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# Are ceramic implants a viable alternative to titanium implants? A systematic literature review

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## Conflicts of interest:

The authors declare no conflicts of interest.

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## Abstract

**Aim:** The aim of this systematic review was to screen the literature in order to locate animal and clinical data on bone–implant contact (BIC) and clinical survival/success that would help to answer the question 'Are ceramic implants a viable alternative to titanium implants?'

**Material and methods:** A literature search was performed in the following databases: (1) the Cochrane Oral Health Group's Trials Register, (2) the Cochrane Central Register of Controlled Trials (CENTRAL), (3) MEDLINE (Ovid), and (4) PubMed. To evaluate biocompatibility, animal investigations were scrutinized regarding the amount of BIC and to assess implant longevity clinical data were evaluated.

**Results:** The PubMed search yielded 349 titles and the Cochrane/MEDLINE search yielded 881 titles. Based upon abstract screening and discarding duplicates from both searches, 100 full-text articles were obtained and subjected to additional evaluation. A further publication was included based on the manual search. The selection process resulted in the final sample of 25 studies. No (randomized) controlled clinical trials regarding the outcome of zirconia and alumina ceramic implants could be found.

The systematic review identified histological animal studies showing similar BIC between alumina, zirconia and titanium. Clinical investigations using different alumina oral implants up to 10 years showed survival/success rates in the range of 23 to 98% for different indications. The included zirconia implant studies presented a survival rate from 84% after 21 months to 98% after 1 year.

**Conclusions:** No difference was found in the rate of osseointegration between the different implant materials in animal experiments. Only cohort investigations were located with questionable scientific value. Alumina implants did not perform satisfactorily and therefore, based on this review, are not a viable alternative to titanium implants. Currently, the scientific clinical data for ceramic implants in general and for zirconia implants in particular are not sufficient to recommend ceramic implants for routine clinical use. Zirconia, however, may have the potential to be a successful implant material, although this is as yet unsupported by clinical investigations.

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Oral implants improve the quality of life for many of our patients (Kuboki et al. 1999; Heydecke et al. 2003, 2005). They were introduced some 30–40 years ago (Brånemark et al. 1969, 1977, 1984; Adell et al. 1970; Schroeder et al. 1976, 1978,

1981; Schulte & Heimke 1976; Schulte et al. 1978a; Adell et al. 1981; Albrektsson 1983). The material of choice for oral endosseous implants has been and still is commercially pure titanium. Ceramics have however been proposed as an alter-

native to titanium, based principally on the following arguments:

- (1) Esthetics: The fact that ceramic materials are white and are mimicking natural teeth better than the gray titanium allows an 'improved' esthetic reconstruction for our patients. This would be the consequent continuation of what began in the supramucosal part with white ceramic implant abutments and all-ceramic crowns fabricated from alumina and zirconia. Using white ceramic implants would preclude the dark shimmer of titanium implants when the soft peri-implant mucosa is of thin biotype or recedes over time.
- (2) Material properties: Potential health hazards may result from the release of titanium particles and corrosion products provoking unwelcome host reactions (for a review, see Tschernitschek et al. 2005). Elevated titanium concentrations have been found in the vicinity of oral implants (Bianco et al. 1996) and in regional lymph nodes (Weingart et al. 1994). Another investigation suggested a sensitization of patients toward titanium (Lalor et al. 1991). In a recent clinical study (Sicilia et al. 2008) on titanium allergy in dental implant patients, the authors found that nine out of 1500 patients showed positive reactions to titanium allergy tests which indicates a prevalence of 0.6%. However, the clinical relevance of the above findings is not clear yet since numerous investigations have demonstrated titanium to be a reliable implant material for long-term use in the oral environment.
- (3) Some patients request the treatment with completely metal-free dental reconstructions. If the number of remaining teeth decreases and implant-borne reconstructions are necessary, then these patients can only be helped using ceramic implants.
- (4) Ceramic implants are 'hip.' At present, the material most often used for producing oral implants is yttria-stabilized tetragonal zirconia polycrystal (Y-TZP, short: zirconia) with or without the addition of a small percentage of alumina. Various developments in the

production process for Y-TZP have led to improved material characteristics. The introduction of the HIP process (HIP: hot isostatic postcompaction) enabled the production of highly compacted structures with fine grain size and high purity of Y-TZP improving the material properties.

Ceramic materials for oral implants were already investigated and clinically used some 30–40 years ago. At that time, the ceramic material utilized was aluminum oxide (polycrystal or single crystal). The Swiss dentist Prof. Sandhaus was one of the first to use aluminum oxide (alumina) to produce his crystalline bone screw (Sandhaus 1968, 1971). Many years later he introduced the Cerasand ceramic oral implant (Sandhaus 1987). Also in the mid-seventies of the last century, the Tübingen implant was introduced (Schulte & Heimke 1976; Schulte et al. 1978a, 1978b). This oral implant system was also fabricated from alumina and was investigated both preclinically as well as clinically (Krempien et al. 1978; Schulte et al. 1978b, 1992; Schulz et al. 1981; Schulte 1981a, 1981b, 1984, 1985; d'Hoedt 1986, 1991; d'Hoedt et al. 1986; Schulte & d'Hoedt 1988; d'Hoedt & Schulte 1989). The same ceramic substrate was used for the Bionit implant system, which was developed in the eastern part of Germany a decade after the Tübingen implant (Müller et al. 1988; Piesold 1990; Piesold et al. 1990, 1991; Piesold & Müller 1991). Further ceramic implant developments in the late seventies and early/mid eighties were the ceramic anchor implant (Brinkmann 1978, 1987; Ehrl & Frenkel 1981), the Pfeilstift-Implant according to Mutschelknauss (Ehrl 1983), the Münch implant (Münch 1984; Strassl 1988) and others (Wörle 1981; Ehrl 1986).

Besides polycrystalline aluminum oxide as implant material, single-crystal alumina (sapphire) has also been used as an implant material (McKinney & Koth 1982; McKinney et al. 1983, 1984a, 1984b; Steflik et al. 1984, 1987; Akagawa et al. 1986, 1992, 1993b; Hashimoto et al. 1988, 1989; Sclaroff et al. 1990). In contrast to the polycrystalline alumina, this material had a glassy appearance. One commercially produced system was the Bioceram implant by Kyocera in Japan (Koth et al. 1988; Steflik et al.

1995; Fartash et al. 1996; Fartash & Arvidson 1997; Berge & Gronningsaeter 2000).

Alumina's physical properties include: a density of the alumina grains of approximately 4 g/cm<sup>3</sup>, a Vickers hardness of 2300, a compressive strength of 4400 MPa, a bending strength of 500 MPa, a modulus of elasticity of 420 GPa and a fracture toughness ( $K_{IC}$ ) of 4 MPa m<sup>1/2</sup>. The high hardness and modulus of elasticity make the material brittle. Combined with the relatively low bending strength and fracture toughness the material is prone to fracture when loaded unfavorably. This might be the reason for there currently being no alumina implant system on the market. Interestingly however, fracture was seldom mentioned in the literature as a reason for implant loss (Strub et al. 1987; Fartash & Arvidson 1997; Pigot et al. 1997). Nevertheless, it seems that fear of fracture hindered dentists from using alumina implants.

