Current Findings Regarding Zirconia Implants

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ABSTRACT

Purpose: The present article aims to analyze the available clinical data on the survival and success rate of dental zirconia implants (ZI).

Material and Method: Studies (2006–2011) listed in the bibliography were obtained by using the key words "zirconia, zirconium, implants, dental, clinical" and combinations of these in different databases and on the internet. These articles served as a basis for the article.

Results: A total of 17 clinical studies were found, involving 1,675 implants and 1,274 patients. In 16 studies, one-piece implant systems were investigated. The survival rates for ZI range from 74–98% after 12–56 months, with success rates between 79.6–91.6% 6–12 months after prosthetic restoration. However, the design of most of the studies show considerable shortcomings, and only low evidence level.

Conclusion: The small number of studies and the limited period of observation permit only a qualified statement on the clinical success of ZI. The results available to date indicate that ZI are inferior to titanium implants (TI) with regard to survival and success rates. Well-conducted long-term studies are urgently needed to permit a meaningful assessment of the survival or success rates of ZI and a statement concerning their application as an alternative to TI.

KEY WORDS: outcome, review, success rate, survival, zirconia implants

INTRODUCTION

Enossal implants are mainly used in modern dental implantology and their reliability has been proven in experimental fundamental studies and long-term clinical observations.[1] The breakthrough in the field of dental implantology is attributed to the Swede Per-Ingvar Brånemark, who inserted the first titanium screw implant in a patient in 1965.[2] Since Brånemark's observation, titanium has established itself as the preferred metal for dental implants. In particular, it is characterized by lightness in weight, great mechanical strength, a high melting point and small degree of thermal expansion. For the manufacture of dental implants, titanium is used both in its commercially pure form and in the form of aluminum alloys free of vanadium (Ti-6Al-7Nb) or containing vanadium (Ti-6Al-4V). Although titanium is a very reactive metal, the sluggishness of its reaction resembles that of platinum. In addition, it possesses a high resistance to corrosion, although as a very base metal, it is inclined to release ions in an electrolyte solution. The reason for this is the spontaneous formation of a passivating layer of oxide on the surface of the titanium after contact with air and liquids. This layer mainly consists of TiO_2, but also contains other oxides, such as TiO and TiO_5, and has a decisive influence on implant osseointegration and the accretion of cells on its surface.[3,4]

Despite titanium's excellent resistance to corrosion, it could be verified that after the insertion of screw implants made of titanium in the jaws, there was an accumulation of titanium in the tissue of the internal organs, particularly in the lungs and bones.[5] High

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amounts of titanium in the vicinity of implants were shown in animal experiments[6,7] and it could be verified that there were deposits of titanium particles in regional lymphatic nodes after the insertion of implants.[8] It is assumed that these fine particles were detached from the surface mechanically during implantation and transported to the lymphatic nodes by macrophages. In none of the investigations were the deposits found accompanied by histologically verifiable signs of inflammation. Besides the detachment of titanium particles during mechanical insertion in the body,[9] it could be confirmed that a weak – but nevertheless verifiable – corrosion takes place between titanium and dental alloys when titanium implants come in contact with metal alloys via saliva[10] or titanium comes in contact with fluoride.[11] The longer a material remains in the tissue, the greater the concentration of its corrosion products.[6] In view of this, the deposit of titanium particles should be evaluated overall as critical.[8] Furthermore, it could be shown that human immune cells can be activated by TiO_2, leading to the creation of free radicals.[12] Although with the use of an enhanced immunological in vitro test procedure, such as the lymphocyte transformation test (LTT), cellular sensibilization toward titanium could be verified in single cases, the clinical relevance of which have not been conclusively assessed to date,[13] no definite hypersensitivity attributable to titanium's passivating layer of oxide is known in the literature up to the present day.[14] Another disadvantage of titanium as an implant material is its gray color. When titanium implants are inserted in the anterior or premolar maxillary region a gray shimmer through the thin peri-implant soft tissue can lead to aesthetic impairments, particularly in those cases where the soft tissue situation is not optimal.[15,16] An increasing general rejection by patients of metallic materials for implants, an (alleged) increased disposition to allergic reactions to metals, and a significantly increased aesthetic standard for prostheses during recent years has led to an increasingly critical attitude toward titanium as an implant material on the part of both patients and dentists and to the desire for metal-free implants. Furthermore, there has been an increase in general interest in modern implant materials with a tooth coloring.[17,18]

However, the use of ceramic implant materials goes back to the first decades of the last century when M. Rock applied for a patent on aluminum oxide in 1930. In 1965, S. Sandhaus had a screw-shaped implant made of alumina patented in England (Degussit Al 23), thus initiating the era of modern aluminum ceramics.[19] In 1976, Sandhaus's implant was followed by the Tübingen implant (Frialit I; Friadent, Mannheim, Germany), a step-shaped implant made of aluminum oxide for immediate implant placement in the anterior area. The Tübingen implant system was strongly propagated in Germany in the early 1980s but disappointed in terms of long-term stability. Consequently, it was withdrawn from the market and finally replaced by the titanium Frialit-II system (Friadent, Mannheim, Germany).[20] Another commercially available single-crystal alumina oral implant system (Bioceram, Kyocera, Kyoto, Japan) did also not meet the demands placed on it and disappeared from the market, too.[21] Ceramic dental implants were then ousted by titanium implants.[22]

