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CURRENT CONCEPTS AND TRENDS IN BIOMECHANICS AND BIOMATERIALS OF ORAL AND MAXILLOFACIAL IMPLANTS

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ABSTRACT
The science of Implantology has undergone numerous modifications and improvement and is highly dynamic. With each improvement and advancement, Implantology has proved to be a boon in disguise to the society and hence its acceptance by the general population has widely increased despite of expensive treatment modality. More of clinical trials conducted on different commercially available implants, its effect on bone and oral tissues as well as the development of implant designs, have increased the success rate of implants to over 95% and specially in anterior mandible where the success rate is over 99%. Latest technological advances in Dental Implantology are reviewed in this article.

Keywords : Dental Implant, Implantology, Recent Advances and Future Trends

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INTRODUCTION

The prime requisites of an ideal prosthesis for the rehabilitation of the stomatognathic system include the restoration of normal contour, function, esthetics, comfort, and speech. In highly complicated and challenging 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. 'Implant therapy' is the answer to such a clinical dilemma. Implant dentistry has ability to achieve an ideal replacement of the lost tissues, regardless of the atrophy, disease, or injury of the stomatognathic system. So, the acceptance of osseo-integrated supported prosthesis by the patients has significantly increased. However, greater the destruction of the stomatognathic system, the more challenging is the rehabilitation. So, with the help of the current availability of the advanced diagnostic tools, many challenging clinical situations can be managed with predictable success.

IMPLANT SURFACE TOPOGRAPHY

Dental implants have a long and successful history with only approximately 5% failure rate. The failure is most likely due to infection, accelerated bone loss, rejection and poor osseointegration with loosening of the implant.[1] The most frequent cause of implant failure is the inability of the bone to form around the biomaterial immediately after implantation.[2] Osseointegration is the structural and functional connection between ordered living bone and the surface of a load carrying implant and it is this interface that should be appropriately and satisfactorily formed during the healing period as well as maintained throughout the post prosthetic loading period for an implant to be successful.[3]

Several modifications have been made in the morphological and chemical characteristics of implant surfaces, thereby increasing its interaction with the surrounding bone (Figure1).

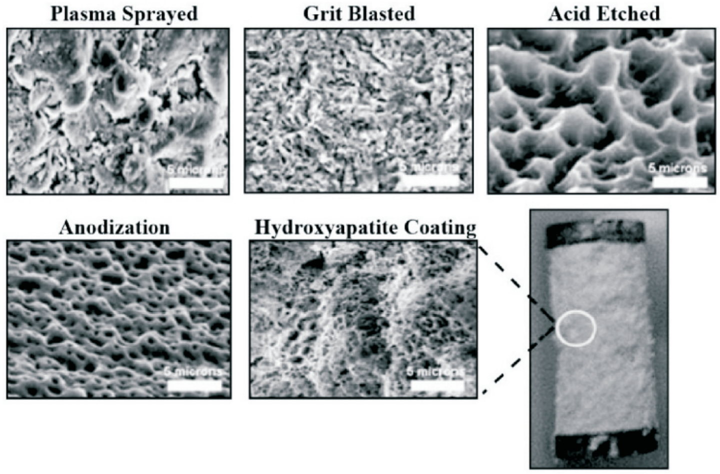

Figure 1: Implant Surface Topography

Mechanical treatment

Mechanical treatments involve either removal of surface material by cutting or abrasive action, or the surface of the implant is deformed by particle blasting.[4] The most commonly employed mechanical techniques are machining, polishing and blasting.

Chemical methods

The chemical methods of implant surface modifications include chemical treatment with acids or alkali, hydrogen peroxide treatment, sol-gel, chemical vapour deposition and anodization to alter surface roughness and composition and enhance wettability/ surface energy of Titanium.[5] The process is done to remove the surface oxide and contamination which leads to a clean and homogenous surface. The acids commonly used include hydrochloric acid, sulfuric acid, hydrofluoric acid and nitric acid.

Physical methods

The physical methods of implant surface modification include plasma spraying, sputtering and ion deposition.

METHODS TO ALTER MICROTOPOGRAPHY -

Turning - the original Brånemark (Nobel Biocare) implant was turned Ti screw with no further surface treatment.[6] Scanning electron microscopy analysis showed that the surfaces of machined implants have grooves, ridges and marks of the tools used for their manufacturing which provide mechanical resistance through bone interlocking.