Currently the material of choice for ceramic oral implants is Y-TZP or possibly Ce-TZP (ceria-stabilized TZP). Compared with alumina, Y-TZP has a higher bending strength (~1200 MPa), a lower modulus of elasticity (~200 GPa) and a higher fracture toughness ( $K_{IC}$ : ~6–10 MPa m<sup>1/2</sup>). Preclinical investigations on the stability of Y-TZP oral implants have shown that this material may be able to withstand oral forces over an extended period of time (Kohal et al. 2006; Andreioteilli & Kohal 2009; Silva et al. 2009). Animal experiments testing the biocompatibility and bone integration of zirconia ceramics are promising. However, as for any implant system, clinical performance (i.e. survival and success rates) of zirconia oral implants is of great interest when advising on the clinical use of such ceramic implants in daily practice.

## Aim of the review

For that reason, the aim of the present systematic review was to answer the following questions by screening different databases for clinical and animal investigations using zirconia as a substrate for oral implants: A) The biocompatibility of zirconia. For this, animal investigations which had reported on osseointegration as assessed by bone-implant contact (BIC) around zirconia

implants, using titanium as controls, were selected. B) The clinical behavior of ceramic implants was evaluated using the available clinical data.

In summary, is there sufficient robust clinical data on the implant survival and implant success (including bone remodeling) of ceramic implants to form a view on whether they are a viable alternative to titanium implants?

Furthermore, since five different companies currently market zirconia oral implants – Bredent medical GmbH & Co. KG with the White Sky implant system; Ceraroot<sup>®</sup> with the Ceraroot<sup>®</sup> one piece zirconia implant system; Incermed SA with various Sigma implant designs, Ziterion GmbH with the zit-z implants; Z-systems<sup>®</sup> with its Z-Look3 implant – another aim of this review was to scrutinize the literature of whether these specific implant systems are backed-up scientifically for clinical use.

Although, to the knowledge of the authors, no alumina ceramic oral implants are currently marketed, we included alumina ceramic implants into the present review and also systematically searched databases for clinical and animal investigations.

## Material and methods

The scientific committee of the European Association of Osseointegration (EAO) entrusted the authors to systematically review the literature to answer the following question: 'Are ceramic implants a viable alternative to titanium implants?' and prepare this review for the 2nd EAO Consensus Conference in Pfäffikon, Switzerland in February 2009. The methodology involved in this systematic review included literature search and selection, inclusion/exclusion of studies, quality assessment and analysis of the extracted data.

### Search strategy for the identification of studies

For the identification of studies included or considered for this review, a detailed search strategy was developed and an extensive literature search performed. The following databases were searched: (1) the Cochrane Oral Health Group's Trials Register, (2) the Cochrane Central Register of Controlled Trials (CENTRAL), (3) MEDLINE (Ovid) and (4) PubMed. The search strat-

egy, which was revised appropriately for each database, used a combination of controlled vocabulary and free text words. It was limited to articles published in English, German or French appearing in peer-reviewed journals and conducted with humans or animals. No publication year limit was applied, so that the search could include the first available year of each particular database to December 2008. The search strategy included the combination of the following medical subject headings (MeSH terms): 'dental implants' AND ('zirconium oxide' OR 'yttria-stabilized tetragonal zirconia polycrystals ceramic' OR 'Ce-TZP-Al<sub>2</sub>O<sub>3</sub>'), 'dental implants' AND 'aluminum oxide,' 'dental implants' AND ('zirconium oxide' OR 'yttria-stabilized tetragonal zirconia polycrystals ceramic' OR 'Ce-TZP-Al<sub>2</sub>O<sub>3</sub>' OR 'aluminum oxide'), and the keywords: alumin\* AND implant, zircon\* AND dent\* AND implant, as well as zircon\* AND osseointegration. Manual searches of the bibliographies of all full-text articles and relevant review articles, selected from the electronic search, were also performed.

Furthermore, in November 2008, the five identified manufacturers of zirconia oral implants were contacted via mail with the following two questions:

- (1). Are there any peer-reviewed scientific publications concerning the clinical success and osseointegration of your zirconia implant system?
- (2). Are there any ongoing unpublished studies regarding the above subject? (i.e. articles in press, etc.)

### Selection criteria

To determine which studies would be included in the present systematic review, the following additional inclusion criteria were applied (Table 1):

- (1) examination of all-ceramic implants;
- (2) clinical studies with a mean follow-up period of  $\geq 1$  year;
- (3) number of subjects and implants stated;
- (4) number and type of test animals clearly mentioned in the study;
- (5) sample size of test animals  $\geq 4$ ;
- (6) clear outcome stated (clinical studies: survival/success rate, bone remodeling/bone loss rate, animal studies: BIC).

**Table 1.** Final inclusion and exclusion criteria

Inclusion criteria	
Articles in English, German and French	
Studies conducted with humans or animals	
All-ceramic implants examined	
$\geq 1$ -year observational study	
Number of subjects and implants stated	
Number and type of test animals stated	
Sample size of test animals $\geq 4$	
Clear outcome*	
Exclusion criteria	
One of the inclusion criteria is not met	
Length of observation period $< 1$ year from implant placement for the clinical studies	
<i>In vitro</i> study, review article, case report, editorial or protocol paper	
Studies reporting on ceramic composites or ZrO <sub>2</sub> /alumina coatings on metallic implants	
Studies using cell culture models	
*Clinical studies outcomes: survival/success rate, (bone remodeling/loss rate), animal studies outcome: bone-implant contact.	

Standard reviews, *in vitro* studies, case and experience reports were excluded because of possible study selection bias and limited clinical relevance, respectively (Sutherland 2000). Also studies using cell culture models or reporting on ceramic composites, ZrO<sub>2</sub>, and alumina coatings on metallic implants were not included in the present review. The reason for the exclusion of metallic implants with ceramic coatings was that compared with all-ceramic implants, biomechanically, they behave differently. Furthermore, the topic of ceramic-coated metal implants would have gone beyond the scope of this review and is addressed in another review of this supplement issue of *Clinical Oral Implants Research*.

### Review methods

The titles and abstracts, when available, of all reports identified through the electronic searches were assessed independently by two reviewers (M.A. and R.J.K). For studies appearing to meet the inclusion criteria, or for which insufficient data were available in the title and abstract to make a clear decision, the full text was obtained. The full reports obtained from all methods of searching were assessed independently by two of the review authors (M.A. and R.J.K) to establish whether the studies met the inclu-

sion criteria. The references from these articles were also manually searched and the potentially relevant papers scrutinized. Any disagreement between the reviewers regarding selection of the studies included was resolved by consensus. Where resolution was not possible, a third reviewer (H.J.W.) was consulted. All studies meeting the inclusion criteria then underwent validity assessment and data extraction. Studies rejected at subsequent stages were recorded and the reasons for exclusion were reported.

