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The Influence of Chemical Elements on Implant Success

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Abstract

BACKGROUND: Dental implantology is a field focused on placing dental implants in areas where natural teeth are missing. The dental implant is embedded in the bone to replace the root of the missing tooth, with a prosthetic structure placed on top. This modern method provides functionality and aesthetics while protecting adjacent teeth from shifting and elongating. Today, there are numerous implant systems that offer various dental implants, providing doctors with options but also creating dilemmas regarding implant and system selection. Dentists sometimes encounter peri-implantitis, which can lead to implant rejection.

AIM: This research study aims to assist dental implant manufacturers and guide practitioners in choosing the right implant for successful implants.

METHODS: For this reason, this study examined three groups of dental implants from different manufacturers. The implants were analyzed using an electron microscope and compared. The surfaces of the dental implants were examined to assess how surface contamination affects implant rejection.

RESULTS: In the first and second groups of implants, multiple chemical elements were detected. Unsurprisingly, the rejected implants showed more elements on their surfaces.

CONCLUSION: Contaminants on dental implants are associated with implantation failures and can be a key factor in the development of peri- implantitis, which may lead to implant rejection.

Introduction

Modifications of the implant surface (micro-topography and micro-design) influence the success of osseointegration and the long-term success of prosthetic rehabilitation with implants. The impact of implant cleanliness on implant success rates, medical comorbidities, in connection with success/failure rates of implants is a subject of interest in many studies.

Authors compared implant surfaces, chemical elements, particle presence, and their impact on implant success [1].

Chemical elements on the surface of dental implants can have both beneficial and detrimental effects on the dental implantation process. These elements can alter surface energy, chemical purity, oxide layer thickness, and composition, potentially leading to implant surface wear. Organic and inorganic contaminants can remain on the implant surface during cleaning processes like acid etching or sandblasting. Variability exists among implants from different manufacturers.

Due to these potential risks, modern implants are manufactured with specialized alloys and coatings that resist corrosion and reduce the release of harmful elements into surrounding tissue [2]. The primary goal of this study is to help resolve these dilemmas by guiding doctors on which dental implants to use to avoid peri-implantitis and achieve successful implantation. In contrast, the implants in the third group differed significantly from those in the first two groups.

Their surfaces had a minimal number of chemical elements, all of which positively impacted the osseointegration process and contributed to successful implantation.

This observation suggests that no rejected implants were found in this third group, emphasizing the importance of selecting implants with surfaces that support biocompatibility and minimize potential contaminants.

This research study aims to assist dental implant manufacturers and guide practitioners in choosing the right implant for successful implantation.

Materials and Methods

In the first and second group of implants (examined groups) we included subgroups with rejected and new implants, while in the third group (control group) only new implants were included.

The first group consisted of implants characterized with TiPurePlus Pi-line surface, cleaned by sandblasting and made of grade 4 pure titanium using a precise technology. Its design is conical with a rounded tip.

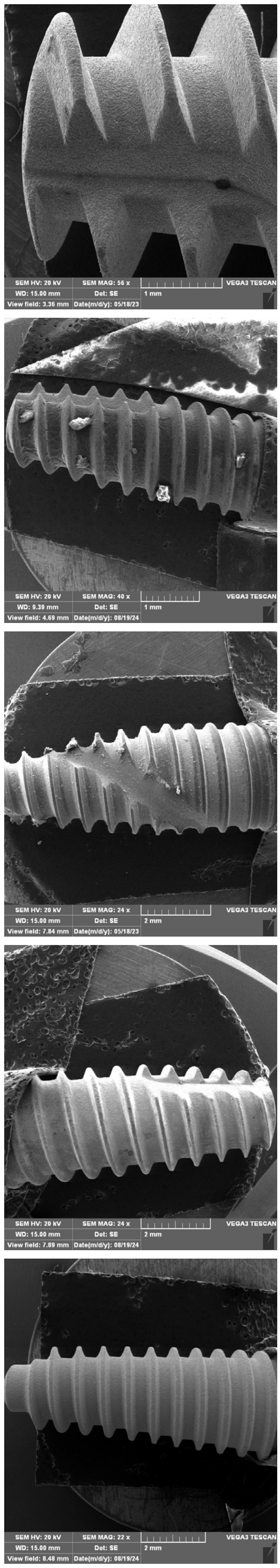
The design of the second group of implants is cylindrical with a double lead thread and two anti-rotation spiral grooves. It is a bone-level implant with a hexagonal shape. The head is straight with micro-threads, the body tapers at the tip with reverse proportion threads, and the tip is dome-shaped without a hole but with grooves.

The third group includes high-quality implants with extensive research background and is among the top five implant systems globally. This implant system offers a wide range of lines with various body and neck designs and materials, focusing on tissue and bone-level implants made from Titanium and Roxolid with an endosteal parallel wall design. No rejected implants were found in the third group; only new, sterile implants were compared with the other two groups.

An electron microscope was used for this study, specifically a scanning electron microscope (SEM) that can achieve resolutions finer than 1 nanometer. The samples were observed in a high vacuum with a Tescan Vega 3 LMU SEM, which allows for the examination of material morphology and chemical composition. In dentistry, samples must first be prepared. If a sample is moist, it is left at room temperature to dry, then placed on a holder with a carbon-based double-sided adhesive tape. The analyses were conducted in a high vacuum with an SE detector for morphology and an EDS detector for chemical analysis at a point [3]. The electron microscope is in the laboratory of Goce Delchev University in Shtip. Electron microscopy is a powerful technique used to analyze dental implant surfaces and identify possible contaminants. Contamination on the implant surface can negatively affect osseointegration and implant success. Here’s how electron microscopy can be used to analyze and detect contaminated implant surfaces [4].