Grit-blasting - with various hard ceramic particles such as alumina (AlO3), titanium oxide (TiO2), silica or calcium phosphate is one way of roughening the implant surface. The size of the blasting particles determines the roughness created and the blasting particles should be chemically stable and biocompatible.

Acid-etching - of a surface with strong acids such as HCl, H2SO4, HNO_3 and HF creates an isotropic surface to enhance osseointegration.[7,8] The most commonly used solutions for acid etching of Ti includes either a mixture of HNO3 and HF or a mixture of HCl and $H2SO_4$. Acid treatment provides homogeneous roughness, increased active surface area and improved bioadhesion.

Dual acid-etched technique - immersion of Ti implants for several minutes in a mixture of concentrated HCl and $H2SO_4$ heated above 100°C (dual acid-etching) is employed to produce a micro rough surface.[9] The dual acid-etched surface produces a microtexture rather than a macrotexture. It enhance the osteoconductive process through the attachment of fibrin and osteogenic cells, resulting in bone formation directly on the surface of the implant.[10]

Anodization - produces a micro and nanoporous oxide layer on the Ti surface. The appearance of the layer from the anodization process depends on current density, concentration and composition of the acids used in the electrolyte solution and the temperature.

Plasma spraying - is a method where particles, HA (Hydroxyapatite) or Ti (Titanium) are projected on the surface through a plasma torch at very high temperature. The particles condense and fuse together on the surface thereby creating a coat. The advantage of plasma coating is that these coatings give implants a porous surface that bone can penetrate more readily.[11]

Plasma spraying with HA particles creates a 50-200 μm thick coat but with poor adhesion to the bulk material and this is believed to be the reason for the long term negative clinical results of such implants.

Sandblasted and acid etched surface

Dental implants are usually both blasted by particles and then subsequent etched by acids. This is performed to obtain a dual surface roughness as well as removal of embedded blasting particles. The etching reduces the highest peaks while smaller pits will be created and the average surface roughness will be reduced.

Fluoride treatment

Ti is very reactive to fluoride ions, forming soluble TiF4 by treating Ti dental implants in fluoride solutions which enhances the osseointegration of dental implants.

Sputter-deposition

Sputtering process is useful technique for the deposition of bioceramic thin films (based on Ca/P systems), due to the ability of the technique to provide greater control of the coating's properties and improved adhesion between the substrate and the coating.

Disadvantage is extensive time consuming, produces amorphous coatings and Ca/P (Calcium Phosphorous) ration of the coating is higher than of synthetic HA.

Radio frequency (RF) sputtering

RF magnetron sputtering is largely used to deposit thin films of Ca/P coatings on Ti implants. The advantage of this technique is that the coating shows strong adhesion to the Ti and the Ca/P ratio and crystallinity of the deposited coating can be varied easily.

Magnetron sputtering

Magnetron sputtering is a viable thin film technique as it allows the mechanical properties of Ti to be preserved while maintaining the bioactivity of the coated HA.

Nano-roughness and nanostructures

Nanostructured materials are defined in the literature as materials containing structural elements with dimensions in the range of 1-100 nm.

SOME METHODS TO ALTER NANOTOPOGRAPHY

Sol-gel coatings

During the sol-gel process, a liquid with a specific composition (i.e. Sol) is converted into a solid gel phase. Thin coatings can be deposited onto a surface by dip or spin coating techniques.

Nanocrystalline Hydroxyapatite coatings

Nanoparticles of HA is prepared by mixing H_3PO_3 and Ca (NO_3) to a Ca/P ratio of 1.67 in the presence of a liquid crystalline phase. The crystalline phase limits particle growth upto 5nm. When HA particles have formed, the liquid crystalline phase is dissolved and the particles can be deposited onto a surface using dicyandiamide.

Biologically Active Drugs Incorporated Dental Implants

Some osteogenic drugs have been applied to implant surfaces. Incorporation of bone antiresorptive drugs, such as bisphosphonate, might be very relevant in clinical cases lacking bone support.