### Quality assessment and data extraction

The quality assessment of the included trials was undertaken independently and in duplicate by two review authors as part of the data extraction process. The publications were sorted into clinical studies, animal studies with loaded implants and animal studies with unloaded implants. Because different types of studies were included, the methodological quality was evaluated. The clinical studies were assessed for allocation concealment, blindness of outcome assessment, definition of inclusion/exclusion criteria, adjustment for potential confounding variables and completeness of follow-up and statistical analysis (Esposito et al. 2005). Considering the above quality assessment criteria, the studies were grouped into the following categories: low risk of bias, moderate risk of bias and high risk of bias. Any disagreement regarding data extraction was resolved with discussion and a third reviewer was consulted where necessary. Data were excluded if agreement could not be reached. For each trial the following data were recorded: study design, risk of bias, first author, year of publication, observation period, number of subjects, number of implants, implant design/surface, success/survival rate of the implants, bone remodeling/loss using apical radiographs (clinical), first author, year of publication, number of animals, number of implants, implant material/design, surface treatment, surface (roughness) characterization and BIC (animals).

### Interreviewer agreement

For the 1230 titles reviewed in the entire search, the reviewers had 27 disagreements (2%) in applying inclusion and exclusion

criteria. Agreement at the title review stage yielded a  $\kappa$  score of 0.9081 (95% confidence interval: 0.8739–0.9423). For the 183 abstracts reviewed, the reviewers had five disagreements (3%) in applying inclusion and exclusion criteria. Agreement at the abstract review stage yielded a  $\kappa$  score also of 0.9019 (95% confidence interval: 0.8172–0.9865). Both  $\kappa$  scores were significantly different from zero ( $P < .001$ ), meaning the agreement was better than chance. For the 101 full-text papers reviewed, the reviewers had no (0%) disagreements in applying inclusion and exclusion criteria.

## Results

The PubMed search yielded 349 titles and the Cochrane/MEDLINE search yielded 881 titles. Independent initial screening of the titles resulted in further consideration of 94 publications from the PubMed search and 89 publications from the Cochrane/MEDLINE search. Based upon abstract screening and discarding duplicates from both searches, 100 full-text articles were obtained and subjected to additional evaluation. A further publication was included based on the manual search. All five identified manufacturers responded to the short questionnaire sent, but did not provide any further information on published peer-reviewed studies already published or ongoing publications. One company reported confidentially on a clinical investigation that will be published soon. This investigation could not therefore be included in this review. The extensive examination resulted in the final sample of 25 studies, namely 10 clinical studies and three animal studies referring to alumina implants, and three clinical studies and nine animal studies referring to zirconia implants. No (randomized) controlled clinical studies regarding the outcome of zirconia and alumina ceramic implants could be identified. Figure 1 describes the selection process.

Meta-analytic methodology was not applied in the current systematic review because of the variation in types of experimental characteristics of the investigations. This decision was based on the premise that meta-analysis can only be performed when the studies share suffi-

cient similarity to justify a comparative analysis (Needleman 2002).

### Excluded studies

Of the 101 full-text articles examined, 76 were excluded from the final analysis (see: List of excluded full-text articles and the reason for exclusion).

The main reasons for exclusion were:

- no BIC reported;
- no observation period/patient number reported;
- overview/presentation of an implant system;
- case series, no clear protocol for a clinical study.

### Alumina implants

#### Animal studies

Three studies investigating outcomes with alumina and zirconia implants in animals met the inclusion criteria and are summarized in Table 2. All studies assessed unloaded alumina implants in comparison with stainless steel, hydroxyapatite, zirconia or titanium (Hayashi et al. 1992; Chang et al. 1996; Dubruillé et al. 1999).

In the investigation by Hayashi et al. (1992), no significant differences in the affinity of bone (BIC) was found for the different materials from 4 to 96 weeks.

Chang et al. (1996) evaluated three different ceramic materials (alumina, zirconia and hydroxyapatite) in rabbits from 2 to 24 weeks. No statistics was performed on the BIC results. Over a period of 8 weeks, the percentage of implant surface covered by bone (BIC) increased similarly for all materials. From 8 to 24 weeks, alumina remained at a level of about 70% BIC, whereas the contact decreased for the other two materials to a low of 12% (zirconia) and 28% (hydroxyapatite).

Dubruillé et al. (1999) investigated the quality of the tissue-implant interface of 18 implants that were placed into the mandibles of nine dogs. The bone was previously filled with calcium carbonate (coral) or hydroxyapatite. Three different types of dental implants were compared (titanium, alumina and zirconia) and the BIC in the cervical, central and apical regions evaluated. They concluded that the mean percentage of BIC was higher in the cervical than in the central and apical

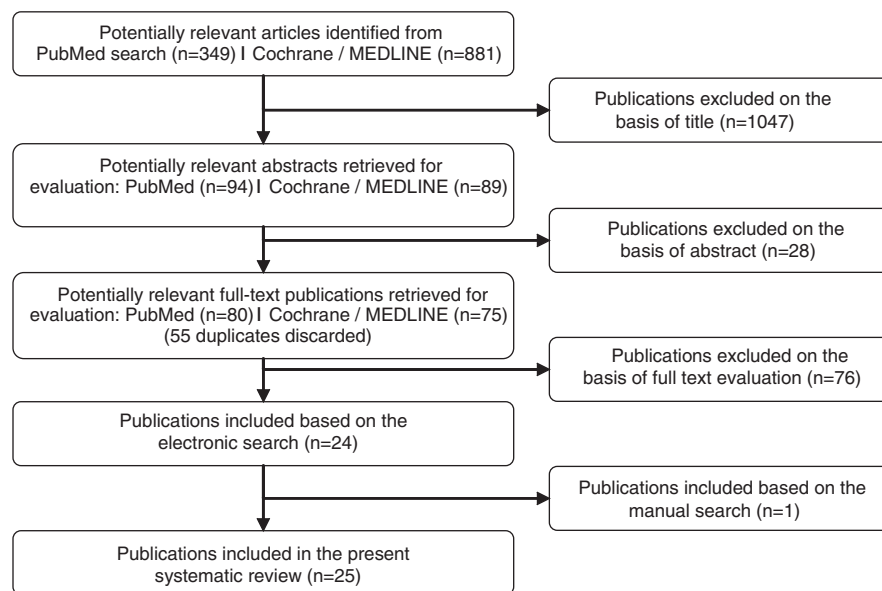


Fig. 1. Flowchart of the search strategy.

regions and was higher for ceramic implants than for titanium implants.

**Clinical studies**

As mentioned above, no randomized-controlled clinical trials, no controlled clinical trials and no high-quality prospective clinical investigations were found. If the inclusion criteria would had been strictly applied – including reporting on bone remodeling/ bone loss – our search would have yielded only two papers (Strub et al. 1987; Berge & Gronningsaeter 2000). Besides cumulative survival rates, these two investigations were the only ones that reported also on bone loss during the observation period. In order not to run the risk of excluding valid information, the authors therefore decided to include clinical investigations that did not report on bone loss, but which had information on success and survival rates. With the modified inclusion criteria, eight more investigations could be included (Wörle 1981; Brose et al. 1988; Koth et al. 1988; De Wijs et al. 1994; Steflik et al. 1995; Fartash et al. 1996; Fartash & Arvidson 1997; Pigot et al. 1997).

However, when extracting all the necessary information from the included studies the risk of bias was moderate to high and the quality of the investigations had to be rated as medium to low (see Table 3).