Very often, the failure of alumina implant ceramic was ascribed to its fracture susceptibility due to its brittleness, low tensile strength, and long-term aging. Interestingly, only in one study implant fracture was stated as the cause of implant failure.[23] According to Koahl and colleagues, the main reason for the withdrawal of some of the alumina implant systems from the market remains unclear. They assumed that the fear of the dentists that alumina implants are prone to fracture might have played the crucial role.[24]

Because of the exceptional biophysical properties of Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) there have been attempts to apply this material as a substitute for metals in dentistry.[25] Its white color, low susceptibility to plaque, excellent biocompatibilty, and biotechnical properties (very high flexural strength, favorable fracture toughness and suitable Young's modulus) also permits manufacturing of qualitatively and aesthetically highly sophisticated implants and other parts required for dental restorations.[26,27] After the very promising results of experimental studies, implant systems made of zirconium ceramic are now available on the market. With the aid of the evaluation of the results of clinical studies our aim is to clarify the question as to whether the demands made on zirconium ceramic implant as an alternative to titanium can actually be fulfilled.

MATERIALS AND METHODS

The present article was drafted with the help of a literature search. The studies (from 2006 to 2011) listed in the bibliography, which were obtained using the search words "zirconia, zirconium, implants, dental, clinical"

and combinations of these in the PubMed, Scopus and Embase databases, and in the Cochrane Library, served as a basis for the article. First, current relevant publications were obtained and, after that, topic-related articles via the link "similar articles." Inclusion criteria were the insertion of zirconia implants in patients, and publication in English or German. As only a few number of studies was available, no further exclusion criteria were specified.

RESULTS

Number and Type of Studies

A total of 21 publications appearing between 2006 and 2011 on the subject of "clinical use of dental implants made of zirconia" were obtained. These consisted of seven case reports, three prospective, and six retrospective clinical studies and a prospective randomized multicenter study (see Table 1). Most of the publications (six) appeared in 2010, followed by four in 2011 (up to July), and three in 2008.

Implant Systems Applied

In 16 of the 17 studies (including case reports), one-piece zirconia implants were applied and only one case report mentioned the application of a two-piece zirconia implant system (Ziterion, Uffenheim, Germany). Implants from Z-Systems (Constance, Germany) were most frequently applied, followed by implants from Bredent (Senden, Germany) and CeraRoot (Barcelona, Spain) in four studies, respectively. In three studies, custom-made zirconia implants were applied and one study investigated implants from Ziterion (Uffenheim, Germany).

Number of Implants Investigated

Altogether, the studies, including the case studies, involved a total of 1,675 implants and 1,274 patients. Apart from one case report, in which 15 implants were inserted in one patient, and another, in which both maxillary incisors were replaced by implants, the case reports each involved one patient and one implant respectively. Most of the implants investigated were made by CeraRoot ($n = 948$), followed by implants from Z-Systems ($n = 604$). A total of 102 implants made by Bredent and 20 custom-made, root-shaped implants were investigated.

Most of the patients, as well as most of the implants, were to be found in the study by Oliva and colleagues[28] in 2010. One implant was inserted in each of 831 patients, respectively. The authors applied implants of five different designs from Cera Root with three differently treated surfaces (UC = uncoated, C = coated, and ICE = acid-etched) and degrees of roughness. As early as 2006, Mellinghoff[29] had reported on the first clinical results of 189 enossal screw implants made of zirconia (Z-Look3, Z-Systems, Constance, Germany), which were implanted in 71 patients between 2003 and 2005. The study by Gahlert and colleagues[30] in 2011 involved 170 Z-Look3 implants (Z-Systems, Constance, Germany) inserted in 79 patients. The retrospective comparative post-investigation of consecutively inserted titanium and zirconia implants by Lambrich and Iglhaut[31] involved 124 patients treated between 2003 and 2006. The study followed up a total of 127 Z-Look3 implants from Z-Systems AG (Constance, Germany) and 234 titanium implants (81 3i Osseotite implants [external hexagon] and 3i OsseotiteCertain implants [internal connection] made by BIOMET 3i Inc. [Palm Beach Gardens, FL, USA] and 153 tapered screw-vent/MTX implants [internal hexagon] from Zimmer Dental GmbH [Freiburg, Germany]). In 2007 Oliva and colleagues[32] published a clinical study on a total of 100 zirconia implants with coated and uncoated surfaces from CeraRoot (Barcelona, Spain), which were implanted in 36 patients.

