

# Soft and hard tissue response to zirconium dioxide dental implants – A clinical study in man

Christian BLASCHKE<sup>1</sup>, DMD & Ulrich VOLZ<sup>2</sup>, DDS

<sup>1</sup> Z-Systems Australasia, Auckland, New Zealand

<sup>2</sup> Z-Systems AG, Constance, Germany

Correspondence to: Christian Blaschke, DMD  
Z-Systems Australasia  
7 Norfolk Road, Stanmore Bay, Auckland, NEW ZEALAND  
TEL: +64 (0) 9 424 5917  
FAX: +64 (0) 9 428 3641  
EMAIL: cblaschke@z-systems.co.nz

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## Abstract

Titanium dental implants have been used successfully in implantology for more than 40 years. Recent research, however, suggests that titanium might have more side effects than previously believed. Zirconia ceramics have been employed in orthopaedic surgery for approximately 30 years and were recently introduced into dentistry as a metal replacement for crown and bridge work as well as implant abutments. Zirconium dioxide has been shown in both *in vitro* and *in vivo* studies to have desirable osseointegrative properties. This clinical study shows that dental implants made from zirconia are a feasible alternative to titanium dental implants. In addition to excellent cosmetic results, zirconia implants allow a degree of osseointegration and soft tissue response that is superior to titanium dental implants.

## Abbreviations & Units

API: Approximal Plaque Index  
PBI: Papilla Bleeding Index

## Introduction

Dental implants are becoming the treatment of choice for the replacement of missing teeth. Not only do they allow tooth replacement but also restore function and cosmetics to a degree generally not achievable with any other kind of dental restorations [2].

While dental implants have been mentioned as early as the 9<sup>th</sup> century, the first successful implants were reported in 1939 by Stock [27]. Later, Brånemark [2] found that titanium was generally biocompatible and showed good osseointegration.

Osseointegration was originally defined as the direct contact of vital bone with the implant surface in the absence of a connective tissue layer. This definition was later modified to describe “a direct structural and functional connection between vital bone and the surface of a loaded implant” [3]. Titanium appeared to be the material of choice, as it was believed that it forms a bio-inert oxide layer on its surface [2,14]. However, several published studies demonstrated corrosion of titanium *in vitro* [29] and *in vivo* [25]. Titanium particles are shown to stimulate bone resorption by inducing differentiation of murine osteoblasts and thus contributing to aseptic loosening [18]. Studies in recent years have demonstrated that titanium can cause DNA damage [6, 7, 9, 28, 30]. Furthermore, titanium has been found in regional lymph nodes after implant

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insertion [33, 25]. Finally, hypersensitivity to titanium has been reported [16, 18, 32, 34], and the induction of inflammatory changes in joint replacements by titanium is currently being discussed [17]. Holgers and co-workers have also described cellular inflammatory reactions around bone anchored percutaneous cochlear titanium implants in patients, indicating immunological response to the implant material [12].

Osseointegration of titanium implants has been studied in detail [2,14], while similar studies regarding zirconium implants are relatively few [19]. Pioneering work in the field of zirconia implants has been done by the Swiss stomatologists Prof. Sami Sandhaus and Dr Katalin Pasche-Vadnai, Lausanne, but unfortunately all articles are published in French [23, 24, 25].

It is generally accepted that a certain degree of soft and hard tissue resorption will take place after metal implant placement [11, 30, 33]. Zirconia, however, has been shown both *in vitro* and *in vivo* to exhibit desirable properties with regard to osseointegration, cell metabolism and soft tissue response. Zirconia also displays a significantly reduced plaque affinity, thereby reducing the risk of inflammatory changes in the adjacent soft tissue [1, 4, 8, 13, 15, 16, 28].

Ceramic materials such as aluminum oxide or zirconia have been used in dentistry for several decades mainly due to their positive material properties, which include biocompatibility and aesthetics. Full ceramic systems are generally used for single tooth restorations and small bridges but also for the restoration of implants [8].

Recently zirconia was introduced in various configurations as an alternative to metal-based crown and bridge work. This material displays excellent mechanical properties, particularly flexural strength (greater than 1000 MPa), hardness (1200–1400 Vickers), and Weibull modulus of 10–12. Zirconia is partially stabilized by small additions of yttrium oxide ( $Y_2O_3$ ) to achieve these favorable properties. By adding aluminum oxide the flexural strength can be further increased [METOXIT AG, Switzerland, personal communication].

