

Zirconia as a Dental Implant Abutment Material: A Systematic Review

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Purpose: The focus of this systematic review was to assess the published data concerning zirconia dental implant abutments from various aspects. **Materials and Methods:** To identify suitable literature, an electronic search was performed using PubMed. The keywords “zirconia,” “zirconium,” “ceramic,” “dental abutments,” “dental implants,” “plaque,” and “bacteria” were included. Titles and abstracts were screened, and literature that fulfilled the inclusion criteria was selected for a full-text reading. Articles were divided into four groups: (1) studies on the mechanical properties of zirconia abutments, (2) studies on the peri-implant soft tissues around zirconia abutments, (3) studies on plaque accumulation on zirconia, and (4) clinical studies on the survival of zirconia abutments. **Results:** The initial literature search resulted in 380 articles. For groups 1 to 4, 11, 4, 7, and 3 articles satisfied the inclusion and exclusion criteria, respectively. Only 1 randomized clinical study was identified. Review of the selected articles showed that zirconia abutments were reliable in the anterior region from both biologic and mechanical points of view. Furthermore, zirconia abutments may represent a material surface less attractive for early plaque retention compared to titanium. Three clinical follow-up studies indicated that zirconia abutments could function without fracture and peri-implant lesions. **Conclusions:** Based on the reviewed literature, zirconia has the potential to be used as a dental abutment material, although some issues have to be studied further. *Int J Prosthodont* 2010;23:299–309.

To date, titanium has held a dominant position as an abutment and implant material in implant therapy,^{1,2} and long-term clinical studies^{3,4} on commercially pure (CP) titanium demonstrate a predictable outcome. Demands for highly esthetic restorations have been raised by an increasing number of patients, which has

led to the introduction of tooth-colored ceramic implant abutments produced in densely sintered alumina.^{5,6} The peri-implant soft tissues around alumina abutments have been documented in both animal and human studies.^{7–10} Abutments made of CP titanium and alumina develop similar peri-implant mucosa, consisting of junctional epithelium and connective tissue attachment. Clinical studies have demonstrated stable peri-implant soft tissues around alumina abutments that have been observed over 3 to 4 years.^{11–13} In addition, since alumina abutments have a toothlike color, a more esthetic outcome could be achieved compared to using titanium abutments. Unfortunately, referred clinical studies^{11–13} have additionally reported fractures to alumina abutments. Although alumina implant abutments perform well biologically as well as esthetically, it is apparent that they possess a fracture risk during both laboratory work and after abutment connection.

Due to this shortcoming in their mechanical properties, yttrium oxide-stabilized zirconia was introduced as an alternative material for implant abutments and it has overtaken alumina as the preferred ceramic abutment material.¹⁴ The unique stress-induced transformation toughening mechanism in zirconia vastly improves its

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mechanical strength and reliability,^{15,16} which has led to the increased use of zirconia as a ceramic biomaterial in both medicine and dentistry.^{17,18} The mechanical and microstructural properties of zirconia, as well as its biocompatibility, have been well documented.^{17,19–21} In dentistry, zirconia has been considered for clinical applications such as frameworks for all-ceramic crowns and fixed partial dentures (FPDs),^{22–24} brackets for orthodontic treatment,²⁵ and implants and abutments.^{26,27}

Zirconia is a polymorphic material that displays four different crystalline structures. At room temperature, pure zirconia exists in a monoclinic form. The addition of stabilizing oxides (eg, yttrium oxide) to pure zirconia generates a multiphase structure, designated the metastable tetragonal phase, which has good mechanical properties. Owing to the metastable tetragonal phase, stabilized zirconia will display a stress-induced transformation toughening mechanism. The transformation from the tetragonal to the monoclinic phase is associated with a 3% to 4% localized volume expansion that induces counteracting compressive stresses in compromised areas.¹⁷ Besides the favorable mechanical properties, zirconia is proposed to accumulate dental plaque to a lesser extent than titanium.²¹

Despite the fact that ceramics as abutment materials have been used in dentistry for a number of years, only a limited number of review articles on ceramic abutments have been published to date.^{27–29} Concerning zirconia abutments, there is, to the authors' knowledge, no systematic review published.