TABLE 1 Publications on Clinical Use of Dental Implants Made of Zirconia

Design of Study	Level of Evidence	Number of Published Studies	References
Prospective randomized trials	Ib	1	41
Prospective trials	IIb	3	28,34,39
Retrospective study	IIc	6	29–32,40,42
Case reports	IV	7	33,46,64–68
Total		17	

Period of Investigation (Table 2)

The post-observation period for the zirconia implants ranged from one to five years in total. Only in the case report by Arnetzl and colleagues[33] was no exact time given. The longest post-observation periods of up to five years (60 months) were to be found in studies investigating implants from Z-Systems or custom-made implants. CeraRoot implants were investigated during a period of between 12 and 36 months and Bredent implants between 12 and 24 months.

Survival and Success Rates of Zirconia Implants (Table 2)

Only in five of the clinical studies (out of a total of ten, as the case reports were not considered) was a distinction made between the survival and success rates of the implants; while the other five studies reported on the success rate, they generally equated it with the survival rate.

In three studies by Mellinghoff,[29] Lambrich and Iglhaut[31] and Pirker and Kocher[34] the probability of survival of the implants was calculated using a Kaplan–Meier analysis. Whereas Mellinghoff indicated an exact percentage for the success rate (79.6%) with 44 patients using the success criteria of Jahn and D'Hoedt[35,36] both Lambrich and Iglhaut and Pirker and Kocher provided data about the success criteria applied (success criteria according to Buser and Lang,[37,38] [Lambrich and Iglhaut[31]] or success criteria according to Jahn and Buser[22,35] [Pirker and Kocher[34]]), but no percentages were given in either study concerning the success of the zirconia implants.

Borgonovo and colleagues[39] reported a 96.16% survival rate for the implants after 24 months and a 91.6% success rate according to clinical radiological criteria six months after prosthetic restoration or at least 12 months after insertion.

The investigation by Gahlert and colleagues[30] differs from the other studies with regard to the calculation of the survival rate. In their study based on all 170 zirconia implants (Z-Look3) inserted between October 2004 and September 2007 they only considered those implants which failed after prosthetic restoration on account of a fracture. This resulted in a failure rate of 7.6% (13/170) or a survival rate of 92.5% after 20–56 months (mean 36, 75 ± 5.34 months).

Inclusion and Exclusion Criteria (Table 3)

If a more exact analysis was made of the criteria for the inclusion or exclusion of patients in the clinical studies (the case reports not being considered), it is noticeable that Blaschke and Volz[40] did not give any detailed information about the patients in their study.

The studies by Mellinghoff,[29] Lambrich and Iglhaut,[31] Oliva and colleagues[28] and Gahlert and colleagues[30] involved non-selected patients. Only the clinical studies by Oliva and colleagues,[32] Pirker and Kocher,[34] Cannizzaro and colleagues[41] and Borgonovo and colleagues[39] gave detailed information about the inclusion and exclusion criteria for the patients in whom zirconia implants were inserted. With the exception of Blaschke and Volz,[40] all other clinical studies gave more or less exact details of the jaw regions in which zirconia implants were inserted. Both Pirker and Kocher[34] and Cannizzaro and colleagues[41] only considered single-tooth gaps in their investigations and gave very exact information on these.

The study by Borgonovo and colleagues[39] included single-tooth gaps and partly toothed jaws in the premolar maxillary and mandible regions. They also provided detailed information including the minimum amount of bone required. The studies by Lambrich and Iglhaut,[31] Gahlert and colleagues[30] and Oliva and colleagues[28,32] all included prosthetic indications (from a single-tooth gap to an edentulous jaw), whereas in the Mellinghoff study[29] only single-tooth gaps and partly toothed jaws were considered.

Detailed Information on Implant Insertion (Table 4)

Point in time post-extractionem. Neither Blaschke and Volz,[40] Mellinghoff,[29] Gahlert and colleagues,[30] nor Borgonovo and colleagues[42] gave exact information on the point in time at which the implants were inserted following loss of teeth. In the studies by Oliva and colleagues[28,32] and Cannizzaro and colleagues,[41] it was merely mentioned that implants were inserted at all points in time post-extractionem. Lambrich and Iglhaut,[31] Pirker and Kocher,[34] and Borgonovo and colleagues[39] all gave more exact information.

Implantation site. The study by Blaschke and Volz[40] gave no indication as to the jaw or region where the zirconia implants were inserted. In the studies by Mellinghoff[29]

