Kumar Adarsh¹, Shubhanjali Sharma², Prashant Malik, Anubhav Sharma⁴, Mallika Sethi⁵ and Dr. Himanshu Thukral*⁶

¹3rd Year, PG Student, Department of Orthodontics, I. T. S Dental College, Muradnagar, Ghaziabad, U.P.
²2nd Year, PG Student, Department of Orthodontics, I. T. S Dental College, Muradnagar, Ghaziabad, U.P.
³MDS, Oral and Maxillofacial Surgeon, Private Practitioner, Ahmedabad, Gujarat.
⁴Senior Lecturer, Department of Public Health Dentistry, I. T. S Dental College, Muradnagar, Ghaziabad, U.P.
⁵Associate Professor, Department of Periodontics and Oral Implantology, I. T. S Dental College, Muradnagar, Ghaziabad, U.P.
⁶Oral and Maxillofacial Surgeon, CEO Sarita Dental Care, Delhi.

ABSTRACT

The science of implantology is highly dynamic. Ever since its introduction into the field of dentistry by Dr. Branemark, it has undergone numerous modifications and improvements. With each improvement and advancement made, implantology has proved to be a boon in disguise to the society and hence its acceptance by the general population has widely increased despite it being a relatively expensive treatment modality. This article gives a brief review of the current concepts and the possible future trends in the field of implantology.

KEYWORDS: Future trends, implantology, recent advances.

INTRODUCTION

The key features and the prime requisites of an ideal prosthesis for the rehabilitation of the stomatognathic system include the restoration of normal contour, function, esthetics, comfort, speech, and health. Assimilation of these features in any prosthesis delivered to the patient is the ideal goal of modern dentistry. However, with the highly complicated and challenging
clinical situations which are commonly encountered in the general practice, an ideal replacement of the lost tissues using the conventional techniques may not be always possible. Answer to such a clinical would probably be implant therapy.\[1\]

Implant dentistry is unique because of its ability to achieve an ideal replacement of the lost tissues, regardless of the atrophy, disease, or injury of the stomatognathic system. This has significantly increased the acceptance of osseointegrated supported prosthesis by the patients. However, greater the destruction of the stomatognathic system, the more challenging is the task of rehabilitation. As a result of the current availability of the advanced diagnostic tools which aid in treatment planning, the improved implant designs, materials, and techniques as a result of continuous research, many challenging clinical situations can be successfully managed with predictable success.\[1\]

**Future of Osseo integrated Oral Implants**

New developments of oral implants have, generally, been focused on changes in the hardware of the implant, that is new materials, designs or surfaces have been introduced with simultaneous claims of these been superior to those used in the past. The bioactive implants-devices capable of implant to bone chemical bonding have become more and more popular. The main advantage of chemical bonding is that it is rapid in contrast to biomechanical bonding. The development of new ceramic material has allowed the manufacture of implants as well as crowns from ceramics thus enhancing esthetics.\[2\]

If we base our look at the future on what is known today, there are obvious ways to improve clinical results. Although the main focus in the past had been on the hardware parameters, the present authors foresee a substantial development in the realization of the importance of software parameters such as surgery and prosthodontics.

Improvement in the surgical technique seems to be a reliable way of increasing oral implant success. The future of Osseo integrated implants will mean greater understanding of the important contributions by the responsible surgeon and prosthodontists. With increasing knowledge, almost all of the problems will be overcome in the future decades.\[3\]

**Surface Treatments in Titanium Dental Implants for Rapid Osseo integration**

In the past 20 years, the number of dental implant procedures has increased steadily worldwide, reaching about one million dental implantations per year. The clinical success of
oral implants is related to their early Osseo integration. Geometry and surface topography are crucial for the short and long-term success of dental implants. These parameters are associated with delicate surgical techniques, a prerequisite for a successful early clinical outcome. After implantation, titanium implants interact with biological fluids and tissues. Direct bone apposition onto the surface of the titanium is critical for the rapid loading of dental implants.\[4\]

There are two types of response after implantation. The first type involves the formation of a fibrous soft tissue capsule around the implant. This fibrous tissue capsule does not ensure proper biomechanical fixation and leads to clinical failure of the dental implant. The second type of bone response is related to direct bone-implant contact without an intervening connective tissue layer. This is what is known as Osseo integration. This biological fixation is considered prerequisite for implant-supported prostheses and their long term success. Regardless of high success rates shown by longitudinal studies, failures do occur. The cause of these failures is in large attributable to failure in bone formation in support of Osseo integration. Besides other parameters, implant surface characteristics are factors affecting the rate and extent of implant bone response as well as the mechanical quality of the bone/implant interface. Nevertheless, there is evidence for implant-bone integration by surface modification. Therefore, optimization of the implant surface is a dynamic field in experimental and clinical implant dentistry which will finally result in new products.\[5\]

