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Breakthroughs in Implant Dentistry

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Abstract: The osseointegration capacity of implant surfaces deteriorates over time. However, the treatment of titanium surfaces with ultraviolet (UV) light restores the original properties of the surface and causes considerable acceleration in the process of osseointegration. This study reviews two recent findings: the aging-like time-dependent biological degradation of titanium surfaces and the discovery of UV photofunctionalization as a solution to this phenomenon. This technology and the associated knowledge herald a new age of implant treatment and provide a novel concept of osseointegration in the science and therapeutics of implant dentistry. In addition, we expect to revolutionize clinical implant therapy through these new concepts.

Key words: osseointegration, implant surface, ultraviolet, dental implant, bone-titanium integration.

Despite its widespread prevalence as a standard and routine method in various prosthodontic treatments, implant therapy still faces many challenges in clinical outcomes. Following a discussion at an implant summit organized by the US Academy of Osseointegration, a consensus was reached that implant success rates worldwide have reached only approximately 92%. Furthermore, the success rates are even lower (60–90%) in cases involving multiple interventions that include bone augmentation and sinus lifting, particularly in smokers and elderly patients.[1, 2] Faster and firmer fixation of titanium implants in bone is extremely important for achieving the necessary increase in the comprehensive success rate, including use in multiple severe cases, and to accommodate the growing demands of modern implant therapy. However, the strength and speed of bone-titanium integration still remain a persistent challenge in dental medicine. In the past, the development of "micro-roughened surfaces" allowed for considerable reduction in healing time and increased the strength of bone-implant integration required for an implant to strongly adhere to the bone. In addition, "nanotopographic titanium surfaces" altered cellular and tissue responses, which may enhance osseointegration.[3] Although the implant technology has markedly improved, there have been no reports of new implant surfaces that can improve the outcomes of difficult or compound cases with great clinical significance. More rapid and complete establishment of bone-implant integration remains a persistent goal.

Biological Aging of Titanium

Over the half-century history of implant research, reports of both animal and human experiments have indicated that the mean bone-implant contact rate or bone coverage of the implant surface is approximately 50%, with the maximum rate being approximately 70%.[4~7] Other areas of the implant surface may be covered with fibrous tissue instead of bone or not covered with any tissue, and it is rare for new bone to later appear at such sites. Consequently, the current technology is unable to induce any more bone growth around such implants. Furthermore, this means that no clinical improvement can be anticipated with the current dental implant technology. The question as to what is preventing the achievement of 100% bone contact rate remains unanswered.

Titanium and titanium alloys are currently widely used as implant materials in all medical and dental

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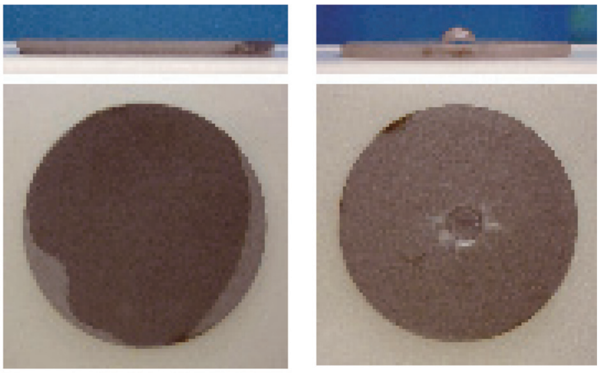

Fig. 1 Surface characterization of titanium disks. Hydrophilic status of two titanium surfaces with different ages. Photographic images of 1 μL H_2O droplets pipetted onto freshly prepared titanium disk and 4-week-old disks.

fields. Successful implant treatment requires the titanium implant to strongly adhere to the bone and act as an anchor. Moreover, titanium is used because it is chemically stable, has excellent rust and corrosion resistance, and most importantly, its bone-binding property does not change over time. However, our research has revealed that although titanium surfaces have an extremely high osseointegration capacity soon after being processed (in a fresh state), this capacity for osseointegration deteriorates over time when the implants are stored without being used. We inserted implants with fresh surfaces directly after processing into animal bone tissue and compared them with implants with old surfaces that had been stored for 4 weeks. The old implants achieved bone contact rates of approximately 50%, whereas the implants with fresh surfaces achieved bone contact rates of approximately 90%.[8)] These results show that the passage of time after titanium surface fabrication results in differences in the osseointegration capacity of implants. We termed this phenomenon as "biological aging of titanium."

Different types of changes occur on implant surfaces over time. Here we discuss changes in surface wettability (hydrophilicity). As is clearly presented in Fig. 1, fresh titanium that has just been processed is extremely hydrophilic, whereas after storage for 4 weeks, the surface becomes hydrophobic. However, hydrophilicity is not the only property of titanium that changes with aging. Although we concentrated mainly on surface wettability, we observed that this change in the hydrophilic status is also associated with a significant increase in the level of surface hydrocarbons.[8)] Furthermore, our findings revealed that biological aging of titanium always occurs as long as the implant is composed of titanium, regardless of the surface type.[9)] Therefore, most implants currently in use have undergone aging, which means that the associated changes limit the osseointegration capacity of titanium in the implants. Here we highlight some very important issues that are directly related to clinical practice.