Wörle (1981) reported an implant survival rate of 84% after a mean of 2.4 years using different alumina ceramic implants. Of the lost implants, three (75%) became

loose after initial integration and one (25%) did not integrate from the beginning. The only investigation prospectively comparing different implant systems was published by Strub et al. (1987). They investigated different titanium implants and the alumina Crystalline Bone Screw. After an observation period of 6 years, the alumina implant showed a survival rate of 25% when used as an anchor for bridges in combination with teeth. Of the eight inserted implants, six (75%) were lost due to fracture. Koth et al. (1988) and Steflik et al. (1995) presented the data for the same patient cohort after 5 and 10 years using the single-crystal sapphire (Al<sub>2</sub>O<sub>3</sub>) Bioceram implant. In 18 patients, 28 implants were inserted in the partially edentulous mandible. Twenty-three implants were used as distal abutments for fixed partial dentures. Twenty-one of these 23 implants were reviewed after 10 years when the authors found an 81% success rate. When the numbers were carefully analyzed and the implants lost in the initial phase included, the success rate dropped to 77.7% after 5 years and to 65.4% after 10 years. Five implants obviously were lost/excluded for reasons of mobility, infection and patient discomfort before reconstruction. Another implant was removed due to excess mobility after 7 months of patient service. No fractures were reported. The survival rates were generally below the survival rates of titanium implants (Lang et al. 2004).

Brose et al. (1988) presented their data on a two-piece custom-made alumina implant after periods of up to 8 years. Thirty-one implants were inserted in 31 patients. The authors found an implant success rate of 23%. All implants obviously failed due to biological reasons: six implants did not integrate and 13 lost integration over various time periods. Five implants were lost to follow up. De Wijs et al. (1994) followed 127 Tübingen alumina implants in 101 patients over a mean period of 4.5 years. The implants were placed in the upper anterior jaw in the regions of former incisors, cuspids and premolars. The reported survival rate in this study was 87%. Again, implants failed because they either did not integrate or lost integration. Fractures of implants were not reported. Two further reports regarding the long-term behavior of single-crystal sapphire implants were presented by Fartash & Arvidson (1997) and Fartash et al. (1996). In the latter investigation (Fartash et al. 1996), 86 patients received 324 Bioceram sapphire implants for the treatment of mandibular edentulism with overdentures. The authors found cumulative success rates after 3, 5, 10 and 12 years of follow-up of 95.2%, 91.3%, 91.3% and 91.3%. Some implants failed before prosthetic treatment but the majority of implants was lost between 36 and 42 months in function, due to loss of osseointegration. Implant fracture as reason for failure was not reported. In their subsequent investigation, Fartash & Arvidson (1997) included the treatment of total edentulism, partial edentulism and single-tooth loss. Fifteen patients received 87 Bioceram implants for the treatment of their edentulous upper and lower jaws. The cumulative success rates after 3, 5 and 10 years were 100%, 100% and 97.7% for the mandible and 58.1%, 44.2% and 44.2% for the maxilla. The 27 partially edentulous patients received 56 implants. The cumulative success rates for the implants in the partially maxilla were 96.3%, 92.6% and 92.6% after 3, 5 and 10 years, respectively, and 100% in the mandible over the whole period. One implant fractured in an edentulous mandible after 6 years in function. The other implants were lost due to mobility and soft tissue encapsulation. Pigot et al. (1997) evaluated the Crystalline Bone Screw in edentulous mandibles to stabilize mandibular overdentures. Thirty-nine

**Table 2. Included animal studies reporting on zirconia and alumina implants**

	Author (year)	Number of animals/implants included	Implant material/design	Surface treatment	Surface characterization	Bone-implant contact
Unloaded implants	Hayashi et al. (1992)	26 dogs (femur)/156 implants	SUS-316 L stainless steel Alumina ceramic (Al <sub>2</sub> O <sub>3</sub> > 99.5%) Zirconia ceramic (ZrO <sub>2</sub> : 95%, Y <sub>2</sub> O <sub>3</sub> : 5%) All screws: diameter 4.8 mm, length 8 mm	NR	Characterization technique not mentioned: SUS-316: Ra 1 μm alumina: Ra 1.3 μm zirconia: Ra 0.9 μm	4 weeks: SUS-316 L: 59% Al <sub>2</sub> O <sub>3</sub> : 60% ZrO <sub>2</sub> : 54% 8 weeks: SUS-316 L: 88% Al <sub>2</sub> O <sub>3</sub> : 84% ZrO <sub>2</sub> : 86% 24 weeks: SUS-316 L: 82% Al <sub>2</sub> O <sub>3</sub> : 77% ZrO <sub>2</sub> : 83% 48 weeks: SUS-316 L: 80% Al <sub>2</sub> O <sub>3</sub> : 76% ZrO <sub>2</sub> : 89% 96 weeks: SUS-316 L: 81% Al <sub>2</sub> O <sub>3</sub> : 81% ZrO <sub>2</sub> : 87%
	Chang et al. (1996)	78 rabbits (tibia)/156 implants	Alumina ceramic (Al <sub>2</sub> O <sub>3</sub> > 99%) Zirconia ceramic (ZrO <sub>2</sub> : > 93%) Dense hydroxyapatite	Smooth test pieces (Kyocera Corporation, Osaka, Japan)	NR	2 weeks: HA: 8 ± 4% Al <sub>2</sub> O <sub>3</sub> : 14 ± 4% ZrO <sub>2</sub> : 2 ± 2% 4 weeks: HA: 21 ± 6% Al <sub>2</sub> O <sub>3</sub> : 24 ± 8% ZrO <sub>2</sub> : 15 ± 6% 6 weeks: HA: 57 ± 6% Al <sub>2</sub> O <sub>3</sub> : 55 ± 6% ZrO <sub>2</sub> : 49 ± 4% 8 weeks: HA: 68 ± 5% Al <sub>2</sub> O <sub>3</sub> : 70 ± 8% ZrO <sub>2</sub> : 65 ± 6% 12 weeks: HA: 50 ± 12% Al <sub>2</sub> O <sub>3</sub> : 74 ± 14% ZrO <sub>2</sub> : 45 ± 15% 24 weeks: HA: 28 ± 6% Al <sub>2</sub> O <sub>3</sub> : 72 ± 12% ZrO <sub>2</sub> : 12 ± 4%
	Dubruillé et al. (1999)	9 dogs/18 implants	Zirconia (Sigma, Sandhaus Incermed SA, Lausanne, Switzerland) Alumina (Cerasand, Sandhaus Incermed SA, Lausanne, Switzerland) Ti (NR)	Zirconia: NR Alumina: NR Ti: machined	NR	Zirconia (6): 65 ± 13% Alumina (6): 68 ± 14% Ti (6): 54 ± 13%

NR, not reported. Number of implants are given in parenthesis in the BIC column.

patients received 141 ceramic implants. In their paper, they listed 16 time intervals with the respective patient and implant numbers and cumulative success rates. For clarity, we have included only the 2–3-year interval in Table 3 and because the cumulative success rate did not drop further as the study progressed. At 2–3

years, 33 patients with 99 implants could be evaluated resulting in a cumulative success rate of 78.1%. Five of the lost implants had fractured. Bioceram implants supporting mandibular overdentures were investigated by Berge & Gronningsaeter (2000). Over a mean observation period of 8.2 years, the authors presented the results

of 30 patients with 116 implants. The cumulative survival rate for the implants amounted to 68.7%. The reason for loss (loss of osseointegration, fracture) was not indicated. The annual bone loss around the implants was 0.2 mm.