The high mechanical strength and biocompatibility of zirconia resulted in its use in a range of implant applications such as finger and hip implants. In dentistry, zirconia is used for root posts, crowns and bridgework, and implant abutments. The biomechanical properties together with bio-inertness and the white color of zirconia results in superior aesthetic dental and implant restorations [33, 34].

Currently, most data on zirconia dental implants are obtained through animal testing, but some human clinical data is already available [15, 16, 33, 34]. This article describes the results of a 5-year study of Z-Lock implants in man.

**Figure 1:** Sidexis® analysis of a digital radiograph. The line on the picture below represents the area analyzed. The graph shows the values which are proportionate to bone density.

## Material & Methods

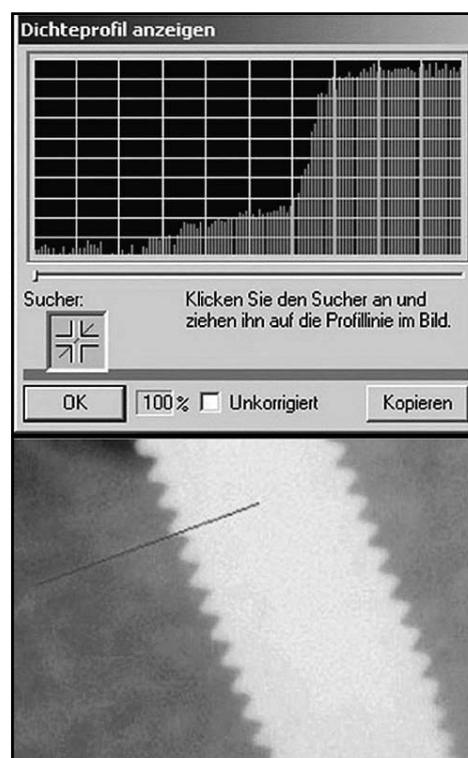
Thirty-four patients received a total of 66 implants (zirconium dioxide fixtures) and were monitored for a 2 to 5 year period. The earlier implants were of the type VOLZIRKON1® and VOLZIRKON2® the latter were Z-Lock3®. All implants were produced by Z-Systems AG (Constance, Germany).

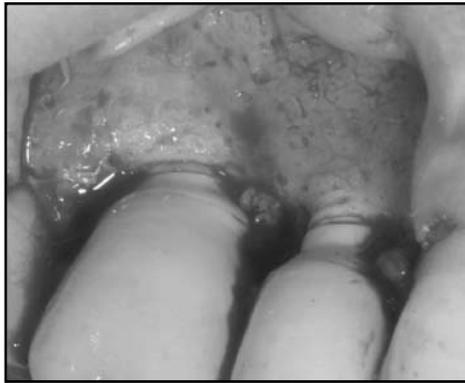
These implants are of a monoblock design with a sandblasted intra-osseous section and a polished transgingival/abutment portion. The prosthetic platform of the Z-Lock3® implants varies from VOLZIRKON1® and VOLZIRKON2® implants in that the abutment shoulder was made broader to facilitate restoration. Furthermore an external hexagonal surface was added to the abutment to make the implant handling easier for the surgeon.

All fixtures were CAD/CAM milled out of Bio-HIP A zirconia blocks. These blocks are produced by condensing ultra fine zirconium dioxide powder with a particle size of 0.2 micron under 1500 bar pressure for several days. As a result, flexural strength and fracture resistance increases. After insertion of fixtures, the patients have been asked to wear either splints or a specific prosthesis to protect the implant during the initial healing period.

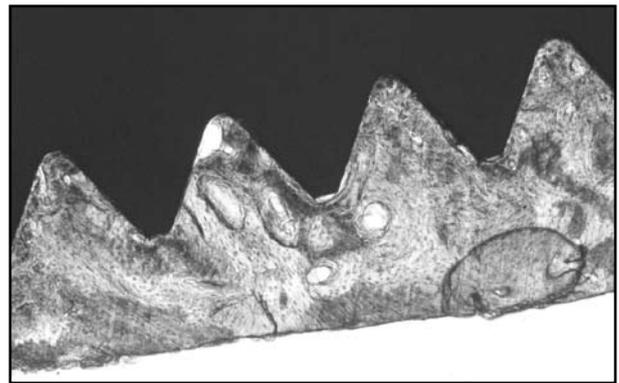
Implants were restored with zirconia superstructures four months (lower jaw) and six months (upper jaw) later. Patients were invited for regular follow-up examinations to re-evaluate the soft and hard tissue response to the implants and restorations. In addition, the state of the implant was reevaluated in February and April 2005.