Immediately following implant placement, a series of events occurs between the host and implant surfaces. In a few words, chemical and physical properties such as ionic composition, hydrophilicity and surface roughness are parameters that play a major role in implant-tissue interaction. Therefore, distinctive alterations of implant surfaces may lead to different and unique chemical as well as physical properties, and might potentially lead to changes in the bone-to-implant reaction.\[2\]

**Chemical Composition of the Surface of Dental Implants**

It is well known that the composition and charges are critical for protein adsorption and cell attachment. For e.g. the surface chemical composition of titanium implants affects the hydrophobicity of the implant surface. Highly hydrophilic surfaces seem to be more desirable than the hydrophobic ones because of their interactions with the biological fluids, cells and tissues. In a recent animal study, Buser et al found that a hydrophilic SLA sand blasting followed by acid etching surface gave higher bone to implant contact than machined surface.
Recently, it was also shown in an animal model that a hydrophilic sand-blasted, acid-etched (SLA) implant surface yielded higher bone-to-implant contact than a regular SLA surface.\(^6\)

Various methods have been developed and tested in order to coat metal implants, e.g. plasma-spraying, sputter-deposition, sol-gel coating, electropheric deposition or biomimetic precipitation. Till now, plasma-spray coating, magnetron-sputtering and more recently sol-gel deposition of nano-sized CaP crystals have been used to coat titanium dental implants in clinical implants.\(^6\)

Many researchers recommended various procedures for improving the surface energy or surface characteristics of the implants to improve the osseointegration.\(^7\)

**METHODS**

- Plasma sprayed titanium
- Plasma sprayed hydroxyapatite
- Sand blasting
- Sand blasting and acid attack
- Anodization
- Electrophoretic deposition
- Sol gel deposition (dip coating)
- Pulsed laser deposition

**Future Trends in Dental Implant Surfaces**

A few strategies should be considered in order to improve both the short and long-term osseointegration of titanium dental implants. These future trends concern the modifications of surface roughness at the nanoscale level for promoting protein adsorption and cell adhesion, biomimetic calcium phosphate coatings for enhancing osteoconduction and the incorporation of biological drugs for accelerating the bone healing process in the peri-implant area.\(^8\)

The main objectives for engineering new dental implant surfaces is to improve the clinical performance in areas with low bone quantity or quality, to predict the clinical outcome of immediate or early loading protocols and to stimulate vertical and horizontal bone growth in order to permit implant placement in sites that lack sufficient height and width of the residual
alveolar ridge. Efforts have focused on the development of new surface technologies and surface characteristics.\[9\]

'New techniques' to deposit Cap (calcium phosphate) coatings onto titanium implant surfaces

Cap ceramics are known for their bioactive properties. Generally, bioactive materials interact with surrounding bone, resulting in the formation of a chemical bond to this tissue ('bone-bonding'). From a commercial point of view, the most successful method to apply Cap coatings to titanium implants has been the plasma-spraying technique. Although the osteoeoinductive and bone-bonding behavior of plasma sprayed coatings is confirmed by numerous studies, serious concerns related to plasma spraying - like poor control of chemical and physical coating parameters - are still not solved. Therefore, researchers have been investigating alternative or complementary techniques to deposit Cap coatings onto titanium implant surfaces.

Because of the huge number of new Cap coating techniques, we decided to discuss only animal data regarding mechanical testing and/or bone-to-implant contact for PLD (Pulsed laser deposition), sputter coating, IBAD (Ion Beam Assisted Deposition), ESD (Electrostatic Spray Deposition) and biomimetic deposition.\[8\]

**PLD (Pulsed laser deposition)**\[9\]

PLD is a physical vapor deposition technique and was widely used during the last decade to deposit thin films of materials of technological interest. In principle, PLO technology is based on the irradiation of a solid target by a focalized pulsed laser beam resulting in a gaseous cloud. In this cloud, plasma composed of electrons, atoms, ions, molecules, clusters and in some cases, droplets and target fragments expands either in vacuum or in a gaseous environment and deposits on a substrate, giving rise to a film. The particles have a high kinetic energy, allowing them to interact effectively with a reactive gas, if present within the deposition chamber. They also have great mobility on the deposition substrate, avoiding the necessity for a high substrate temperature. In the interaction between the target and the laser beam, many different thermal and electronic mechanisms are involved, but in general the composition of the gaseous phase is often very different from that found in thermal equilibrium vaporization allowing the deposition of materials with a complex stoichiometry. Although in vitro experiments indicated that PLD might be a suitable technique to coat titanium implants with thin Cap films, only a very limited number of peer-reviewed
publications are available dealing with in vivo studies. However, the available studies indicate that PLD CaP-coated implants resulted in a favorable bone response compared with non-coated implants.