In summary, these clinical investigations using different alumina oral implants for up

**Table 3. Included clinical studies (case series) reporting on alumina implants**

Design (risk of bias)	Author (year)	Observation period (years)	Number of patients/implants included	Implant design/surface	Implant survival/success rate (%)	Bone remodeling/loss (mm)
Retrospective (high)	Wörle (1981)	Mean 2.4	16/25 partially edentulous	Different Al <sub>2</sub> O <sub>3</sub> implants (Frialit Fritz, Tübingen, Sandhaus)	84	NR
Prospective (moderate)	Strub et al. (1987)	6.9 6 6.6 7	41/60 partially edentulous	Linkow Blade Implant Crystalline Bone Screw (Incermed SA Lausanne, Switzerland) Ebauches Double Blade Implant Intramobile Cylinder Extension Implant	CSR: 94.7 CSR: 25 CSR: 61.3 67.3	1.2 1.5 0.5–1 2
Prospective (moderate)	Koth et al. (1988)	5	18/28 partially edentulous Mn	Single-crystal sapphire implant (Bioceram, Kyocera America Inc., San Diego, CA, USA)	77.7	NR
Prospective (high)	Brose et al. (1988)	3.2 (up to 8 years)	31/31 partially edentulous	Two-piece custom-made Al <sub>2</sub> O <sub>3</sub> implant	23 <sup>according to the authors</sup> 17 <sup>when calculated with the given numbers in publication</sup>	NR
Prospective (moderate)	De Wijs et al. (1994)	Mean 4.5	101/127 partially edentulous	Tübingen (polycrystalline Al <sub>2</sub> O <sub>3</sub> ) implant (Frialit, Friedrichsfeld AG Mannheim, Germany)	87	NR
Prospective (moderate)	Steflik et al. (1995)	5, 10	18/28 partially edentulous Mn	One-piece fire-polished, Single-crystal sapphire implant (Bioceram, Kyocera America Inc.)	77.7, 65.4	NR
Prospective (moderate)	Fartash et al. (1996)	3, 5, 10, 12	86/324 edentulous Mn	Single-crystal sapphire implant (Bioceram, Kyocera Corporation)	CSR: 95.2, 91.3, 91.3, 91.3	NR
Prospective (moderate)	Fartash & Arvidson (1997)	3, 5, 10 3, 5, 10 3, 5, 10	15/87 edentulous Mn & Mx. 7/7 single tooth replacement 27/56 partial edentulism	One-piece single-crystal sapphire implant (Bioceram, Kyocera Corporation)	Mn CSR: 100, 100, 97.7 Mx. CSR: 58.1, 44.2, 44.2 CSR: 96.3, 92.6, 92.6 CSR: 96.3, 92.6, 92.6	NR
Prospective (moderate)	Pigot et al. (1997)	2–3	39/141 Edentulous Mn	Crystalline Bone Screw (Incermed SA)	CSR: 78.1	NR
Retrospective (high)	Berge & Gronningsaeter (2000)	Mean 8.2	30/116 15/60 were lost to follow-up	One-piece single-crystal sapphire implant for support of mandibular overdentures (Bioceram, Kyocera Corporation)	CSR 68.7	Mean bone loss 2.21 mm (for 52 implants)

Mx, maxillae; Mn, mandible; NR, not reported.

to 10 years showed survival/success rates in the range of 23–98% for the different indications (single-tooth replacement, partially dentate patients and edentulous patients).

**Zirconia implants**

Animal studies

Nine studies investigating the outcomes with zirconia oral implants in animals met the inclusion criteria and are summar-

ized in Table 4. Six studies assessed unloaded zirconia oral implants (Stanic et al. 2002; Scarano et al. 2003; Aldini et al. 2004; Sennerby et al. 2005; Depprich et al. 2008; Hoffmann et al. 2008) and three studies examined loaded zirconia implants in animals (Akagawa et al. 1993a, 1998; Kohal et al. 2004). Two studies (Stanic et al. 2002; Aldini et al. 2004) reported on the osseointegration of bioactive glass-coated and uncoated zirconia implants in

sham-operated and ovariectomized rats. It was found that the glass coating enhanced the osseointegration rate at 30 (BIC in sham-operated and ovariectomized rats: 45%/50% and 55%, respectively) and at 60 days (BIC in sham-operated and ovariectomized rats: 56%/55% and 68%, respectively). Scarano et al. (2003) investigated the bone response to 20 Y-TZP implants, which were inserted in the tibiae of five rabbits. According to the

**Table 4. Included animal studies reporting on zirconia implants**

	Author (year)	Number of animals/ Implants included	Implant material/ design	Surface treatment	Surface characterization	Bone-implant contact
Unloaded implants	Stanic et al. (2002)	14 rats/28 implants	YSTZ implants YSTZ coated with RKKP <sup>®</sup> bioactive glass	NR	Profilometry YSTZ: Ra 1.26 μm, Rt 10.28 μm YSTZ coated: Ra 0.37 μm, Rt 3.27 μm	30 days: YSTZ (7): 45 ± 17% RKKP <sup>®</sup> -YSTZ (7): 72 ± 24% 60 days: YSTZ (7): 56 ± 32% RKKP <sup>®</sup> -YSTZ (7): 74 ± 17%
	Aldini et al. (2004)	20 rats (osteopenic)/ 40 implants	YSTZ implants YSTZ coated with RKKP <sup>®</sup> bioactive glass	NR	NR	Sham-operated rats 30 days: YSTZ (5): 50 ± 16% RKKP <sup>®</sup> -YSTZ (5): 77 ± 11% 60 days: YSTZ (5): 55 ± 27% RKKP <sup>®</sup> -YSTZ (5): 74 ± 12% Ovariectomized rats 30 days: YSTZ (5): 55 ± 22% RKKP <sup>®</sup> -YSTZ (5): 81 ± 10% 60 days: YSTZ (5): 68 ± 16% RKKP <sup>®</sup> -YSTZ (5): 76 ± 15%
	Scarano et al. (2003)	5 rabbits/ 20 implants	Zirconia experimental implants	Passivation, different cleaning steps	NR	4 weeks: 68%
	Sennerby et al. (2005)	12 rabbits/ 96 implants	Y-TZP experimental implants; screw type Ti; screw type	Group 1 (Y-TZP): machined Group 2 (Y-TZP): machined presintered, surface roughened using pore-former A Group 3 (Y-TZP): machined presintered, surface roughened using pore-former B Group 4 (TiUnite)	Interferometer Group 1: Sa 0.75 μm, Sds 0.09 1/μm <sup>2</sup> , Sdr 14.2% Group 2: Sa 1.24 μm, Sds 0.09 1/μm <sup>2</sup> , Sdr 82.6% Group 3: Sa 0.93 μm, Sds 0.09 1/μm <sup>2</sup> , Sdr 51.5% Group 4: Sa 1.3 μm, Sds 0.06 1/μm <sup>2</sup> , Sdr 113.1%	6 weeks: Group 1 (24) femur: 46%; tibia: 19% Group 2 (24) femur: 60%; tibia: 31% Group 3 (24) femur: 70%; tibia: 22% Group 4 (24) femur: 68%; tibia: 24%
	Hoffmann et al. (2008)	4 rabbits/ 8 implants	Y-TZP (Z-Look 3) Ti (Osseotite)	Y-TZP: NR Ti: sandblasted, acid etched	NR	2 weeks: Y-TZP: 55% Ti: 47.6% 4 weeks: Y-TZP: 71.5% Ti: 80%
	Depprich et al. (2008)	12 minipigs (tibia)/ 48 implants	Y-TZP Ti	Y-TZP: acid etched cpTi: acid etched	Information from the manufacturer of implants, characterization technique not mentioned: Y-TZP: Ra 0.598 μm Ti: Ra 1.77 μm	1 week: Y-TZP: 35 ± 11% Ti: 48 ± 9% 4 weeks: Y-TZP: 45 ± 16% Ti: 99 ± 10% 12 weeks: Y-TZP: 71 ± 18% Ti: 83 ± 11%
Loaded Implants	Akagawa et al. (1993a, 1993b)	4 dogs/ 12 implants	Y-TZP experimental implants; screw type	Barrel polished	NR	Unloaded implants (6): 82% Loading period: 3 mo Loaded implants (6): 70%