Thus, the increased use of zirconia as an abutment material calls for a systematic reevaluation of available data on zirconia. The purposes of this paper were therefore to review the literature systematically regarding: (1) the mechanical properties of zirconia abutments from in vitro studies, (2) a histologic evaluation of peri-implant soft tissue responses around zirconia abutments from in vivo studies, (3) plaque accumulation or bacterial adhesion onto zirconia from both in vitro and in vivo studies, and (4) the survival of zirconia abutments from clinical studies

Materials and Methods

Search Strategy

A literature search focusing on the purposes previously mentioned was performed electronically using the PubMed database. The literature was divided into four groups following the intended purposes.

Articles published and recorded in PubMed through July 2009 were searched using the following key words: "zirconia" and "dental abutments," "zirconium" and "dental abutments," "zirconia" and "dental implants,"

"zirconium" and "dental implants," "zirconia" and "plaque," "zirconium" and "plaque," "ceramic" and "plaque," "zirconia" and "bacteria," "zirconium" and "bacteria," and "ceramic" and "bacteria." The searches were limited to articles written in English with an associated abstract. The electronic searches were complemented by manual searches through the bibliographies of the resulting articles and related reviews selected from the electronic search.

Inclusion and Exclusion Criteria

In this review, studies on zirconia ceramic composites or materials coated by zirconium compounds were excluded; only tetragonal zirconia polycrystals or partially stabilized zirconia were included. Additional inclusion criteria for each study selection were included as follows:

- Group 1: In vitro studies on the mechanical properties of zirconia abutments. Included studies investigated the fracture strength or fatigue of zirconia abutments or implant units, which involved an implant, a zirconia abutment, and a crown.
- Group 2: In vivo studies on peri-implant soft tissue responses around zirconia abutments or implants. Included studies investigated dental implants used in the oral cavity and the soft tissues around implant components made of zirconia (ie, abutments, healing caps, or around transmucosal zirconia implants). Included studies also examined the histologic analysis of the peri-implant soft tissue and the normal peri-implant soft tissue (not experimentally induced inflammatory tissue).
- Group 3: Studies on plaque accumulation or bacterial adhesion onto zirconia. Included studies used zirconia as a material or substrate for plaque accumulation or bacteria adhesion and had a description not only about the microbiologic analysis but also the surface topography of the substrate or material.
- Group 4: Clinical studies on the stability of zirconia abutments. Included studies reported clinical results of zirconia abutments, had a minimum number of 20 subjects at the baseline examination (case reports were excluded), and had at least a 1-year follow-up period. If there were several studies following the same population, only the most recent was included in this review.

Statistics

No meta-analysis was performed because there were too few studies in each review category and great variations in study design were evident. The statistics presented were taken from the reviewed articles.