Bisphosphonates

Bisphosphonate incorporated on to Ti implants increased bone density locally in the peri-implant region with the effect of the antiresorptive drug limited to the vicinity of the implant.[12] Other experimental studies using PSHA (Plasma-Sprayed Hydroxyapatite) 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 Ti implant surface. Increase in peri-implant bone density is bisphosphonate concentration-dependent.

Antibiotic Coating

Gentamycin along with the layer of HA (hydroxyapatite) can be coated onto the implant surface, which may act as a local prophylactic agent along with the systemic antibiotics in dental implant surgery. Tetracycline-Hydrochloric acid functions as an antimicrobial agent capable of killing microorganisms present on the contaminated implant surface. Tetracycline also enhances blood clot attachment and retention on the implant surface during the initial phase of the healing process and thus promotes osseointegration.

IMPLANT-ABUTMENT INTERFACE

These include:

External hex - a distinct projection extends external to the body of the implant.

Internal hex - the implant abutment connection is recessed into the body of the implant. Internal connection implants were developed to overcome the clinical complications of the external hex implants. It increases incidence of abutment screw loosening, fracture and dynamic micro motion at the implant-abutment interface[13](Figure 2).

Figure 2: External Hex and Internal Hex

Advantages of internal hex include reduced vertical height platform for restorative components, distribution of lateral loading deep within the implant, shielded abutment screw, long internal wall engagements that create a stiff, unified body that resists joint opening, wall engagement with the implant that buffers vibration, potential for a microbial seal, extensive flexibility and ability to lower the restorative interface to the implant level esthetically.[14]

Internal implant-abutment connections can be either passive fit/slip fit joint with 6 or 12 point internal hex or it may be friction fit with no space between the mating components. This is also referred to as the Morse taper connection. Morse taper implant abutment connection design includes a tapered projection from the implant abutment, which fits into a tapered recess in the implant. There is a friction fit and cold welding at the implant abutment interface to prevent rotation under function. The taper may be 8° as seen in ITI Straumann or Ankylos implant systems or 11° as seen in Astra. 1.5 degree tapered rounded channel is seen in the Bicon implant system.[15]

A new internal connection implant design (e.g. Osseotite Certain, 3i Implant Innovations, Inc., Palm Beach Gardens, FL) has recently been introduced. This design incorporates an audible and tactile "click" when the components are properly seated. The advantage of this unique feature is that it eases placement for the clinician and may reduce the need for radiographs following placement of the restorative components.

IMPLANT THREAD DESIGN

Threads are designed to maximize initial contact, enhance surface area, and facilitate dissipation of loads at the bone-implant interface. Functional surface area per unit length of the implant may be modified by varying three geometric thread parameters: thread pitch, thread shape, and thread depth(Figure 3).

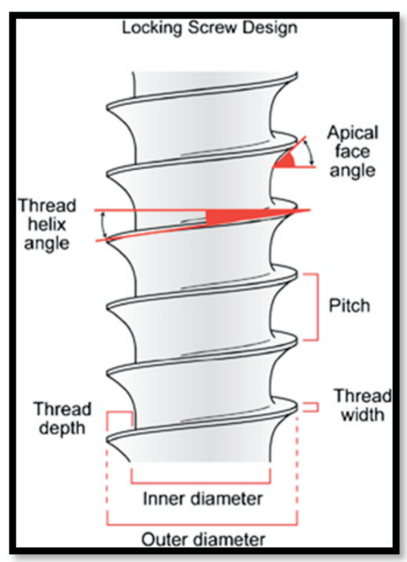

Figure 3: Diagrammatic Representation of Thread Geometry

Thread Pitch

Thread pitch is the distance measured parallel between adjacent thread form features of an implant. The height of the threaded portion of the implant body divided by the pitch equals the threads per unit length. The thread pitch may be used to help resist the forces to bone with poorer quality. Because the softest bone types are 58% weaker than ideal bone quality, the implant thread number may be increased to increase the overall surface area and reduce the amount of stress to the weaker bone trabeculae. Therefore if force magnitude is increased, implant length is decreased, or bone density decreased, the thread pitch may be decreased to increase the thread number and increase the functional surface area. Each implant pitch has a different number of threads per unit length and a different amount of functional surface area. The thread number is most significant for the shorter length implants. For example, the Straumann ITI 6- and 8-mm-long implants may only have three threads to carry the compressive load. On the other hand, the thread pitch of other implant designs may feature 7 to 10 threads for a similar length. The greater the thread number, the greater the initial fixation and the greater the overall surface area after loading.