Clinical impacts of titanium aging

Unfortunately, the current scientific technology is unable to prevent titanium aging. Several reports regarding titanium aging published in top scientific journals have suggested the following important clinical problems:

1. Are the implants currently in use in the best condition?

Considering the current methods of implant distribution and sale, it appears almost impossible to avoid implant aging. Although it is known that implants that are less than 3 days old have a relatively high osseointegration capacity, it is impossible to deliver these implants to their end-users, dentists and surgeons, within 3 days of manufacture. This indicates that the integration capacity of implants currently in use is degraded to some extent.

2. How is the extent of implant aging assessed?

The dates of manufacture of implants are currently not recorded. Accordingly, there are no means by which dentists can determine how much time has passed since manufacture of the implants delivered to them or the extent to which their osseointegration capacity has decreased.

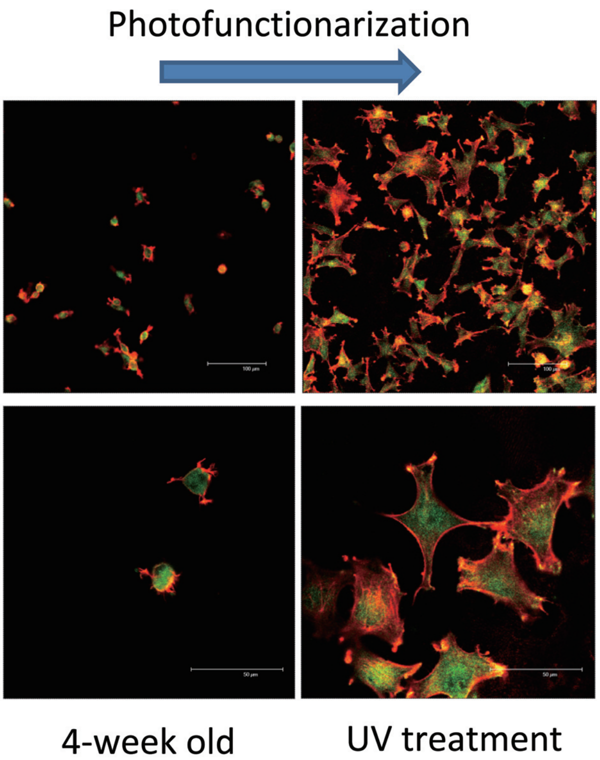

Fig. 2 Confocal microscopic images of cell density (top panels) and initial behavior (lower panels) of osteoblasts 3 h after seeding with or without UV treatment.

3. Do all implants have the same osseointegration capacity?

When the age of implants in use differs, they will also differ in their osseointegration capacity. For example, if a patient undergoes insertion of 3 implants, there is no guarantee that all 3 implants will have the same osseointegration capacity. The same situation arises when 2 patients undergo insertion of 1 implant each. Because the dates of manufacture are not recorded, there is no way of ascertaining the likely osseointegration capacity of any particular titanium implant.

Now that such unprecedented and extremely serious clinical problems have been clarified, what actions should we, as dentists, take in order to achieve better treatment outcomes for our patients? As mentioned above, the current scientific technology does not offer any effective means of preventing titanium aging. However, titanium aging can be overcome by photofunctionalization.

Photofunctionalization of Titanium Implants

Photofunctionalization has been identified and developed as a means of recovery of titanium aging.[10)]

This process involves treating implant surfaces with multiple beams of ultraviolet (UV) light of a specific wavelength and intensity; simply applying commercially-available UV light for a few minutes will not have any biological effect. Photofunctionalization not only induces recovery of implant surfaces from titanium aging but also has additional effects.

One such physical change is the conversion of the implant surface from a hydrophobic to a hydrophilic surface while also markedly improving its affinity to blood. However, hydrophilicity is not the only characteristic of implants with a high osseointegration capacity,[11)] and photofunctionalization increases the osseointegration capacity by improving various other physical characteristics.[12)]

A change in biological properties is also demonstrated by osteoblasts that have adhered to an implant surface after 3 h in culture. The left panels of Fig. 2 show adhesion on a normal titanium rough surface, whereas the right panels show osteoblast adhesion on a titanium rough surface after photofunctionalization. On the normal titanium rough surface, few cells are present and they are small and round, attached to the surface with no ability to spread sufficiently. In contrast, on the titanium surface that has undergone photofunctionalization, cells are apparent and they have spread significantly over the surface, with cell processes extending in various directions. In addition, animal experiments have demonstrated that photofunctionalization triples the strength of bone-titanium integration in the period soon after insertion.[10)] These results strongly support the hypothesis that photofunctionalization of titanium surfaces increases the amount of bone that develops around an implant, while also speeding up the process of bone formation.