TABLE 2 Observation Period, Survival, and Success Rate of Zirconia Implants

No	Author/Year/Reference	Observation Period	Implant Survival Rate	Implant Success Rate
		Z-Systems Constance, Germany (one-piece implants)		
1	Blaschke and Volz **2006**[40]	≤60 months	98% after 12–24 months	
2	Mellinghoff **2006**[29]	≤12 months	93% after 12 months (Kaplan–Meier-analysis)	79.6% [success criteria according to Jahn and D'Hoedt[35,36] ($n = 44$)]
3	Lambrich and Iglhaut **2008**[31]	≤45 months	**91.3% (Zirconia)** 94.8% (3i-Osseotite) 99.3% (MTX-)TSV) after 45 months (Kaplan–Meier-analysis)	success criteria according to Buser and Lang[37,38] (but without radiographs), no percentages
4	Cannizzaro and colleagues **2010**[41]	12 months	85% immediate loading 90% no immediate loading (after 12 months)	
5	Gahlert and colleagues **2011**[30]	≤56 months	92.35% after 20–56 months	not specified
		CeraRoot, Barcelona, Spain (one-piece implants)		
1	Oliva and colleagues **2007**[32]	12 months	98% after 12 months	
2	Oliva and colleagues **2008**[65]	12 months		
3	Oliva and colleagues **2010**[67]	36 months		
4	Oliva and colleagues **2010**[28]	≤60 months	94.95% after 24 months (92.77%: UC, 93.57%: C, 97.60%: ICE)	
		Bredent, Senden, Germany (one-piece implants)		
1	Aydin and colleagues **2010**[66]	12 months		
2	Arnetzl and colleagues **2010**[33]	not specified		
3	Borgonovo and colleagues **2010**[42]		total (all implants): 89.1% augmentated bone: 74.0%, native bone: 97.0%	
4	Borgonovo and colleagues **2011**[39]	≤24 months	96.16% after 24 months	91.6% (clinical radiological criteria 6 months after prosthetic restoration)
		Custom made one-piece implants		
1	Pirker and Kocher **2008**[64]	24 months		
2	Pirker and Kocher **2009**[34]	24 months	0% group A after 24 months 92% group B after 24 months (Kaplan–Meier-analysis)	success criteria according to Jahn[35] and Buser, no percentages
3	Pirker and colleagues **2011**[68]	24 months		
		Ziterion, Uffenheim, Germany (two-piece implants)		
1	Nevins and colleagues **2011**[46]	12 months		

TABLE 3 Inclusion and Exclusion Criteria of Studies

Author/Year/Reference/Study Design	Inclusion and Exclusion Criteria
Z-Systems Constance, Germany (one-piece implants)	
Blaschke and Volz **2006**[40] *prospective study*	patient data not specified
Mellinghoff **2006**[29] *retrospective study*	48 female and 23 male unselected patients; age range 17 to 71 years; single gaps and partly edentulous jaws
Lambrich and Iglhaut **2008**[31] *retrospective study*	62 female and 62 male unselected patients; mean age 48 years; all prosthetic indications (from a single gap to a fully edentulous jaw)
Cannizzaro and colleagues **2010**[41] *prospective randomized multi-center study* (only 4 out of 16 participating centers delivered data!)	detailed inclusion and exclusion criteria immediate loading: 13 female and 7 male patients, mean age 39 years (range 26–55 years); no immediate loading: 10 female and 10 male patients, mean age 38 years (range 18–54 years); one single tooth implant in the maxilla or mandibula (residual bone height ≥10 mm, thickness ≥ 5 mm)
Gahlert and colleagues **2011**[30] *retrospective study*	unselected patients single gaps and partly to fully edentulous jaws
CeraRoot, Barcelona, Spain (one-piece implants)	
Oliva and colleagues **2007**[32] *retrospective study*	unselected patients, age range 28–78 years exclusion criteria: smoker or patients with a health condition or disease contraindicating oral surgery, including pregnancy and breastfeeding all prosthetic indications, including sinus lifting
Oliva and colleagues **2010**[28] *prospective study*	513 female and 318 male unselected patients, mean age 48 years (range 19–80 years) exclusion criteria: ≥10 cigarettes/day, health condition or disease contraindicating oral surgery, including pregnancy and breastfeeding
Bredent, Senden, Germany (one-piece implants)	
Borgonovo and colleagues **2010**[42] *retrospective study*	unselected patients 8 single gaps and partly edentulous jaws
Borgonovo and colleagues **2011**[39] *retrospective study*	detailed inclusion and exclusion criteria 1 female and 15 male patients, mean age 54 years (range 36–72 years) single gaps and partly edentulous jaws in the premolar area of the maxilla or mandibula (residual bone height ≥8 mm, thickness ≥ 4 mm)
Custom made one-piece implants (one-piece implants)	
Pirker and Kocher **2009**[34] *prospective study*	group A: 4 female and 3 male patients, mean age 40 ± 8 years (range 27–60 years) group B: 4 female and 8 male patients, mean age 45 ± 12 years (range 27–65 years) single tooth gap, uncompromised periodontal ligaments in the anterior or premolar region indications for tooth extraction: root caries, vertical or horizontal root fracture, endodontic lesions, unsuccessful root canal treatment exclusion criteria: crestal bone defects, surgical tooth removal affecting the bone