Thread Shape

Thread shape is another important characteristic of overall thread geometry. Thread shapes in dental implant designs include: square, V-shape, buttress, and reverse buttress.

The force transfer for occlusal loads to the bone is similar to that of the V-thread design. Dental implant applications dictate the need for a thread shape optimized for long-term function (load transmission) under occlusal, intrusive (the opposite of pull out) load directions.

The square or power thread provides an optimized surface area for intrusive, compressive load transmission. Most automobile jacks or engineering designs built to bear a load use some form of a square design. Yet very few implant designs have incorporated a square thread design (BioHorizons, Ankylosis)

A buttress thread shape may also load the bone with primarily a compressive load transfer (e.g., BioLok). The thread shape has primarily design applications for loading conditions, but may also contribute to the initial healing stage for the direct bone interface.

The V-shaped and reverse buttress thread shapes had similar BIC percent and similar reverse torque values to remove the implant after initial healing. The square thread design had a higher BIC percent and a greater reverse torque test value. So it appears thread shape may also be a para meter in an implant design for the initial healing phase of osseointegration (Figure 4).

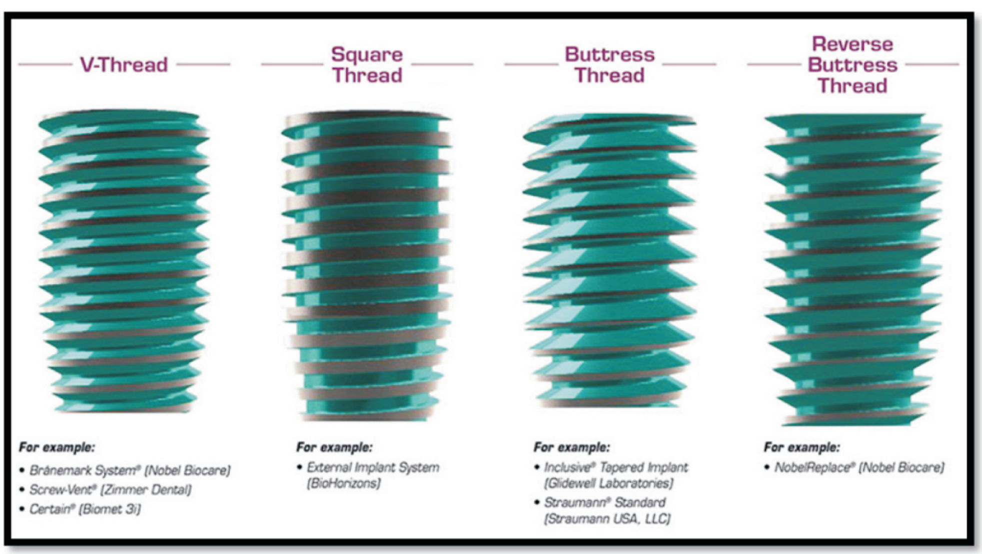

Figure 4: Representation of Different Implants Systems Thread Design

Thread Depth

The thread depth is the distance between the major and minor diameter of the thread. Conventional implants provide a uniform thread depth throughout the length of the implant. A straight minor diameter, which is used in almost every screw-type dental implant, results in uniform cross-sectional area throughout a parallel-walled implant length.

Different manufacturers use different thread depths. Some threaded implants have a 0.24-mm thread depth (Nobel Replace), the thread depth of Straumann ITI is 0.3 mm, and the thread depth of many V-shape threads is 0.375 mm (Biomet 3i and Zimmer Screw-Vent). The square thread of the 4-mm-diameter BioHorizons implant body has a 0.42-mm thread depth. Therefore, if all other factors were equal, each type of implant in these examples would have a different functional surface area directly related to the depth of the thread, with BioHorizons having the most surface area and Nobel Replace the least.

The more shallow the thread depths, the easier it is to thread the implant in dense bone, and the less likely bone tapping is required prior to implant insertion. Because implant surgeons often decide what implant they will insert based on ease of surgical insertion, it is not unusual that an implant with fewer threads and less deep threads are selected, because both conditions facilitate insertion (Figure 5).