Sputter Coating\textsuperscript{[10]}
Sputtering is a process whereby atoms or molecules of a material are ejected in a vacuum chamber by bombardment of high energy ions. The particles dislodged in this way deposit on a substrate placed within the vacuum chamber. Several sputter techniques are described, whereby radiofrequency (RF) magnetron sputtering is largely used to deposit thin films of CaP coatings on titanium (experimental) implants.

IBAD (Ion Beam Assisted Deposition)\textsuperscript{[11]}
IBAD is, besides RF magnetron sputtering and PLD, a third vacuum deposition technique to deposit thin ceramic coatings on metals. Typically, IBDA involves one or two ion beam sources that impinge a bioceramic target to produce an elemental cloud towards the surface of a substrate. This condition results in CaP coatings normally ranging from a few angstroms to several micrometers thick.

ESD (Electrostatic Spray Deposition)\textsuperscript{[12]}
The basic principle of ESD as a technique for applying CaP coatings onto titanium implant surfaces is the generation of an aerosol out of organic solvents containing calcium and phosphate ions. Under the influence of a high voltage, the aerosol is directed toward a heated substrate. Evaporation of the solvent results in the intended CaP coating on the substrate. The major advantages of this technique include the control over the chemical composition and over the morphological properties of the CaP coating.

Biomolecules coated onto titanium implant surface\textsuperscript{[13]}
ECM peptide sequences or proteins coated onto titanium implant surfaces. The fundamental role of the ECM for osteoblast function is the starting point to functionalize titanium implant surfaces with native or synthetic molecules based on peptides, proteins and growth factors found therein. Cell-to-ECM contact is mediated by cell adhesion receptors, e.g. integrins. Integrins bind to specific amino acid sequences, in particular to the RGD sequence found not only in type I collagen, but also in fibronectin, vitronectin, osteopontin and bone sialoprotein.
In addition, as bone is composed of an organic matrix (90% collagenous proteins), strengthened by an inorganic CaP phase (carbonate hydroxyapatite), research has focused on the development of bio-inspired composite coatings that resemble the unique nano-composite structure bone tissue, thereby offering an added value over coatings consisting of merely organic or inorganic components. Composite coatings made of both collagen and CaP have therefore generated a great deal of interest for implant surface modification.

**Surface roughness at the nanoscale level**[14]

The chemistry and roughness of implant surfaces play a major role in the biological events that follow implantation. Only a few studies have reported modifications to the roughness as well as the chemistry at the nanometer scale in a reproducible manner. Most of these attempts have used processing methods from the electronic industry such as lithography and surfaces laser-pitting. In vitro experimental studies, have demonstrated that the attachment of osteoblastic cells was enhanced on submicron scale structures but not on smooth surfaces. Well-developed filopodia directly entered nanometer sized pores for the initial attachment of the osteoblastic cells. These nanometer structures may also give the cells positive guidance by means of the selective attachment of osteoblasts to the implant surface. This selective attachment process might result in the improvement of initial healing around dental implants.

**Biomimetic Calcium Phosphate Coatings on titanium dental implants**[15]

In order to avoid the drawbacks of plasma-sprayed HA coatings, scientists have developed a new coating method inspired by the natural process of biomineralization. In this biomimetic method, the precipitation of calcium phosphate apatite crystals onto the titanium surface from simulated body fluids (SBF) formed a coating at room temperature. Biomimetic deposition is a method whereby a biologically active bone-like apatite layer is formed on a substrate surface by immersion of the substrate in simulated body fluid (SBF) under physiological conditions of temperature (37°C) and pH (7.41). The main benefits of this deposition technique are the possibility to include drugs and growth factors in the CaP coatings, while complex implant geometries can be coated using this soaking procedure. Accelerated biomimetic strategies have been developed by using metastable SBF after supersaturation with carbon dioxide gas or dissolution of sodium hydrogen carbonate salts. In both cases, the gradual release of CO₂ gas is accompanied by release of hydroxyl anions according reaction \( \text{HCO}_3^- + \text{OH}^- + \text{CO}_2 \), thereby increasing the solution pH and the accelerated deposition of biomimetic apatite crystals onto the substrate.
In corporation of biologically active drugs into titanium dental implant\(^{[16]}\)

The surface of titanium dental implants may be coated with bone-stimulating agents such as growth factors in order to enhance the bone healing process locally. Members of the transforming growth factor (TGF-B) superfamily, and in particular bone morphogenetic proteins (bmps), TGF-B1, platelet derived growth factor (PDGF) and insulin-like growth factors (IGF-1 and 2) are some of the most promising candidates for this purpose. Experimental data, in which bmps have been incorporated into dental implants, have been obtained from a variety of methodologies.