Results

In the first and second groups of implants, multiple chemical elements were detected. Unsurprisingly, the rejected implants showed more elements on their surfaces. However, an interesting observation was that even the surfaces of new implants from these groups contained chemical elements that could contribute to implant rejection (Figure 1a-e) [4].



a) b) c) d) e)

Figure 1: a) New implant from the first group; b) Rejected implant from the first group; c) New implant from the second group; d) Rejected implant from the second group; e) New implant from the third group

Discussion

With the help of scan electron microscopy, a variety of chemical elements were found on implant surfaces in all study groups. The chemical elements dominated in first and second group. In contrast, the implants in the third group differed significantly from those in the first two groups. Their surfaces had a minimal number of chemical elements, all of which positively impacted the osseointegration process and contributed to successful implantation.

Influence of Chemical Elements

1. Titanium (Ti)

- *Tissue Reaction:* Titanium is the most commonly used material for dental implants due to its high biocompatibility and low toxicity. When exposed to air, a thin titanium oxide layer (TiO_2) forms on its surface, protecting the implant from corrosion and enabling stable interaction with bone tissue.[5]
- *Promotion of Osseointegration:* This titanium oxide layer is essential for osseointegration, as it stimulates the growth of osteoblasts (bone-forming cells) around the implant, creating a faster and stronger bond with the bone.
- *Modification Methods:* Titanium surfaces can be treated with sandblasting and acid etching to create a porous structure, enhancing surface contact and bone anchorage.

2. Calcium (Ca) and Phosphorus (P)

- *Calcium-Phosphate Coatings:* Calcium and phosphorus are primary components of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), a natural component of human bone. Applying a hydroxyapatite layer on the implant surface can increase its affinity with bone tissue and accelerate osseointegration.
- *Improved Adhesion:* Calcium-phosphate coatings enhance initial mechanical stability and facilitate faster bonding, while also reducing the likelihood of inflammatory reactions that may lead to implant rejection.

3. Zinc (Zn)

- *Antimicrobial Properties:* Zinc is known for its antimicrobial effects, helping to reduce bacteria and prevent infections in the peri-implant region. This is crucial for successful implantation, as infections can complicate healing and decrease implant success.
- *Promotion of Osteogenesis:* Zinc also promotes bone tissue growth, contributing to implant stability and long-term durability.
- *Corrosion Protection:* Some studies show that adding zinc to titanium implants improves corrosion resistance, prolonging the implant's lifespan and increasing its durability in the oral environment.

4. Magnesium (Mg)

- *Natural Bone Element:* Magnesium, as part of bone tissue, is essential for bone mineralization and plays a role in osteoblastic activity.
- *Faster Healing:* Research suggests that adding magnesium to the implant surface can enhance the rate of osseointegration and expedite the healing process. Magnesium-coated implants tend to enable quicker bonding and adaptation of the bone tissue.
- *Biodegradation and Risk:* Although magnesium positively influences bone integration, controlled release is crucial since excessive biodegradation may cause implant instability.

5. Silver (Ag)

- *Antimicrobial Properties:* Silver is used for its strong antimicrobial properties and is added to implant surfaces to prevent infection. Silver-coated implants generally show significant bacterial reduction near the surface, increasing the chances of successful implantation.

Some chemical elements on implant surfaces that may negatively impact the implantation process include:

- Nickel: Can cause allergic reactions in some individuals, leading to tissue inflammation around the implant.
- Chromium and Cobalt: Due to their oxides, these elements can cause reactions in sensitive patients.
- Lead: Rarely used, but its presence can be toxic and damage surrounding tissue.
- Cadmium: A toxic element that, if found in trace amounts on implants, may cause toxic reactions in the body.
- Zinc and Copper: When released in high concentrations, they may trigger inflammatory reactions.
- Iron: Excessive iron release from the implant can cause localized oxidative stress in the tissue.
- Nickel: Commonly used in medical alloys for its strength and corrosion resistance, but it is a known allergen. Many people develop allergic reactions to nickel, causing inflammation, redness, and irritation around the implant. Nickel allergies are particularly common among individuals with sensitive skin and may slow the healing process.

- Chromium: Found in stainless steel and alloys used in implants, chromium is typically stable but may release toxic ions when corroded. This can lead to inflammation and tissue damage, especially in patients sensitive to metals. Hexavalent chromium is particularly toxic.
- Cobalt: Often used with chromium in medical alloys, cobalt may be released from implants due to friction and corrosion, causing inflammation and immune responses in sensitive patients. Elevated cobalt levels have been linked to toxicity risks, potentially harming tissues and organs.
- Lead: Although rarely used directly in medical implants, trace amounts may appear in some alloys or as contaminants. Lead is toxic to tissue, causing toxic reactions even in small quantities. Prolonged exposure may lead to severe health issues, including nervous system damage.
- Zinc and Copper: Used in biocompatible alloys, but excessive release may induce inflammatory reactions. While essential trace elements, high concentrations can disrupt tissue balance around the implant, hindering healing.[5]
- Iron: A fundamental part of stainless steel and relatively biocompatible, iron can release ions under corrosion, causing oxidative stress in cells. This may damage surrounding tissue and lead to inflammatory responses, particularly in humid or physiological conditions.

Conclusion

The chemical elements present on the surface of dental implants play a crucial role in the success of process of osseointegration (biological stability, secondary stability). Titanium remains the primary choice for implants due to its biocompatibility and durability, while adding elements (modification of implant surfaces) such as calcium, phosphorus, zinc, magnesium, and silver can significantly enhance osseointegration, increase stability, and reduce infection risks [6].

Contaminants on dental implants are associated with implantation failures and can be a key factor in the development of peri- implantitis, which may lead to implant rejection [7].

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