TABLE 4 Specific Data on Implant Size and Implant Insertion

Author/Year/Reference	Time Point of Implantation	Region of Implant Insertion	Implant Dimensions
	Z-Systems Constance, Germany (one-piece implants)		
Blaschke and Volz **2006**[40]	not specified	not specified	not specified
Mellinghoff **2006**[29]	not specified	every region	diameter: 3.2–5 mm length: 10–14 mm
Lambrich and Iglhaut **2008**[31]	355 (94.4%) late implants 7 (1.9%) delayed immediate implants 14 (3.7%) immediate implants	every region	Zirconia: diameter: 3.2–5 mm length: 10–13 mm Titanium: diameter: 3.25–5.7 mm length: 8–6 mm
Cannizzaro and colleagues **2010**[41]	any time after tooth extraction	anterior maxilla: 16 implants maxillary premolar area: 11 implants maxillary molar area: 2 implants anterior mandible: 2 implants mandibular premolar area: 7 implants mandibular molar area: 2 implants	diameter: 3.25–5/6 mm length:10/11.5–14/15.5 mm
Gahlert and colleagues **2011**[30]	not specified	all except two implants: anterior maxilla and premolar area	diameter: 3.25 mm (12/13, „reduced diameter“) diameter: 4 mm (1/13)
	CeraRoot, Barcelona, Spain (one-piece implants)		
Oliva and colleagues **2007**[32]	any time after tooth extraction	every region aesthetic region: 34 implants posterior Maxilla: 46 implants anterior Mandible: 4 implants posterior Mandible: 16 implants	not specified
Oliva and colleagues **2010**[28]	any time after tooth extraction	anterior maxilla: 192 implants posterior maxilla: 305 implants anterior mandibula: 59 implants posterior mandibula: 275 implants	not specified
	Bredent, Senden, Germany (one-piece implants)		
Borgonovo and colleagues **2010**[42]	not specified	anterior maxilla: 30 implants posterior maxilla: 14 implants anterior mandibula: 2 implants	mean diameter: 3.93 mm mean length: 12.13 mm
Borgonovo and colleagues **2011**[39]	4 implants inserted in immediate post-extractive sockets	maxillary premolar area: 22 implants mandibular premolar area: 4 implants	mean diameter: 3.93 mm mean length: 12.4 mm
	Custom made one-piece implants (one-piece implants)		
Pirker and Kocher **2009**[34]	group A: 1–4 days post extractionem group B: 1–8 days post extractionem	anterior and premolar region	individual

and Lambrich and Iglhaut,[31] implants were inserted everywhere in both jaws but no details were given. All the other clinical studies provided more or less detailed information on the jaw regions in which zirconia implants were inserted.

Size of implants. In 3 (Blaschke and Volz,[40] Oliva and colleagues[28,32]) of the 10 clinical studies, neither the sizes nor the diameters of the implants were stated. In the investigation by Pirker and Kocher,[34] custom-made, root-identical implants were applied. The remaining six clinical studies provided information about both the sizes and diameters of the implants.

Augmentative measures (Table 5). In four investigations (Blaschke and Volz,[40] Mellinghoff,[29] Pirker and Kocher[34] Gahlert and colleagues[30]) there was no information about augmentative measures being undertaken when inserting the implants. In the six remaining studies, detailed information was given in some cases about the augmentative measures undertaken. These ranged from filling the extraction alveoli with autologous bone or bone substitute material (BSM) (Cannizzaro and colleagues[41]) to a sinus lift (Lambrich and Iglhaut[31] and Oliva and colleagues[28,32]).

Healing of the Implant (Table 5)

With the exception of two studies, the implants healed without loads in all investigations. In the study by Cannizzaro and colleagues,[41] a distinction was made between healing with and without immediate loading, whereas no information about healing was to be found in the study by Gahlert and colleagues.[30]

Prosthetic Restoration (Table 5)

With the exception of the studies by Mellinghoff[29] and Gahlert and colleagues,[30] all the studies provided information about the duration of healing. On the contrary, most of the studies lacked detailed information on the type (e.g., crown or bridge) (Blaschke and Volz,[40] Oliva and colleagues,[28,32] Lambrich and Iglhaut,[31] Borgonovo and colleagues[39,42]) or the material (Lambrich and Iglhaut,[31] Pirker and Kocher,[34] Gahlert and colleagues,[30] Borgonovo and colleagues[39,42]) of the prosthetic restoration.

DISCUSSION

Not least because of its white color and exceptional biophysical properties, it stands to reason that zirconium oxide (ZrO_2) should be used to develop biocompatible, qualitatively, and aesthetically high-quality implant systems.[25,43] On account of its strength and toughness to fracture zirconium ceramic is often described as "ceramic steel." Because of its extreme hardness and low temperature conductance zirconia has been widely used in the industry for a long time. It is used, for example, to make fuel cells, cutting tools and parts subject to high thermo-mechanical stress in automotive construction, and aviation and aerospace industries.[44] Zirconia stabilized with yttrium oxide (Y-TZP) is almost exclusively used in the field of dental ceramics. In recent times, attempts have increasingly been made to establish Y-TZP as a material in the field of dental implantology. A disadvantage of the pure yttria-stabilized zirconia is a tendency to age and thus degrade the mechanical properties in vivo. In a moist environment, the yttrium ion can be leached and its stabilizing effect on the zirconia lattice is lost.[26] Maybe as a consequence, the excellent strength and toughness to fracture might no more be sufficient to still carry the loads of oral implants.