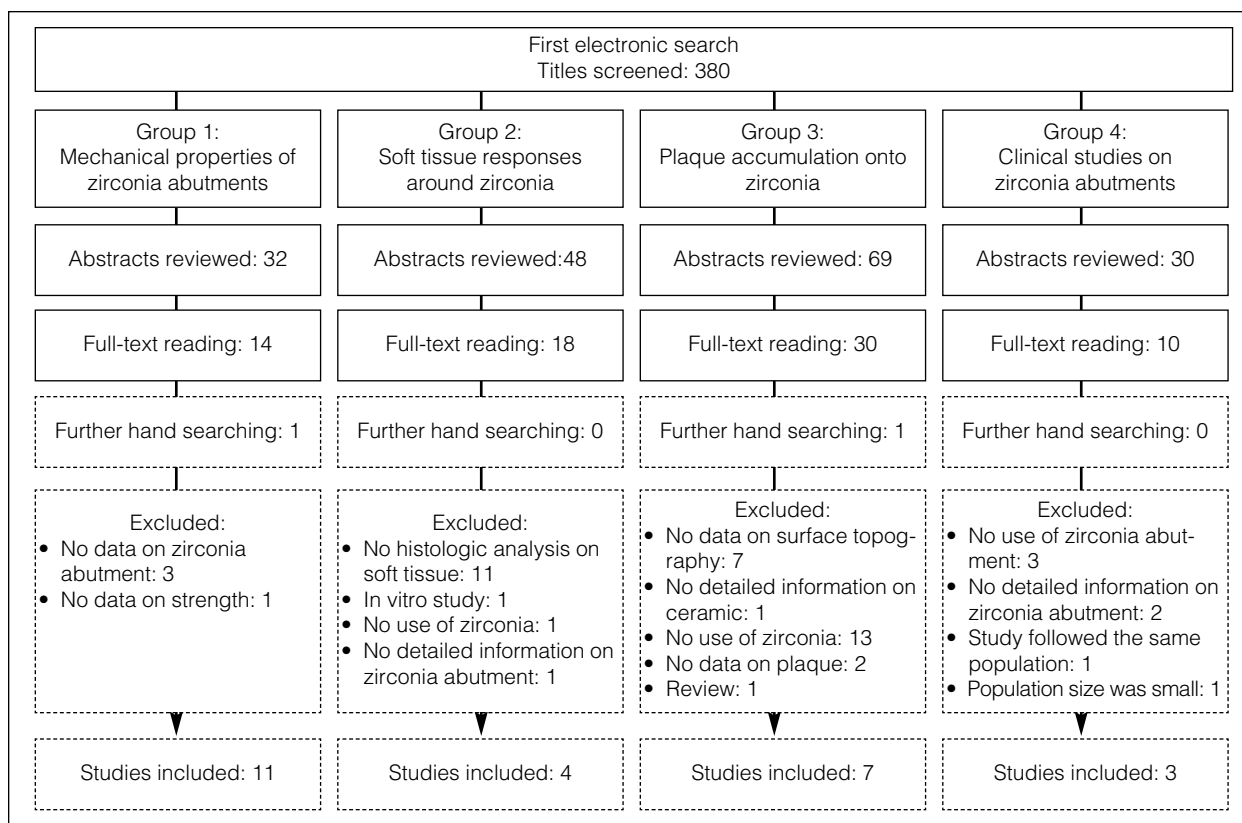


Fig 1 Overview of the search strategy used with the number of articles screened and included in the systematic review.

Results

Study Characteristics

The initial PubMed search resulted in 380 papers. After screening and taking into consideration the inclusion criteria for groups 1 to 4, 11, 4, 7, and 3 articles remained, respectively (Fig 1). Unfortunately, a direct comparison of the various results was difficult to obtain since the study designs of the reviewed articles in each category varied.

Group 1

From the 11 studies reviewed in this category,³⁰⁻⁴⁰ two types of zirconia abutments were identified (Table 1). One type was composed of all-zirconia^{30,32-34,36,40} and the other was reinforced with metal (titanium) at the implant-abutment interface (zirconia abutment complexes).^{31,35,37} All reviewed literature in this category, except for 1 study,³⁵ evaluated the strength of the zirconia abutment combined with implants or implant replicas and crowns. Of these 10 studies, 4 evaluated the strength of the zirconia abutment after thermomechanical fatigue³¹⁻³³ or after cyclic loading,³⁴ whereas the

remaining 6 studies evaluated strength using static loading only.^{30,36-40} In the experiment without cyclic loading of zirconia abutments, Yildirim et al³⁰ reported a mean fracture load of the zirconia abutments of 737 N. This finding has also been confirmed by other researchers.^{37,38} The fracture strength against cyclic loading or thermomechanical fatigue was, however, reduced significantly.³¹⁻³⁴ Gehrke et al³⁴ reported a decreased strength of zirconia from 672 N without cyclic loading to less than 405 N after cyclic loading using loads between 100 and 450 N for up to 5,000,000 loading cycles. Thermomechanical fatigue studies on zirconia³¹⁻³³ at loads of less than 50 N for 1,200,000 loading cycles showed decreased strength (between 457 and 281 N) compared to the results of Yildirim et al.³⁰