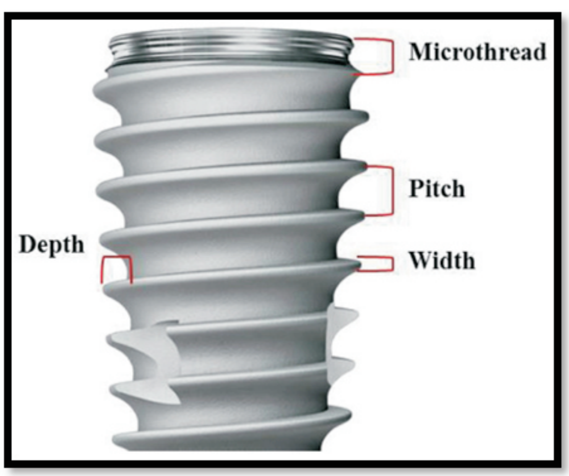

Figure 5: Thread Depth

PLATFORM SWITCHING

Another concept introduced to minimize the crestal bone loss when compared to the conventional implant-abutment junction (IAJ). It refers to the use of a smaller diameter abutment on a larger diameter implant collar which shifts the margin of the IAJ inward, toward the central axis of the implant. The inward movement of the implant abutment junction is believed to shift the inflammatory cell infiltrate to the central axis of the implant and away from the adjacent crestal bone, which is thought to limit crestal bone resorption[16](Figure 6).

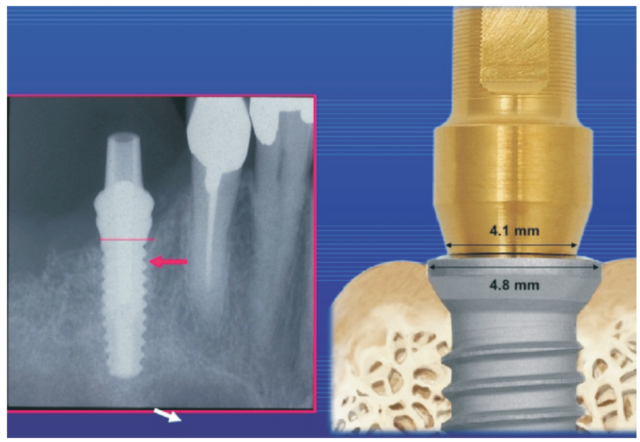

Figure 6: Platform Switching

One-piece implant completely eliminate the implant-abutment interface and the problems associated with it such as micro leakage, bone loss, gingivitis etc., It also mimic the natural tooth in its construction with a seamless transition from the implant body to the abutment. These implants have many advantages like strong unibody design, no split parts, single stage surgery with either flap or flapless approach and simple restorative technique.

IMPLANT ABUTMENTS

The abutments are available in pre-fabricated or customizable forms and can be prepared in the dental laboratory either by the technician or by utilizing computer-aided design/computer-aided manufacturing techniques. The materials of preference are densely sintered high purity alumina (Al_2O_3) ceramic and yttria (Y_2O_3) stabilized tetragonal zirconia polycrystal ceramics, zirconia being the stronger of the two.[17]

Improvements in the ceramic are made by adding coloring oxides to zirconia ceramic before the sintering process in order to change its whitish color and enhance the esthetic outcome.

ZIRCONIA IMPLANTS

Tissue discoloration and allergic reactions in patients who have come in contact with titanium have been reported. Currently, there are five zirconia implant systems commercially available. These are Sandhaus, Sigma implant system, Ceraroot system (Ceraroot, Barcelona, Spain), the White Sky system (Bredent Medical, Senden, Germany), the z-systems implant system (z-systems, Konstanz, Germany), and the zit-z ceramic implant system (Ziterion GmbH, Uffenheim, Germany). However, regarding the clinical use of zirconia oral implants, scientific information is lacking (Figure 7).

Figure 7: Zirconia Implant

IMPLANT LOADING PROTOCOLS

Conventional loading protocols as mentioned by Branemark required an undisturbed healing of the implant 3 months in the mandible and 4 to 6 months in the maxilla.[18,19]

Conventional loading of dental implants is defined as being greater than 2 months subsequent to implant placement.