Table 4. Continued

Author (year)	Number of animals/ Implants included	Implant material/ design	Surface treatment	Surface characterization	Bone-implant contact
Akagawa et al. (1998)	7 monkeys/ 28 implants	Y-TZP experimental implants; screw type	Barrel polished	NR	Loading period: 12 mo Single freestanding implants (4): 54–71% Connected freestanding implants (8): 58%–77% Implant-tooth supported (4): 70–75% Loading period: 24 mo Single freestanding implants (3): 66–81% Connected freestanding implants(6): 66–77% Implant-tooth supported (3): 66–82%
Kohal et al. (2004)	6 monkeys/ 24 implants	Y-TZP experimental implants; custom made (ReImplant) Ti implants (control), same design as Y-TZP	Y-TZP implants: machined, sandblasted Ti implants: same treatment; additionally acid etched	NR	Healing time: 9 mo Loading period: 5 mo Y-TZP implants (12): 68% Ti implants (12): 73%

Number of implants are given in parentheses in the BIC column.  
mo, months; NR, not reported.

authors, all implants were osseointegrated without signs of inflammation or mobility. The mean BIC was calculated to be 68%. In another study, Sennerby et al. (2005) evaluated the bone tissue response to zirconia implants with two different surface modifications in comparison to machined, non-modified zirconia implants and to oxidized titanium implants. Ninety-six implants were placed in 12 rabbits. A "strong" bone tissue response to surface-modified zirconia implants was observed after 6 weeks of healing. The modified zirconia implants showed a resistance to removal torque forces similar to those of oxidized titanium implants and a four- to fivefold increase compared with machined zirconia implants. In a recent study, Hoffmann et al. (2008) compared the degree of early bone apposition around four zirconia dental implants and four surface-modified titanium implants at 2 and 4 weeks after insertion in the femurs of four rabbits. A comparably high degree of bone apposition could be observed on all implants during early healing. Depprich et al. (2008) inserted 24 acid-etched zirconia implants and 24 acid-etched titanium implants into the tibia of 12 minipigs. BIC was evaluated after 1, 4

and 12 weeks. Histological results did not show statistically significant differences between the two groups at any timepoint.

Akagawa et al. (1993a) presented the bone tissue response to loaded and unloaded zirconia implants in the dog mandible. A total of 12 implants were placed in four dogs in a one-stage procedure. The authors reported high degrees of BIC 3 months after implantation, with no significant differences between the groups. However, loss of crestal bone height was evident around the loaded implants. In a second investigation, Akagawa et al. (1998) evaluated the possibility of long-term stability of osseointegration around 32 zirconia implants placed in the mandibles of eight monkeys using the one-stage procedure with (1) single freestanding implant support, (2) connected freestanding implant support or (3) a combination of implant and tooth support. After 2 years there were no significant differences in clinical features among the different groups, and a direct bone apposition and stable osseointegration were observed. Kohal et al. (2004) compared loaded titanium implants with loaded zirconia implants in the same model. Twelve custom-made titanium implants and 12 zirconia implants were used to support

metal crowns in the maxillae of six monkeys. No implant was lost over an observation period of 14 months and no mechanical problems were reported. Histology revealed no differences in the bone tissue response between the titanium and zirconia implants.

#### Clinical studies

Only three retrospective observational cohort investigations were identified in the international literature and were included in the present review (see Table 5) (Mellinghoff 2006; Oliva et al. 2007; Lambrich & Iglhaut 2008). Mellinghoff (2006) published the clinical results of 189 zirconia implants inserted in 71 patients. Only 53 implants had received a definitive prosthetic reconstruction at the time of the last recall visit. The 1-year survival rate of the implants was 93%. Nine of the 189 placed implants had to be removed, eight of these implants during the healing phase. The author reported that six implants were lost due to increased implant mobility, one implant fractured 1 week after prosthetic reconstruction. In another retrospective study, Oliva et al. (2007) evaluated the success rate of 100 one-piece zirconia dental implants inserted in 36 patients

**Table 5. Included clinical studies (case series) reporting on zirconia implants**

Design (risk of bias)	Author (year)	Observation period (years)	Number of patients/implants included	Implant design/surface	Implant survival rate/success rate (%)	Bone remodeling/loss
Retrospective (high)	Mellinghoff (2006)	1	71/189	Z-Systems AG One-piece implants with a sandblasted intraosseous section and a polished transgingival portion	93	NR
Retrospective (high)	Oliva et al. (2007)	1	36/100	Ceraroot Five different implant designs-porous surface (bioactive ceramic-coated and noncoated group)	98	NR
Retrospective (high)	Lambrich & Iglhaut (2008)	1.8	124/361 Ti: 234 Y-TZP:127	Z-Systems AG One-piece implants with a sandblasted intraosseous section and a polished transgingival portion	Ti Mx: 98.4 Mn: 97.2 Y-TZP Mx: 84.4 Mn: 98.4	NR

Mx, maxillae; Mn, mandible; NR, not reported.

after 1 year of follow-up. Five implant designs with two different surfaces were examined. Simultaneous bone augmentation or sinus elevations were performed in the cases of insufficient bone height or width. The overall implant success rate after 1 year was 98% in both the bioactive ceramic-coated and noncoated groups. Two implants (one of each surface) failed 15 days after implant installation due to implant mobility. No further implant failures were reported. In a further retrospective investigation by Lambrich & Iglhaut (2008), the survival rates of rough titanium implants and one-piece zirconia implants were compared. The study followed up a total of 361 implants (234 titanium/127 zirconia) inserted in 124 nonselected patients. The mean observation period was 21.4 months. The survival rate of the titanium implants was 98.4% in the maxilla and 97.2% in the mandible, while zirconia implants had a survival rate of 84.4% in the maxilla and 98.4% in the mandible. In total, 11 zirconia implants were lost, 10 implants in the maxilla and one implant in the mandible. All failures occurred in the healing period or within the first 6 months after loading. There is no information on implant fractures as reason for implant loss. The difference in the survival rate of zirconia implants in the maxilla was explained as a result of low primary stability in soft and augmented bone and premature loading.