Growth Factor Coatings\(^{[17]}\)

Growth factors are signaling proteins that promote replication, differentiation, protein synthesis and/or migration of appropriate cell types. In case of endosseous titanium implants, an enhanced proliferation and differentiation of undifferentiated mesenchymal cells, osteoprogenitor cells and preosteoblasts into osteoblasts may enhance bone healing. Therefore, the rational to coat titanium implants with locally acting growth factors is the assumption that the release of these growth factors might improve the remodeling process at the bone implant interface, leading to enhanced bone response.

BMPS

A particular class of growth factors, BMPs, has shown considerable potential to stimulate bone formation both in extraskeletal sites and in defect models in different species. BMPs originate from the TGF-β family and include at least 18 different proteins. As BMP-2 possesses high osteoinductive potential, it was considered to be an interesting candidate growth factor to coat titanium implants. While BMP-2 is used more commonly, BMP-4 is also considered as a candidate growth factor that might improve the remodeling process at the bone-implant interface.

Besides promoting bone formation, BMPs stimulate recruitment, proliferation, and differentiation of osteoclasts as well. Hence, they may promote the resorption of newly formed bone almost as soon as it has been laid down onto a titanium implant surface. Consequently, it should be kept in mind that the net volume of bone deposited may be lower in the presence than in the absence of BMPs. Additionally, the applied dose of the drug is critical, because an over dosage can trigger the production of intrinsic BMP inhibitors, such as noggin. Therefore, it might be possible that BMPs, in contrast to the desired enhancement
of bone regeneration at the bone-implant interface, may possibly impair the osteoconductivity of the implant surface.[18]

Non-Bmp Growth Factors
Besides BMPs, other growth factors loaded onto titanium implant surfaces were tested in animals as potential agents to enhance osseointegration (De Jonge et al. 2008). Examples are: Growth hormone (GH) [Blom et al. 1998], platelet derived growth factor (PDGF), combined with insulin like growth factor-I [IGF-I] (Stefani et al.2000), platelet released growth factor (PRGFs) [Fuerst et al. 2003], TGF-β2 [De Ranieri et al. 2005], plasma rich growth factors [PRGFs] (Anitua 2006) and fibroblast growth factor-human fibronectin fragment fusion protein [FGF-hFNIII] (Park et al. 2006).

The surface of implants could also be loaded with molecules controlling the bone remodeling process. Incorporation of bone antiresorptive drugs, such as bisphosphonates, might be very relevant in clinical cases lacking bone support, e.g. resorbed alveolar ridges. It has been shown recently that a bisphosphonate incorporated on to titanium implants increased bone density locally in the peri-implant region. The effect of the antiresorptive drug seems to be limited to the vicinity of the implant. Experimental in vivo studies have demonstrated the absence of negative effects but only a slight increase in dental implant osseointegration. Other experimental studies using plasma sprayed HA coated dental implants immersed in pamidronate or zoledronate demonstrated a significant increase in bone contact area. The main problem lies in the grafting and sustained release of antiresorptive drugs on the titanium implant surface. Due to the high chemical affinity of bisphosphonates for calcium phosphate surfaces, incorporation of the antiresorptive drug on to dental implants could be achieved by using the biomimetic coating method at room temperatures.[19,21]

SL Active
The SL Active dental implant surface (Institute Straumann) is a further development of the SLA surface. The SLA surface is in principle produced by coarse grit-blasting with 0.25-0.5 mm corundum grit at 5 bar followed by acid etching. Such a standard titanium oxide surface exhibits low surface energy because of adsorbed hydrocarbons and carbonates from ambient air. In addition to the SLA surface, the SL Active surface is rinsed under nitrogen protection to prevent exposure to air and then stored in a sealed tube containing an isotonic NaCl solution characterized the SL Active surface in comparison with the SLA surface. No differences in surface topography were found. For surface wettability, a statistically
significant difference was observed. Dynamic contact angle (DCA) measurements were indicated that the SLA surface was hydrophobic while the SL Active surface was hydrophilic. Additionally, the chemical composition between the surface types varied. The SL Active surface had increased oxygen and titanium concentrations in comparison with SLA surface. Conversely, the SL Active surface demonstrated a reduced carbon concentration. Osteoblasts grown on such modified surfaces exhibited a more differentiated phenotype characterized by increased alkaline phosphatase activity and osteocalcin production and generated an osteogenic microenvironment through higher production of prostaglandin E2 and transforming growth factor beta2.\(^{[22-24]}\)