All implants were radiologically examined to determine the crestal bone quality. The radiographs were either of digital nature or digitalized conventional radiographs.



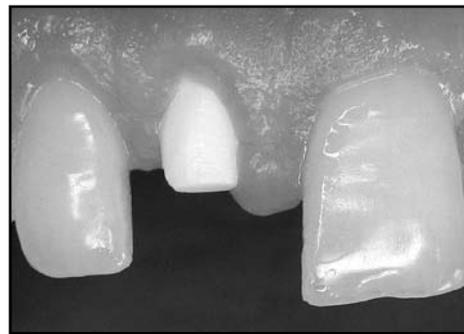


**Figure 2:** Clinical photograph of surgically uncovered implant crown interfaces showing the absence of crestal troughing. In contrast the bone curves onto the implant surface.



**Figure 3:** Histology of a zirconia implant in man.

**Figure 4 (right):** Healthy soft tissue attached to the implant abutment section after osseointegration has taken place.



The bone density was evaluated using appropriate software (Sidexis®). Therefore, not only quantitative but also qualitative analysis of the crestal bone was possible (Fig. 1).

One patient underwent explorative surgery, after giving written consent, which allowed visual inspection of the crestal bone (Fig. 2). This procedure was not repeated on other patients due to ethical concerns. Histological evaluation of one extracted implant, which had been fractured due to trauma, has been carried out as well.

To clinically assess the health status of soft tissue surrounding the implant, Approximal Plaque Index (API), Papilla Bleeding Index (PBI), and attachment level were recorded and compared to the levels with the patients' natural teeth.

## Results

One to two years following implantation, 98% of 66 implants showed good osseointegration. No fixture had failed after the prosthesis was fitted. One fixture broke due to external trauma and consequently had to be removed. The implant was removed with adjacent bone attached to the implant and a histological examination was carried out. The histological examination, performed by Prof. W Wagner, University of Mainz, Germany, showed direct bone to implant contact. No fibrous layer was detected. Signs of a foreign body reaction were not observed (Fig. 3).

In addition, 97.5% of all implants showed dense cortical bone in the sense of a lamina dura in the absence of any sign of crestal bone troughing. The reliability of the radiological analysis was confirmed in one patient.

All clinical parameters such as API, PBI, attachment level, and probing depth, revealed healthy soft tissue conditions. The values for attachment level were all in the range of the patients' natural teeth, if not better. API and PBI showed significantly better values compared to the patients' natural teeth (Fig. 4).

## Discussion

Zirconia implants showed desired biological properties, such as good osseointegration and favorable soft tissue reactions. The rate of osseointegration is very similar, if not better, than that reported for titanium [2, 14]: 97.5% of all implants showed the formation of a lamina dura, suggesting an increased quality of osseointegration [16]. A possible explanation could be that zirconia acts as a calcium cathode and therefore promotes the regeneration of cortical bone. Furthermore, *in vivo* studies demonstrated that zirconia will cause a significantly greater release of metalloproteinases-2 and -9 than titanium, thereby promoting osseointegration better than titanium [5, 20].

The soft tissue response to the zirconia surface was excellent. Common soft tissue problems as reported with conventional titanium fixtures were not observed. This might be due to the low plaque affinity (shown by the low APIs and PBIs) of the implant surface making oral hygiene easier for the patient [10]. As mentioned previously, titanium implants may lower metabolic rates of osteoblasts [18, 30]. This could lead to coronal troughing of the bone adjacent to implants, thereby causing soft tissue recessions as well. None of the zirconia implants

showed such bone troughing in follow-up examinations.

In contrast to titanium18, zirconium does not appear to induce hypersensitivity [18, 32].

In conclusion, the results of this study strongly suggest that zirconia fixtures such as Z-Lock3 are suitable for restorations with high cosmetic demands, especially in patients with clinical metal allergy. These implants also represent a significant improvement over titanium fixtures due to the development of a lamina dura in the coronal aspect of the implant. Hopefully these results will be confirmed by larger clinical studies comparing the hard and soft tissue responses to the implant fixtures.

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