## Discussion

### Alumina oral implants

Although alumina ceramics are obviously not used anymore as a substrate for oral implants, the authors decided to include this material in their review. Extensive preclinical (animal) and clinical investigations were performed to evaluate this material regarding its use as oral implant material. In the included animal models alumina did osseointegrate similarly in comparison to titanium or hydroxyapatite. From a biocompatibility standpoint (here: bone integration), this material was and still is appropriate to be used as oral implant material.

Clinical investigations using alumina implants up to 10 years showed survival/success rates in the range of 23–98% for the different indications (single-tooth replacement, partially dentate patients and edentulous patients). In general, the survival rate was lower compared with the ones found in systematic reviews for titanium implants where 5-year survival rates of 95.4% for implants supporting single crowns and 96.8% for implants supporting fixed-partial dentures were presented (Lang et al. 2004; Pjetursson et al. 2004; Jung et al. 2008). The only exception where long-term survival rates with alumina implants were comparable to titanium implants are the investigations by Fartash & Arvidson (1997) and Fartash et al. (1996).

To the knowledge of the authors, however, no alumina implant system is marketed anymore. Recently, the Bioceram (single-crystal sapphire) implant was withdrawn from the market.

Some investigations reported on early implant loss (no osseointegration occurred obviously) and others on implant fractures. The latter adverse event seemed to prevent dentists to use this ceramic implant material. When screening the literature, it was realized that no scientific investigations could be found dealing with the stability of alumina ceramic implants before its clinical use.

### Zirconia oral implants and osseointegration

In the present systematic review, animal studies dealing with zirconia implants outnumbered the clinical studies. Osseointegration was evaluated from 2 weeks to 24 months after inserting the implants in different animals, in different implant sites and under different loading situations. The percentage of BIC as a measure of osseointegration ranged from a low of 2% after 2 weeks in the tibia of rabbits (Chang et al. 1996) to a high of 86.8% after 96 weeks in the tibia of dogs (Hayashi et al. 1992) with a mean value above 60% (Tables 2 and 4). A similar mean BIC ratio was reported in another systematical review (Wenz et al. 2008). Only a few animal investigations used titanium implants as a control group (Dubruillé et al. 1999; Kohal et al. 2004;

Sennerby et al. 2005; Depprich et al. 2008; Hoffmann et al. 2008). As with alumina implants, the above studies could show that bone reacts similarly or even better to zirconia as it does toward titanium and therefore zirconia could be used – from an osseointegration standpoint – as a material for the fabrication of oral implants. However, with the exception of the study by Kohal et al. (2004), there were no other studies comparing loaded titanium implants with loaded zirconia implants in the same animal model. Besides similar BIC, Kohal et al. (2004) could show that the soft tissue compartments above the periimplant bone had a similar thickness for the test and control group.

Noteworthy are the results of Akagawa et al. (1998) and Akagawa et al. (1993a) because they found an apparent loss of crestal bone in the group of early loaded zirconia implants.

A parameter that can possibly influence the process of early bone formation is the implant surface. Aldini et al. (2004) coated Y-TZP implants with a bioactive glass and found faster bone healing and a better osseointegration rate in osteopenic bone. Furthermore, Sennerby et al. (2005) reported that Y-TZP implants with a moderately roughened surface showed a four- to fivefold increase in resistance to removal torque compared with machined Y-TZP implants and a direct bone formation could only be observed on implants with a modified surface. Unfortunately, with the exception of three studies (Stanic et al. 2002; Sennerby et al. 2005; Depprich et al. 2008), no information on surface microtopography was given. One investigation was able to show that a similar roughness on titanium and zirconia implants led to similar BIC (Sennerby et al. 2005). The second investigation comparing titanium and zirconia implants could show similar bone-to-implant contact, however, with different roughnesses (Depprich et al. 2008).

#### Quality assessment of clinical investigations

In a publication on quality assessment of randomized-controlled trials of oral titanium implants it was ‘... concluded that study methodology was generally poor’ (Esposito et al. 2001). Hence, the authors of that publication found at least some randomized-controlled trials for titanium

**Table 6. Definitions of types of evidence originating from the US Agency for Health Care Policy and Research (1993)**

Statements of evidence	
Ia	Evidence obtained from meta-analysis of randomized-controlled trials
Ib	Evidence obtained from at least one randomized-controlled trial
Ila	Evidence obtained from at least one well-designed controlled study without randomization
Ilb	Evidence obtained from at least one other type of well-designed quasi-experimental study
III	Evidence obtained from well-designed nonexperimental studies, such as comparative studies, correlation studies and case studies
IV	Evidence obtained from expert committee reports or opinions and/or clinical experiences of respected authorities
Grades of recommendations	
A	Requires at least one randomized-controlled trial as part of a body of literature of overall good quality and consistency addressing the specific recommendation (Evidence levels Ia, Ib)
B	Requires the availability of well conducted clinical studies but no randomized clinical trials on the topic of recommendation (Evidence levels Ila, Ilb, III)
C	Requires evidence obtained from expert committee reports or opinions and/or clinical experiences of respected authorities. Indicates an absence of directly applicable clinical studies of good quality (Evidence level IV)

implants. Such investigations, however, do not exist for ceramic implants.

The study methodology for the clinical investigations included in this review has to be rated as questionable especially for the zirconia implant studies (Mellinghoff 2006; Oliva et al. 2007; Lambrich & Iglhaut 2008). Because of the high risk of bias the scientific value of these reports has to be considered as low.

Shortcomings in most studies were that – if at all – only minimal information was given on the study methodology (study design), e.g. the inclusion/exclusion criteria, patient dropout, implant locations, radiographic bone remodeling, soft tissue health, prosthetic reconstructions and success criteria. Also no information was given on whether the study had a structured investigation plan including follow-up sessions. In addition, most of the investigations were retrospective.

If only publications would have been selected that reached evidence level III (well-designed nonexperimental descriptive studies or higher) (US Department of Health and Human Services 1993) (Table 6), no zirconia clinical study would have been included.

It is well-known that randomized-controlled clinical trials offer the best evidence for reviews dealing with the effectiveness of therapy (Carlsson 2005). However, for reviews that are dealing with so-called ‘emerging’ therapies – zirconia implant treatment is regarded as such – other designs of investigations, such as nonrandomized

trials, case-series and even animal studies should be considered. However, each study type must be evaluated separately and their limitations to answering the review question should be made explicit (Needleman 2002).

For our review, nevertheless it has been considered beneficial to include all the above hierarchies of evidence to show that research in this field is taking place on the one hand, but that on the other the low level of evidence in this area demands more well-designed clinical studies in future research.

## Conclusion

Our systematic review could identify histological animal studies showing similar BIC contact between alumina, zirconia and titanium. However, only cohort investigations were found which did not allow to positively answering the introductory question. Currently, the scientific clinical data for ceramic implants in general and for zirconia implants in particular are not sufficient to recommend ceramic implants for routine clinical use (grade of recommendation: C) (Table 6).