However, there exist to date only a very few experimental and clinical studies that permit definite statements to be made on the application of zirconia implants.[26,45] The aim of the present article was to search the literature so as to obtain and analyze current clinical studies applying zirconia implants. In particular, it should be ascertained whether sufficient valid clinical data on the survival and success rates of zirconia implants are available to permit a statement on their application as an alternative to titanium implants.

Implant Systems Made of Zirconia

A total of 17 clinical studies (including case reports) published on the subject of "clinical application of dental zirconia implants" were obtained for the period of the investigation. So far, the development of two-piece implant systems made of zirconia has been hampered by the physical properties of the ceramic.[25] This is shown by the fact that to date only one case report on a two-piece implant system made of zirconia (Ziterion, Uffenheim, Germany) has been published.[46]

Thirteen studies investigated four commercially available implant systems made of zirconia (Z-Systems [Constance, Germany], Bredent [Senden, Germany], Ziterion [Uffenheim, Germany], CeraRoot [Barcelona, Spain]), while the remaining four studies investigated custom-made one-piece implants. The Z-Systems

TABLE 5 Data on Regenerative Procedures, Type of Healing, and Prosthodontic Treatment

Author/Year/Reference	Regenerative Procedures	Type of Healing	Prosthodontic Treatment
	Z-Systems Constance, Germany (one-piece implants)		
Blaschke and Volz **2006**[40]	not specified	non-loaded healing with protective splint or special prosthesis	mandible: >4 months after implant insertion; maxilla: >6 months after implant insertion; supra constructions made of zirconia, but no further specification
Mellinghoff **2006**[29]	not specified	non-loaded, transmucosal healing with protective splint	cemented zirconia crowns or bridges
Lambrich and Iglhaut **2008**[31]	lateral/vertical augmentation, sinus lifting	non-loaded healing; postoperative immediate implant protection by fitting protective stents (tooth supported) or mucosa-supported protective dentures relieved on the fitting surface	mandible: >3 months after implant insertion; maxilla: >6 months after implant insertion; prosthetic treatment not specified
Cannizzaro and colleagues **2010**[41]	gaps >2 mm between the implant and the alveoli were filled with autogenous bone or bone substitutes; no membranes or grids allowed	loaded and non-loaded healing with provisional crowns	cemented ceramic crowns 4–5 months after implant insertion
Gahlert and colleagues **2011**[30]	not specified	not specified	2/13: bridge placed on 2 implants 1/13: cantilever bridge 10/13: single crown
	CeraRoot, Barcelona, Spain (one-piece implants)		
Oliva and colleagues **2007**[32]	31 implants (16 coated/17 uncoated) with additional bone regenerative procedures; 19 implants (10 coated/9 uncoated) with sinuslifting procedures	non-loaded healing; 41 implants (21 coated/20 uncoated) were immediately restored with a provisional prosthesis, 20 of which were splinted to neighboring teeth or implants	4 months after implant insertion; 8 months after bone augmentation; all definite restorations were slightly in infraocclusion; prosthetic treatment not specified
Oliva and colleagues **2010**[28]	162 implants with additional bone regenerative procedures; 47 implants with sinuslifting procedures	non-loaded healing; immediate provisional restoration with vacuum stent; 137 implants with cemented provisional restoration slightly out of occlusion	4 months after implant insertion; 6–11 months after bone augmentation; all supra constructions made of zirconia were slightly in infraocclusion; prosthetic treatment not specified
	Bredent, Senden, Germany (one-piece implants)		
Borgonovo and colleagues **2010**[42]	35 implants with additional bone regenerative procedures	non-loaded healing; partially splinted to neighboring teeth	6 months after implant insertion; 10 months after bone augmentation; prosthetic treatment not specified
Borgonovo and colleagues **2011**[39]	12 implants with bone substitutes and membranes	non-loaded healing with special prosthesis; 8/10 implants were splinted to neighboring teeth	6 months after implant insertion; 8 months after bone augmentation; prosthetic treatment not specified
	Custom made one-piece implants (one-piece implants)		
Pirker and Kocher **2009**[34]	not specified	non-loaded healing (crown stumps)	single crowns 3–13 months after implant insertion

implants came on to the market in 2004 and the Ziterion implants in 2006. According to information from the manufacturers, 7,600 implants were sold by Z-Systems up to 2008. Ziterion did not reply to the request by Wenz and colleagues[26] for information on their sales figures. In contrast to commercially available dental zirconia implants, the number of manufacturers and suppliers of implant systems made of titanium is considerable. For example in a review article on the success of various root-shaped implant systems made of titanium Esposito and colleagues[47] considered more than 55 implant manufacturers.

Most of the zirconia implants investigated had a sand-blasted surface (Z-Systems, Bredent, and Ziterion). The surfaces of the implants from CeraRoot had been treated in various ways. In 2007, Oliva and colleagues[32] published a clinical study of a total of 100 zirconium implants with coated and uncoated surfaces from CeraRoot, which were implanted in 36 patients. In 2010, the same authors published a study in which one implant was inserted in each of a total of 831 patients, respectively.[28] The authors applied implants with five different designs and three differently treated (uncoated, coated, and acid-etched) or rough surfaces made by Cera Root.