Three studies^{30,32,33} compared the strength of zirconia abutments with alumina abutments. Two of them showed that zirconia abutments had significantly higher strength than alumina abutments,^{30,32} whereas one failed to show any significant difference between them.³³ Although it is not possible to compare fracture strength values between various studies because of differences in study design, the reviewed articles demonstrated that zirconia abutments could be used in the anterior region of the dentition safely, where the physiologic maximal

Table 1 In Vitro Studies on Mechanical Properties of Zirconia Abutments

Study	Materials	Study design	Results
Yildirim et al ³⁰	Alumina abutments (n = 10) All-zirconia abutments (partially stabilized, n = 10)	Implant: Brånemark Crown: glass ceramic Cyclic loading: none (only static loading) Angle of force application: 30 degrees to vertical	Mean fracture load: Al = 280.1 N, Zr = 737.6 N Significant difference: Al vs Zr
Butz et al ³¹	Zirconia abutment complexes (n = 16) Alumina abutments (n = 16) Titanium abutments (n = 16)	Implant: Osseotite Crown: metal crowns (nonprecious alloy) Cyclic loading: 1.2 million cycles of thermo-mechanical fatigue with a force of 30 N Angle of force application: 50 degrees to vertical	During the cyclic loading, one alumina abutment fractured. Mean fracture load: Zr = 281 N, Al = 253 N, Ti = 305 N Significant difference: Zr vs Al, Ti vs Al
Att et al ³²	Titanium abutments (n = 16) Alumina abutments (n = 16) Zirconia abutments (n = 16)	Implant: Replace Select Crown: all-ceramic with zirconia copings Cyclic loading: 1.2 million cycles of thermo-mechanical fatigue with a force of 49 N Angle of force application: 45 degrees to vertical	All specimens survived 1.2 million cycles of dynamic loading. Median fracture resistance: Ti = 1,251 N, Al = 457 N, Zr = 241 N Significant difference: Ti vs Al and Zr, Al vs Zr
Att et al ³³	Titanium abutments (n = 16) Alumina abutments (n = 16) Zirconia abutments (n = 16)	Implant: Replace Select Crown: all-ceramic with alumina copings Cyclic loading: 1.2 million cycles of thermo-mechanical fatigue with a force of 49 N Angle of force application: 45 degrees to vertical	All specimens survived 1.2 million cycles of dynamic loading. Median fracture resistance: Ti = 1,454 N, Al = 422 N, Zr = 443 N Significant difference: Ti vs Al and Zr
Gehrke et al ³⁴	All-zirconia abutments (n = 7)	Implant: XiVE Crown: spherical caps (no description in detail) Cyclic loading: at most 5 million cyclic loading with a force of 100 to 450 N Angle of force application: 30 degrees to vertical	During static loading: 672 N After 811,023 to 5 million cycles: 268.8 N After 10,000 cycles: 403.2 N No description of statistics
Canullo et al ³⁵	Zirconia abutment complexes (n = 20)	Implant: none Crown: none Cyclic loading: none (only static loading) Angle of force application: 30 degrees to vertical	Mean maximum load: 436 N
Sundh and Sjögren ³⁶	Mg-PSZ abutments (n = 10) HIPed Y-TZP abutments (n = 10) Titanium abutment with zirconia coping (n = 10)	Implant: Straumann (titanium with stainless steel analog) Crown: none but zirconia copings Cyclic loading: none (only static loading) Angle of force application: 90 degrees to vertical	All combinations of ceramic abutments and implants exceeded 300 N (individual values not shown). Significant difference: Ti vs Mg-PSZ (Ti < Mg-PSZ)
Aramouni et al ³⁷	Zirconia abutment complexes (n = 20) Zirconia abutment (n = 20) Noble metal abutment (n = 20)	Implant: 3i Certain or SLA Straumann Crown: all-ceramic made of Empress 2 Cyclic loading: none (only static loading) Angle of force application: 45 degrees to vertical	Mean fracture strength: ZiReal = 792.7 N, synOcta Ceramic Blank = 604.0 N, UCLA = 793.6 N Significant difference: synOcta vs ZiReal and UCLA
Kerstein et al ³⁸	All-zirconia abutment (Atlantis zirconia, n = 29) All-zirconia abutment (Procera AllZirkon, n = 29)	Implant: Nobel Biocare Crown: none Cyclic loading: none (only static loading) Angle of force application: 40 degrees to vertical	Mean fracture strength: Atlantis = 831 N, AllZirkon = 740 N Significant difference: Atlantis vs AllZirkon
Kim et al ³⁹	Pressable metal ceramic custom implant abutments (n = 10) All-zirconia abutments (n = 10)	Implant: implant analog (Replace Select) Crown: all-ceramic lithium disilicate pressable ceramic crowns (IPS e.max Press) Cyclic loading: none (only static loading) Angle of force application: 30 degrees to vertical	Mean fracture strength: pressable metal ceramic = 901.67 N, zirconia = 480.01 N
Adatia et al ⁴⁰	Y-TZP ceramic abutment Group 1 (n = 10): no modification Group 2 (n = 10) and group 3 (n = 10): chamfer preparation with occlusal reduction using a high-speed dental handpiece	Implant: implant analog (stainless steel) Crown: none Cyclic loading: none (only static loading) Angle of force application: 30 degrees to vertical	Mean fracture strength: Group 1 = 429 N, Group 2 = 576 N, Group 3 = 547 N Significant difference: none