Alumina implants did not perform satisfactorily and therefore are not a viable alternative to cpTi implants based on our review. Zirconia, however, may have the potential to be a successful implant material but no clinical investigation can support this assumption yet.

Furthermore, the fact that zirconia implants are offered on the market without

any scientific background has to be seen critically and brings a statement to mind which was expressed regarding such a circumstance recently by Albrektsson et al. (2007): 'In many cases, commercial hype has replaced the careful scientific approach once represented by the early pioneers of osseointegration. In fact, we cannot solely blame the involved commercial bodies,

since oral implants nowadays are routinely placed by clinicians who obviously do not ask for clinical results before testing these various systems, perhaps acceptable if implant changes are small but not so after substantial changes in implant design (and implant material, remark of the present authors) or recommended handling of it. Unfortunately, control bodies such as the

Food and Drug Administration have placed oral implants in their category IIa where clinical pretrials are deemed unnecessary. Europeans have followed suit in their CE-marking procedure that neither asks for any clinical pretrials before introducing novel implants on the market.'

And this development is not for the benefit of our patients.

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## List of excluded full-text articles and the reason for exclusion

- Akagawa, Y., Hashimoto, M., Kondo, N., Satomi, K., Takata, T. & Tsuru, H. (1986) Initial bone-implant interfaces of submergible and supramergible endosseous single-crystal sapphire implants. *The Journal of Prosthetic Dentistry* 55: 96–100. Exclusion criteria: no bone-to-implant contact reported.
- Atkinson, P.J., Roberts, E.W. & Khudayer, Z.M. (1984) Porous ceramic materials as immediate root implants. *Journal of Dentistry* 12: 189–202. Exclusion criteria: no bone-to-implant contact reported.
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- Brinkmann, E. (1978) Das Keramik-Anker-Implantat nach Mutschelknauss. *Zahnärztliche Praxis* 29: 148–150. Exclusion criteria: presentation of an implant system.
- Brinkmann, E. (1980) Enossale Implantate aus Aluminiumoxidkeramik. *Zahnärztliche Praxis* 31: 328–330. Exclusion criteria: editorial paper.
- Brinkmann, E. (1983) Indikation und Anwendung keramischer Implantate aus Aluminiumoxid (BioIox). *Swiss Dent* 4: 23–24; 28, 29–30 passim. Exclusion criteria: review.
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- Brinkmann, E.L. (1987) Das keramische Ankerimplantat als endständiger Brückenpfeiler (Klasse II nach Brinkmann)–Erfahrungsbericht nach zehn Jahren klinischer Anwendung (II). *Quintessenz* 38: 993–1003. Exclusion criteria: presentation of an implant system.
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- Chess, J.T. (1979) Current status of the Synthodont aluminum oxide ceramic implant. *Journal of Oral Implantology* 8: 654–658. Exclusion criteria: presentation of an implant system, no clinical investigation, no patient or implant numbers, no survival/success rate reported.
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- Cook, S.D., Anderson, R.C. & Lavernia, C.J. (1983a) Histologic and microradiographic evaluation of textured and nontextured aluminum oxide dental implants. *Biomaterials, Medical Devices, and Artificial Organs* 11: 259–269. Exclusion criteria: no bone-to-implant contact reported.
- Cook, S.D., Weinstein, A.M., Klawitter, J.J. & Kent, J.N. (1983b) Quantitative histologic evaluation of LTI carbon, carbon-coated aluminum oxide and

- uncoated aluminum oxide dental implants. *Journal of Biomedical Materials Research* **17**: 519–538. Exclusion criteria: no bone-to-implant contact reported.
- Cremer, T. (1987) L'implant dentaire en  $Al_2O_3$ , Frialite. *Actualités odonto-stomatologiques* **41**: 641–648. Exclusion criteria: presentation of an implant system.
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- d'Hoedt, B. & Schulte, W. (1989) A comparative study of results with various endosseous implant systems. *The International Journal of Oral & Maxillofacial Implants* **4**: 95–105. Exclusion criteria: no survival/success rate reported.
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- Donath, K. (1986) Ist die Osteointegration der Dentalimplantate abhängig vom Implantatmaterial? *ZWR Das Deutsche Zahnärzteblatt* **95**: 1146–1148. Exclusion criteria: only human biopsies, no clinical study.
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- Ehrl, P.A. (1983b) Vergleichende Untersuchung von Einzelzahn- und Blattimplantaten aus  $Al_2O_3$ -Keramik. *Österreichische Zeitschrift für Stomatologie* **80**: 97–102. Exclusion criteria: no survival/success rate reported.
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- Ehrl, P.A., Reuther, J. & Frenkel, G. (1981)  $Al_2O_3$ -ceramic as material for dental implants: experimental and clinical study for the development of screw- and extension-implants. *International Journal of Oral Surgery* **10**: 93–98. Exclusion criteria: case series, no protocol for a clinical study.
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- Guglielmotti, M.B., Renou, S. & Cabrini, R.L. (1999) A histomorphometric study of tissue interface by laminar implant test in rats. *The International Journal of Oral & Maxillofacial Implants* **14**: 565–570. Exclusion criteria: no ceramic implants investigated.
- Hashimoto, M., Akagawa, Y., Nikai, H. & Tsuru, H. (1988) Single-crystal sapphire endosseous dental implant loaded with functional stress – clinical and histological evaluation of peri-implant tissues. *Journal of Oral Rehabilitation* **15**: 65–76. Exclusion criteria: no bone-to-implant contact reported.
- Hobkirk, J.A. (1981) Patterns of cortical bone growth around alumina implants. *Journal of Oral Rehabilitation* **8**: 143–154. Exclusion criteria: no bone-to-implant contact reported.
- Kent, J.N., Cook, S.D., Weinstein, A.M. & Klawitter, J.J. (1982) A clinical comparison of LTI carbon, alumina, and carbon-coated alumina blade-type implants in baboons. *Journal of Biomedical Materials Research* **16**: 887–899. Exclusion criteria: no bone-to-implant contact reported.
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- Müller, W., Piesold, J. & Glien, W. (1988) Eigenschaften und klinische Anwendung von Kieferimplantaten aus Aluminiumoxidkeramik Bionit. *Stomatologie der DDR* **38**: 673–678. Exclusion criteria: no survival/success rate reported.
- Münch, M. (1987) Das Sofort- und Spatimplantat nach Münch aus BioloX. Ein klinischer Erfahrungsbericht nach sechs Jahren. *ZWR Das Deutsche Zahnärzteblatt* **96**: 456–458; 460, 464–456. Exclusion criteria: no observation period and patient number reported.
- Mutschelknauss, E. & Dörre, E. (1977) Extensionimplantate aus Aluminiumoxid-Keramik (I). *Quintessenz* **28**: 21–25. Exclusion criteria: presentation of an implant system.
- Nentwig, G.H. (1985) Enossale Implantate aus Aluminiumoxidkeramik ( $Al_2O_3$ ). *Zahnarzt* **29**: 87–97. Exclusion criteria: review.
- Neunhoeffer, H. (1981) Prothetische Versorgung von Implantaten aus Aluminiumoxid-Keramik. *Quintessenz* **32**: 2049–2053. Exclusion criteria: case series, no protocol for a clinical study.
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