In general, all modifications of the implant surface serve to optimize the implant-bone contact by increasing the contact surface between implant and bone cells. The surface structure should also help to stimulate bone regeneration emanating from the bony embedding tissue in a similar way to a guide rail. Until recently, the possibilities for structuring the surfaces of ceramic implants were limited compared to titanium.[48] Only in the last few years have experimental studies that investigated zirconium ceramic implants with an etched surface been published.[49,50] A good overview of osseoinegration of zirconia implants is to be found in the reviews by Andreiotelli and colleagues,[51] Ozkurt and colleagues[52] and Wenz and colleagues.[26] Although the zirconia implants mostly performed considerably worse compared to titanium implants in terms of surface roughness, the data in the experimental studies published to date indicate that the osseointegration of ceramic implants is comparable to that of titanium ones. In an article by Schultze-Mosgau and colleagues,[53] zirconia was even superior to titanium.

The study by Pirker and Kocher[34] is interesting from this point of view. They conducted a comparative clinical investigation in which sandblasted, root-identical zirconia implants were inserted in the patients of group A, while the implants inserted in group B also exhibited macroretention. In group A, all six implants were lost within 2 months, while the 12 implants in group B were found to have a 92% survival rate. The authors attributed the losses in group A to the fact that without macroretention, a too-strong primary fitting of the root-identical implant in the alveolus resulted. Because of the resulting pressure on the bone, resorbtion occurred in the area of the alveolar bone during the healing phase, which ultimately led to a loosening and loss of the implant. In contrast to the results of Pirker and Kocher, Oliva and colleagues[28,32] found no significant differences between the various modifications of the zirconia implant surfaces, although in the 2010 study,[28] the uncoated – and thus the smoothest – implants performed worse, compared to the coated or etched zirconia implants.

A general disadvantage of one-piece implant systems made of zirconia is additionally the load-free healing they require. One-piece zirconia implants also have to be inserted in an optimal vertical position to obtain excellent aesthetic results in the anterior tooth area, which considerably impedes or restricts handling. Moreover, it was found in several studies that with one-piece zirconia implants, the grinding required may lead to increased transformation of the ceramic in the monocline phase and to the creation of microscopic cracks, which has an adverse effect on the physical properties of the ceramic and possibly on its long-term stability.[54–56]

Survival and Success Rates of Zirconia Implants

The success of an inserted implant can be described by indicating its survival or success rate. With the aid of a Kaplan–Meier survival time analysis it is possible to calculate the probability that an event will occur before a certain point of time. This method has the advantage that it can also be used when the periods of observation are not identical for all patients.[57] However, a Kaplan–Meier analysis of the implant retention time merely serves to determine the survival time and does not consider other factors that might lead to a worse prognosis. To counter this problem, several authors have established clinical and radiological criteria, with the help of which a more extensive evaluation of the success rate of dental implants can be made (e.g., success criteria according to Albrektsson and colleagues,[58] Buser and Lang,[37,38] and Jahn and D'Hoedt[35,36]). The results of the

present study show that only 5 of the 10 clinical studies (case reports not being considered) distinguished between the survival and success rates of the implants, while although the 5 other studies reported on the success rate they, as a rule, equated it with the survival rate. A calculation of the probable survival time using a Kaplan–Meier analysis was performed in three studies with rates ranging from 0% to 93%. Thus, with Mellinghoff,[29] the survival rate was 93% after 12 months, with Lambrich and Iglhaut[31] 91.3% after 45 months, and with Pirker and Kocher[34] 0% in group A after 2 months and 92% in group B after 24 months. Only Mellinghoff gave detailed data on the 79.6% success rate in 44 patients using the success criteria of Jahn and D'Hoedt. On the other hand, both Lambrich and Iglhaut and Pirker and Kocher indicated the success criteria but did not state success rate percentages. Borgonovo and colleagues[39] gave a 96.16% implant survival rate after 24 months without, however, using a Kaplan–Meier analysis. According to clinical radiological criteria, the success rate was 91.6% 6 months after prosthetic restoration or at least 12 months after insertion of the implant.

The lowest success or survival rate of 74% was to be found in the investigation by Borgonovo and colleagues[42] of implants inserted in augmented bone. On the other hand, the implants inserted in native bone showed a success or survival rate of 97%. Implantation in extraction alveoli (immediate implantation), as investigated by Cannizzaro and colleagues,[41] reduced the survival rate to 60% compared to 97% in the case of late implantation. In contrast, in the same investigation, no significant differences in survival rates were to be found between implant with (85%) or without (90%) immediate loading. In the Lambrich and Iglhaut[31] study, in which survival rates of differing titanium implants were compared with zirconia implants, the zirconia implants performed the worse with a rate of 91.3% after 45 months (94.8% 3i osseotite and 99.3% [MTX] TSV).