Zr = zirconia; Al = alumina; Ti = titanium; Mg-PSZ = magnesia partially stabilized zirconia; HIPed = hot isostatic pressed; Y-TZP = yttrium oxide partially stabilized zirconia; SLA = sandblasted, large-grit, acid-etched.

occlusal forces reach approximately 300 N.^{41,42} Concerning mechanical strength, zirconia abutments work as well as alumina abutments.

Group 2

Four papers were found to fulfill the inclusion criteria in this group (Table 2).⁴³⁻⁴⁶ These studies indicated that zirconia was a suitable abutment material compared to titanium concerning tissue responses. Furthermore,

Table 2 In Vivo Studies on Peri-Implant Soft Tissue Responses Around Zirconia Abutments or Implants

Study	Materials	Study design	Results
Kohal et al ⁴³	Custom-made titanium and zirconia implants	Animal study (six monkeys): Implants were placed transmucosally. Nine months later, single crowns were cemented and plaque control program was initiated. Five months after crown placement, the biopsy was taken for histologic examination.	The peri-implant soft tissue around zirconia implants showed similar dimensions between landmarks to that around titanium implants.
Degidi et al ⁴⁴	XiVE plus implants with titanium or zirconia healing caps	Human histologic study (five patients): Implants were placed and left to heal in a nonsubmerged mode with healing caps. Half of the implants were supplied with titanium healing caps and half with test zirconium healing caps. Patients underwent oral hygiene sessions of scaling and root planing and were enrolled in a strict maintenance program. After a 6-month healing period, gingival biopsy was performed with a circular scalpel for immunohistochemical evaluation.	The inflammatory infiltrate was mostly present on the titanium specimens. Their extension was much larger than that of zirconium oxide specimens.
Welander et al ⁴⁵	Astra Tech implants with titanium, zirconium, or gold-platinum alloy abutments	Animal study (six dogs): Implants were placed submerged. One month after implant placement, four test abutments were placed in a randomized order. A plaque control program was initiated. Two and 5 months after abutment connection, a biopsy was taken for histologic examination.	The titanium and zirconia abutments promoted proper conditions for soft tissue healing, but gold-platinum alloy abutments did not.
Teté et al ⁴⁶	Implants with a machined titanium neck (Oct-In) Implants with a zirconia neck (Z1)	Animal study (five swine): Implants were placed using a single-stage flapless surgical procedure and were not functionally loaded. Oral hygiene was performed on the day of surgery and monthly during the experimental period (3 months). Animals were sacrificed 3 months after implant insertion for histologic analysis.	Collagen fiber orientation was similar regardless of implant neck material. Moreover, zirconia showed connective tissue adhesion that was similar to that seen on the machined titanium surface.