**Ti Unite**

The TiUnite implant surface (Noble Biocare Holding AG) is manufactured by anodic oxidation, representing an electro-chemical anodization process used to modify machined surfaces. It has been shown that this electrochemical anodization process increases the surface micro-texture and changes the surface chemistry (Sul et al. 2002b, 2002c, 2006). In vivo experiments in tibias of rabbit indicated that electrochemical oxidization of titanium implants can lead to titanium oxide properties such as oxide thickness, micropore configurations and crystal structures, with statistically significantly higher RTQ values after 6 weeks of healing compared with the non-chemically modified, machined surface. Al-Brektsson and Wennerberg (2004a) supplemented the description of the TiUnite surface by reporting that it had a relatively thin oxide layer (a few hundred nanometers) and was minimally rough in the upper region, whereas the apical region displayed an oxide thickness in the range of more than 10\(\mu\)m and a roughness of more than 2 \(\mu\)m.\(^{[25-26]}\)

**Nanotite**

Next to the OsseoSpeed surface with nano scale topography, the Nanotite surface (3i Implant Innovations) with a CaP nano particle modification of a minimally rough titanium alloy implant surface is currently available for clinical use. The surface has been described as being created by a particulate sol-gel deposition method using discrete crystalline deposition (DCD) of CaP (nominal crystal size 20-100 nm) with a surface coverage of approximately 50%. The suggested nano-feature size of the tightly adherent adsorbed CaP/DCD crystal is 20-100nm.\(^{27}\)

**Friadent Plus\(^{[28]}\)**

The Friadent Plus implant surface (Dentsply Friadent) is manufactured by large grit blasting (354-500\(\mu\)m) and acid etching in hydrochloric acid/sulfuric acid/hydrofluoric acid/oxalic acid
and finally neutralized proprietary process of Dentsply Friadent (Rupp et al. 2004). This chemical process leads to commercially available implants with a regular micro-roughness with pores in the micrometer dimension overlying a macro-roughness structure caused by the grit blasting (Papalexiou et al. 2004). The micropores are irregularly rounded, steep sized, with flat or sharp edges, approximately 3-5µm in diameter and 2-3 µm in depth. Within these micropores even smaller micropores of <0.5-1 µm diameter are located. The surface roughness is associated with increased wettability. Rupp et al.(2004) showed that the Friadent plus surface is initially hydrophobic as indicated by a mean DCA of 140º, but on second contact with water, this changes to an extremely hydrophilic behavior (DCA=0º).

In summary, the various available studies show that the applied implant surface-roughening procedures not only create surface roughness but also result in modification of the surface chemistry. Although there is sufficient proof in animal as well as human studies that implant surface modification induces a safe and predictable implant-to-bone response, it is not clear whether this effect is caused due to the surface roughness or the related change in the surface composition.[29]

Also, it should be mentioned that in addition to the thin-film technology, other techniques such as elcrophoretic deposition, hot isostatic pressing, sol-gel deposition can be used for CaP deposition.

In the light of the current review, it has been noticed that there is an increasing trend to install oral implants on more challenging cases, especially in elderly patients with poor wound healing due to e.g. diabetes, other metabolic malconditions, osteoporosis, radiation therapy etc. As a consequence, there is a need to establish surfaces that will lead to predictive improvement of implant-to-bone response. Evidently, the currently available methods to modify implant surface composition show potential to control the biological activity of the implant surface. Still additional animal as well as human studies are needed to provide more insight into the bone response as evoked and to generate a predicted bone response.[30]

CONCLUSION

Implant dentistry enables the restoration of nearly every clinical situation ranging from partially to totally edentulous patients with greater success and predictability. With all the advancements that have been made so far in the field of implantology, the goal still remains to further simplify the existing procedures, reduce the time duration of implant therapy for
both the patient and the clinician, make the treatment cost effective and improvise the success rate. An effort to achieve this goal along with a thorough training of the dental professionals to perform as a team and long-term maintenance by the patients surely makes implants the future of dentistry.

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