Numerous studies are concerned with the success or survival rate of titanium implants. A recently published review article by Koller and colleagues[59] found survival rates ranging from 97% to 100% for titanium implants after between 3 and 10.4 years. On the other hand, Holm-Pedersen and colleagues[60] noted a survival rate of between 82% and 94% after 10 years. The success rates for titanium implants were given as ranging from 61% to 98%.[61,62]

If the six implants in group A, which were all lost within 2 months in the Pirker and Kocher[34] study, are discounted, a survival rate of between 74% and 98% after 12–56 months is to be found for zirconia implants. The success rate is given in two studies and is 91.6% 6 months after prosthetic restoration with Borgonovo and colleagues[39] and 79.6% after 12 months with Mellinghoff.[29] The validity of these survival or success rates found is limited, firstly because of the small number of studies and the resulting small number of patients and implants and secondly because of the limited period of observation. The 17 studies available (including case reports) include a total of 1,675 implants and 1,274 patients, with the Oliva and colleagues[28] study involving as many as 831 patients and implants. Thus, the remaining 17 studies involve only 844 implants and 443 patients. Furthermore, the observation period in the studies amounts to a maximum of five years so that long-term observations are lacking. Alone the multicenter study by Brocard and colleagues[61] involved 1,022 ITI implants. The authors also found that the success rate was initially high but fell after 5–7 years. From this point of view and with special regard to the potential lack of long-term hydrothermal stability of Y-TZP, well designed long-term studies are urgently needed so as to permit a meaningful assessment of the survival or success rates of zirconia implants.

Evidence Level of the Clinical Studies

With the help of so-called evidence levels and grades of recommendation an attempt is made to assess the scientific value of clinical studies. According to recommendations by the US Agency for Health Care Policy and Research (AHCPR), evidence levels are assessed on a scale of I to IV.[63] Studies in the Ia category (meta-analyses or randomized controlled studies) have the highest evidence levels and studies in the IV category (expert opinions) the lowest. The higher the evidence level, the better the scientific grounds for a therapy recommendation. The grade of recommendation is determined using the evidence-based studies available.

The 17 clinical studies published on the subject of "clinical use of dental zirconia implants" during the period of the study comprised seven case reports, six retrospective, three prospective clinical studies, and one prospective randomized multi-center study. Overall, it was found that almost all studies – with the exception of the prospective randomized multi-center study by

Cannizzaro and colleagues[41] and the prospective studies by Borgonovo and colleagues[39] and Pirker and Kocher[34] – were extremely poorly designed, thus meriting only a very low evidence level (<level III). It is particularly noticeable in the retrospective investigation by Blaschke and Volz[40] that essential data were lacking concerning design of the study, patient sample and criteria for inclusion and exclusion. Neither was there any information about the success criteria. Furthermore, the authors are the developers and distributors of the implant systems investigated so that a certain degree of subjectivity is to be assumed in this study. In the studies by Mellinghoff,[29] Lambrich and Iglhaut,[31] Oliva and colleagues[28] and Gahlert and colleagues[30] non-selected patients were included in the investigation and differing prosthetic indications (from a single-tooth gap to partly toothed or edentulous jaws) were included in the studies without being differentiated further. Although the study by Gahlert and colleagues is included in the evaluation, its design differs considerably from that of the other clinical studies. It focuses on the investigation of fractured implants from a total collection of inserted zirconia implants. However, the study definitely permits a statement to be made on the survival and success rates of zirconia implants. A considerable shortcoming of the prospective randomized multi-center study by Cannizzaro and colleagues,[41] in which zirconia implants with and without immediate loading were compared, is that patient data from only four of the 16 treatment centers which actually took part in the study could be considered. Consequently, only 40 patients and 40 implants (20 with and 20 without immediate loading) were included in the study. Hence, the study lacks validity on account of the small number of probands, and the evidence level of Ib aimed at for the prospective randomized multi-center study could not be obtained. The prospective study by Borgonovo and colleagues[39] likewise appears deficient and does not obtain a high evidence level, as the limit for the indications for implant insertion was not set carefully enough. The authors did in fact try to increase the quality of their study by including only 26 implants inserted in the premolar region in the evaluation instead of the original 54 implants, but multiple implantations, partly with augmentative measures, were also carried out as well as immediate and single-tooth implants. The implants were inserted in both the maxilla and the mandible, with some of the provisional single-tooth implants being interlocked with the neighboring teeth during the healing phase.

The only study to obtain evidence level IIa was that of Pirker and Kocher[34] as this is a study with a good design and clearly formulated criteria for both inclusion and exclusion and evaluation.

The clinical studies evaluated can only be awarded recommendation grade C, as apart from the Pirker and Kocher study the remaining clinical studies do not even obtain evidence level III.

CONCLUSION

Because of the small number of clinical studies published to date and the limited observation periods, which only in single cases extend up to 5 years, only a qualified statement on the clinical success of zirconia implants can be made. The results available to date indicate that zirconia implants are inferior to titanium ones with regard to survival and success rates. As most of the studies display considerable shortcomings regarding design, well-designed long-term studies are urgently required so as to permit a valid assessment of the survival or success rates of zirconia implants and a statement on their suitability as an alternative to dental implants made of titanium.

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