peri-implant soft tissues around zirconia exhibit the potential to heal faster than when in contact with titanium. Kohal et al⁴³ evaluated and compared the conditions of soft and hard tissues in contact with zirconia and titanium implants in monkeys. The authors concluded that bone and soft tissues appeared to integrate with zirconia as well as titanium. This finding was also confirmed by other researchers.^{45,46} Welander et al⁴⁵ compared abutments made of titanium, zirconia, and gold-platinum alloy in dogs. The soft tissue barrier formed around titanium and zirconia abutments displayed equal and stable conditions following 2 and 5 months of healing. On the other hand, gold-platinum abutment sites demonstrated an apical shift of the barrier epithelium and the level of marginal bone over the same time period.

Degidi et al⁴⁴ conducted a human histologic study to compare peri-implant soft tissues in contact with titanium and zirconium oxide healing caps. Although no clinically visible plaque accumulation or bleeding on probing was recorded in either group, the inflammatory infiltrate was observed more frequently in the peri-implant soft tissues around titanium healing caps compared to the zirconia healing caps.

Group 3

Seven papers were found and reviewed in this category (Table 3).^{47–53} Generally, lower plaque formation was recorded on zirconia specimens compared to other evaluated materials. Nakazato et al⁴⁷ compared plaque

formation in vivo on six different materials, including alumina, titanium, and zirconia. They hypothesized that the implant surface properties might play important roles in bacterial adherence during the early stages of plaque formation after being affected to a greater extent by the material's surface roughness than by its surface free energy. Since the materials used in their study had different surface roughness levels, it could not be determined if and how the various surface factors affected the adherence of oral bacteria. Rimondini et al,⁴⁹ however, were able to evaluate the role of bacterial adhesion on zirconia and titanium specimens with equivalent average surface roughness (Ra) values both in vivo and in vitro. The various strains of oral bacteria studied included *Streptococcus sanguis*, *Actinomyces*, *Porphyromonas gingivalis*, and *Streptococcus mutans*. *S. mutans* exclusively displayed significantly increased attachment to zirconia specimens (Ra = 0.18 µm) compared to titanium specimens (Ra = 0.22 µm) after an incubation period of 36 hours in vitro. In vivo, however, zirconia specimens accumulated significantly fewer bacteria than titanium specimens after 24 hours. Scarano et al⁵⁰ confirmed the latter finding in vivo by comparing zirconia and titanium specimens with surface roughness values of 0.76 µm and 0.73 µm, respectively. The percentage of disk surface covered by bacteria was significantly lower on zirconia than on titanium after 24 hours. However, in the studies where early bacterial adhesion (within 2.5 hours) to zirconia and other dental ceramic materials were compared, no differences were reported.^{52,53}