Early loading of dental implants is defined as being between 1 week and 2 months subsequent to implant placement.

Immediate loading of dental implants is defined as being earlier than 1 week subsequent to implant placement.

Immediate loading of micro roughened dental implants may be done for partially edentulous sites in the esthetic zone.

Conventional loading (greater than 2 months subsequent to implant placement) is the procedure of choice for partially edentulous sites in the esthetic zone when stability is considered inadequate for early or immediate loading, specific clinical conditions exist such as compromised host and/or implant site, presence of parafunction or other dental complications, need for extensive or concurrent augmentation procedures.

PERI IMPLANT SURGERY

Using various graft materials available in present time, alveolar resorption following trauma, extraction, or infection resulting in ridge form with deficient width and/ or height can be well taken care of, with tissue preservation or augmentation procedures. Onlay bone grafts may be used for external augmentation of horizontal or vertical alveolar ridge deficiencies while the bone splitting technique may be used to reduce surgical morbidity and complications associated with grafting procedures.

Distraction osteogenesis is one of the newest procedures which allows for a vertical bone gain of 3-20 mm without the use of graft material bone ring augmentation is another such technique which allows bone transplantation and implantation to be performed on large three-dimensional bone defects in a single operation. Osteoconductive and osteoinductive graft materials are now available which help in accelerating the healing process and will have extensive future application.

IMAGE-GUIDED IMPLANTOLOGY

A revolutionary development in field of imaging now allows a real-time navigational implant surgery, wherein the implant surgery is guided by an on-screen computer guidance thereby allowing easy intra-operative adjustments (Figure 8). It is an expensive machine, it requires long hours of calibration which are the drawbacks of image – guided implantology.

Another option available is the use of stereolithographic surgical splints which help to place implants at the predetermined sites which greatly enhances the speed of implant placement.[20]

Figure 8: Image Guided Implantology

MINI IMPLANTS

Mini dental implants (MDI) are titanium alloy implant screws that are ultra-small in diameter i.e. 1.8 mm wide. These implants come handy in clinical situations where acceptable and satisfactory function cannot be achieved with conventional prosthesis. Mini dental implants are indicated in flabby ridges, atrophic ridges or in cases with poor availability of residual bone where there is denture instability or lack of retention, commonly seen in edentulous mandible[21], in patients with severely resorbed mandibular ridges, conventional implants may not be the best treatment option. So, mini dental implants can be successfully used with immediate loading and ongoing stabilization.

TANTALUM IMPLANTS

Tantalum is a lustrous transition metal that is highly corrosion resistant. Porous tantalum metal in orthopaedic implants was found to be highly successful. This led to its incorporation in the design of root-form endosseous titanium implants as a new form of implant surface enhancement. It enhance the osseointegration by combining bone ongrowth along with bone ingrowth[22] (Figure 9).

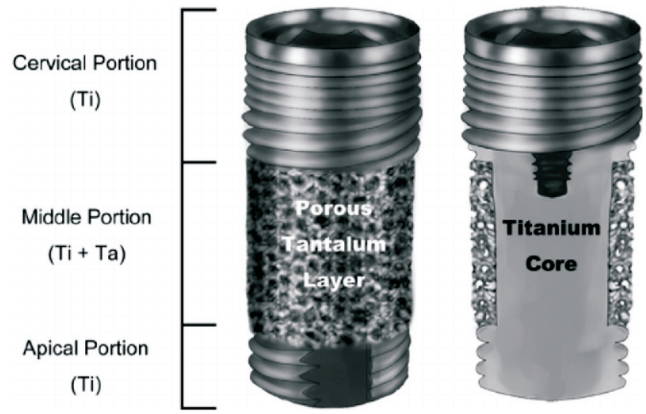

Figure 9: Tantalum Implants

LONG IMPLANTS

Implants anchored in the zygomatic bone are an alternative to posterior bone grafting in the edentulous or partially edentulous maxilla. The length of these implants ranges from 30 to 52.5 mm. The surgical approach consists of using the frontal part of the zygomatic bone as an anchorage for zygomatic implants, with support from the maxillary palatal or alveolar bone, without any bone augmentation. Zygomatic implant and prosthesis are an effective rehabilitation remedy for maxillary defects resulting from tumor resection.[23]

STEM CELLS IN IMPLANTOLOGY

Implant dentistry is highly predictable and offers great flexibility to restore even the most complex clinical situations, it has its drawbacks. The major drawback is the long healing period ranging from 3 to 9 months and even with all the advancements made, there still exists a failure rate varying from 5% to 10% depending on the various existing patient-related factors.