A bone-implant contact rate of 98% was reportedly achieved for titanium surfaces following photofunctionalization, which is close to 100% in effect. This near-perfect bone formation phenomenon has been newly termed "*super osseointegration*." Considering that the contact rate of implants not treated with photofunctionalization is 55%, the significance of this technique is obvious.[10] Moreover, analysis of the bone surrounding implants, which is necessary for successful implantation, revealed that when implants that were a few months old were directly inserted after UV light application, over 98% (close to 100%) bone formation was achieved around the implant.[13]

Clinical Impact of Photofunctionalization

Photofunctionalization is expected to contribute to current implant therapy in several ways. Its greatest clinical benefit is the provision of implants of a standardized quality with a high osseointegration capacity (unaffected by aging) to all patients, for all types of cases, and involving all sites of residual ridge. As discussed in the section on "biological aging of titanium," there is no way to determine the amount of aging that implants have undergone. If this could be determined, dentists could avoid inserting implants with a low osseointegration capacity. Photofunctionalization solves this issue by making it possible to always use implants in excellent condition. In other words, it is a means of providing standardized high-quality implant treatments. In addition, photofunctionalization offers various other benefits. 1) Photofunctionalization improves the osseointegration speed of the implant itself and thus can also reduce implant healing time. 2) Because it increases the osteoconductivity of implants, this technique can greatly contribute to improving the success rates in complex and/or difficult cases, including those involving implant insertion along with bone grafting. 3) Photofunctionalization can lower the technological hurdles for implant treatments so that more patients can benefit from such treatments. 4) If photofunctionalization can be used to achieve almost complete bone contact for implants, patients would require shorter implants, consequently reducing the need for surgical procedures, such as bone grafting or sinus lifting, prior to implant insertion.[14] This would reduce treatment times as well as treatment costs. 5) Photofunctionalization can lead to improved load sharing around implants, thereby increasing their long-term stability.[15] Taking into account all these benefits, photofunctionalization is expected to bring about an unprecedented revolution in treatment paradigms (concepts, strategies, etc.) for the use of dental implants by rapidly improving clinical outcomes.

Photofunctionalization has characteristics that differ markedly from conventional implant surface improvement techniques with regard to effects, applicability, and scientific background. In contrast to surface improvement techniques implemented in the past by implant manufacturers, photofunctionalization has been shown to exert effects on all titanium implant surfaces tested to date.[16] This makes it applicable to almost all types of implants currently in use. In other words, it can be introduced without altering any of the systems currently in use by dentists, and the benefits of photofunctionalization can be achieved with any brand of implant surface as long as it is titanium.

Educational Benefits of Photofunctionalization and Biological Aging of Titanium

The discovery of photofunctionalization and the related concept of titanium aging have had great scientific and educational effects around the world because of their strong scientific basis and universal applicability. The discovery of titanium aging and the invention of the principle of photofunctionalization, along with its effects, have been introduced in national educational programs (syllabuses) in Germany, Switzerland, and Austria. This has great significance, demonstrating that photofunctionalization is probably the first surface-improvement technique to come into common use, with students and even medical interns now learning it as part of their educational curriculum. Furthermore, definitions of photofunctionalization and the concept of *super osseointegration* along with phototechnology, which causes titanium to change from a bioinert to a bioactive material, have now been included in well-known textbooks on titanium science.

Hopes and Future Perspectives

We anticipate that the concepts of photofunctionalization and biological aging of titanium and the above-mentioned features have demonstrated that this technology and the associated knowledge herald a new age for implant treatment. In addition, we hope to revolutionize clinical implant therapy through these new concepts. Meanwhile, an additional crucial finding from this review associated with the knowledge of aging is the impact on the science of the related fields of implants and titanium. The age of titanium samples has not been standardized under experimental conditions till date. In future research, it may be extremely important when comparing different titanium samples to ensure that they are of uniform age so as to standardize the research outcome. Based on these achievements, future studies should investigate the mechanisms that link the hydrophilic status of the surface, the removal of hydrocarbons, and the enhanced bioactivity of implant surfaces. Furthermore, as the ultimate aim, we intend to report future findings of clinical research to evaluate these technologies.

Finally, the implant treatment presented in this review has been discussed only with regard to the point before regular maintenance; however, increased bone contact rates cannot be maintained indefinitely. Our most important responsibility, as dentists, is the permanent maintenance of inserted implants. This is impossible without fundamental dental treatments, namely periodontal and root canal treatments, in addition to prosthetic treatments performed by skilled and experienced practitioners. I would like to conclude this review by expressing my earnest hope that we will engage in implant treatments after acquiring sufficient clinical knowledge and skills.

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