particles	1. Combined with silver NPs 2. It's being used as a chelating agent in a nano-hydroxyapatite-coated Ti implant	Resins-composite fixatives Implants	Targino et al.,2014[65] Kim et al., 2013[66]
QAC Nanostructures	1. Coated as a quatemarian ammonium compound with 2. An organosilane, silicon NPs, and epoxy silicate 3. Resin composite materials as a cross-linking quintenary ammonium polyethyleneimine (QPEI)	Resins composite fixatives Resins composite-materials	Gong et al., 2014 [67] Beyth et al., 2010[68-70]

The journey of dental implants reflects a rich convergence of material science, biomechanics, and clinical ingenuity. What began with primitive attempts using natural substances has evolved into highly engineered titanium systems that define modern implantology.[1-10] A turning point came with Brånemark's discovery of osseointegration, which laid the biological groundwork for predictable and long-lasting implant success.

Among the many factors influencing implant performance, surface modification stands out as particularly impactful. Techniques like sandblasting, acid etching, anodization, and plasma spraying has each contributed to improving bone–implant contact and speeding up integration.[10-20]

Yet, none are without drawbacks—plasma-sprayed coatings, for example, may struggle with adhesion over time, while hydroxyapatite layers can degrade under certain physiological conditions.[20-25] Emerging technologies such as nanostructured surfaces and biomimetic coatings are pushing the boundaries of implant design. By incorporating nanoparticles, growth factors, and bioactive agents, researchers aim to recreate the bone's natural microenvironment and enhance cellular interactions. These innovations are promising, but they also raise important questions about long- term safety, cost, and clinical viability questions that demand thorough investigation.[25-40]

Despite the growing array of surface treatments, direct comparisons between them remain scarce. Few studies have rigorously evaluated different approaches under consistent clinical conditions. Meanwhile, digital tools like CAD/CAM and finite element analysis has refined implant design, but their influence on biological outcomes is still being explored.[40-70]

This review highlights the importance of bridging laboratory advances with clinical realities. Moving forward, collaborative research efforts should focus on well-designed clinical trials, longitudinal studies, and systematic reviews to guide evidence-based decisions in surface treatment selection.

Summary and future research

In conclusion, the history of dental implants has been a stunning and fascinating journey of growth and progress. One can only pause and marvel at how inventive man has been throughout the ages in this area of research and investigation. A variety of materials, including gold ligature wire, shells, ivory, chromium, cobalt, iridium, and platinum, were initially used to create dental implants. The gaps once held by natural teeth have been filled with a range of structures, from spiral stainless steel implant designs to double helical inventions and endosseous root shapes, thanks to the swift and tenacious work of dental researchers and doctors. Dental surfaces were also modified to hasten the healing of osseointegration.

Hydroxyapatite, composites, carbon, glass, ceramic, and titanium oxide were all used to create changed surfaces. Dental implant research has advanced over time, and new materials, shapes, and surface coatings have been developed to offer people the greatest tooth replacement options for their immediate and long-term need.

DECLARATION

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no conflict of interest.

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