Stem cell technology is the answer to overcome these drawbacks. Stem cell grafting is the latest technology in helping the bone to grow in deficient regions of the jaw. Stem cells may be derived from various regions such as the tip of the removed tooth root called as the root apical papilla or may be aspirated from the iliac crests and placed against the receiving site in the jaw bone.[24] However, stem cell implant technology is currently not an option for replacing the missing teeth.

LASER-LOK 3.0 DENTAL IMPLANT SYSTEM

- Two-piece 3mm design offers restorative flexibility in narrow spaces.
- 3mm threadform shown to be effective when immediately loaded.
- Implant design is more than 20% stronger than competitor 3.0 implant when loaded.
- Laser-Lok microchannels create a physical connective tissue attachment.
- Laser-lok 3.0 BioHorizons is the only company that can claim (FDA-cleared) that its implant surface establishes a physical connective tissue attachment (unlike Sharpey fiber attachment).

This tissue connection:

- is functionally oriented,
- inhibits epithelial cell downgrowth and
- enables crestal bone adjacent to the implant to attach and be retained

The establishment of a physical, connective tissue attachment (unlike Sharpey fibers) to the Laser-Lok surface has generated an entirely new area of research and development: Laser-Lok applied to abutments. This could provide an opportunity to use Laser-Lok abutments to create a biologic seal and Laser-Lok implants to establish superior osseointegration – a solution that offers the best of both worlds. Alternatively, Laser-Lok abutments could support peri-implant health around implants without Laser-Lok. In a recent study, Laser-Lok abutments and standard abutments were randomly placed on implants with a grit-blasted surface to evaluate the differences. In this proof-of-principle study, a small band of LaserLok microchannels was shown to inhibit epithelial downgrowth and establish a connective tissue attachment (unlike Sharpey fibers) similar to Laser-Lok implants. This time, however, the attachment was established above the dental implant-abutment connection and even on implants with a machined collar. The resulting crestal bone levels were higher than what was seen with standard abutments and provides some insight into the role soft tissue stability may play in maintaining crestal bone health (Figure 10).

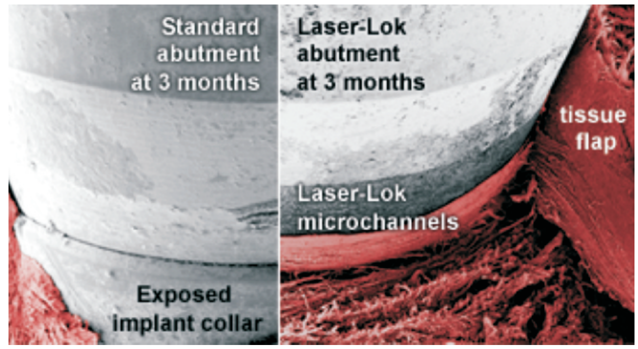

Figure 10: Laser Lok Implant Abutment

DISCUSSION

Implantology is a dynamic science which has been under a constant process of improvisation.

Various modifications have been introduced to reduce the crestal bone loss and achieve primary stability which is one of the major factors that determines the success of the implant therapy. Implant surface modifications using nanotechnology has opened new opportunities for the manipulation of implant surfaces.

Various implant-abutment interfaces that are available with different implant systems also concentrate on minimizing the crestal bone loss which is a prime requisite to maintain a healthy soft tissue profile which is in turn will affect the final esthetics. The concept of platform switched implant-abutment junction is highly effective in minimizing the crestal bone loss.[25]

Recent advances with respect to the materials used in implant manufacturing and the variations in the implant surface morphology have helped achieving even better results. Zirconia implants have come into being for particularly restoring the high esthetic zones.

However, the future of implantology may be ruled by further research and advancement in stem cell technology wherein stem cells may be used to create living dental implants. Stem cell dental implants could well be a promising future of implant dentistry.

CONCLUSION

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. Efforts 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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