Table 3 Studies on Plaque Accumulation or Bacterial Adhesion onto Zirconia

Study	Materials	Study design	Results
Nakazato et al ⁴⁷	Single-crystal alumina (Ra = 0.090 µm) Polycrystal alumina (Ra = 0.854 µm) Partially stabilized polycrystal zirconia (Ra = 0.369 µm) Hydroxyapatite (Ra = 0.518 µm) Pure titanium (Ra = 0.142 µm) Heat-polymerized acrylic resin (Ra = 0.109 µm)	In vivo study (3 subjects): Disks of each material were set on the gingiva of the subjects using removable devices. Tooth brushing was not permitted. The disks were removed after 4 and 48 hours. The disks were subjected to SEM observations and microbiologic examination.	At the 4-hour setting time, poly crystal alumina and hydroxyapatite had a higher concentration of bacteria. However, after 48 hours, the material surfaces were uniformly covered. No apparent differences were observed.
Bollen et al ⁴⁸	CP titanium abutments (Ra = 0.21 µm) Zirconia (Polyzir) abutments (Ra = 0.06 µm)	In vivo study (6 subjects with implant-supported overdentures): The two test abutments were delivered using the split-mouth technique. After 3 and 23 months, both clinical and microbiologic examinations were repeated.	There were no major differences both quantitatively and qualitatively between the supra- and subgingival plaque of the two test abutment surfaces.
Rimondini et al ⁴⁹	Titanium disks (Ra = 0.22 µm) Polished zirconia disks (Ra = 0.18 µm) High-polished zirconia disks (Ra = 0.04 µm)	In vitro study (7 specimens of each material): Test specimens were anaerobically incubated for 36 hours with bacteria precultured in broth. In vivo study (10 subjects): Removable devices were produced and three specimens (one of each type) were fixed mechanically into the silicone stent. The device was fixed onto the buccal region of the molar or premolar of each volunteer. Subjects suspended any oral hygiene procedures for 24 hours. Disks were then removed and observed with SEM.	In vitro test: Polished zirconia disks showed significantly more adherent <i>S mutans</i> than high-polished and titanium. In vivo test: The zirconia disks accumulated significantly fewer bacteria than titanium disks.
Scarano et al ⁵⁰	Titanium disks (Ra = 0.73 µm) Zirconia disks (Ra = 0.76 µm)	In vivo study (10 subjects): Removable devices having test disks were adapted to the molar-premolar region. Neither cleaning procedures nor agents for chemical plaque control were applied to the disks for 24 hours. Disks were then removed and observed with SEM.	The percentage of the disk surface covered by bacteria on the zirconia specimens was significantly lower than that of titanium specimens (12.1% and 19.3%, respectively).
Scotti et al ⁵¹	Polished zirconia disk (no Ra available) Glazed zirconia disks (no Ra available)	In vivo study (2 subjects): Samples were fixed on buccal and palatal surfaces of individual oral appliances made of light-cured resin. The presence or absence of bacteria on the surfaces was recorded using SEM at 20 minutes and 1 and 6 hours.	No significant difference was found in bacteria presence between glazed and polished zirconia samples
Meier et al ⁵²	Glass (control; Ra = 0.24 µm) Feldspathic ceramic (Ra = 0.26 µm) Glass-infiltrated alumina (Ra = 1.33 µm) Zirconia-reinforced glass-infiltrated alumina (Ra = 1.34 µm) Tetragonal stabilized zirconia (Ra = 0.26 µm)	In vitro study (5 specimens of each material): Before adhesion, specimens were exposed to sterile human saliva for 15 minutes. Adhesion was performed using four different streptococci and a flow chamber for 1 hour.	The materials' properties, surface roughness, and glass content had only a weak influence on streptococci adhesion.
Rosentritt et al ⁵³	Zirconia: Circon Base (Ra = 0.22 µm) Digizon (Ra = 0.08 µm) Inceram Y-TZP (Ra = 0.22 µm) Veneering glass ceramic: Circon Ceram S (Ra = 0.22 µm) Omega 900 (Ra = 0.57 µm) GC Zirconia (Ra = 0.10 µm) Glass (control)	In vitro study (15 specimens of each material): After 2 hours of incubation with artificial saliva, specimens were incubated with various streptococcal suspension for 2.5 hours.	A low adhesion of several strep tococci to glass ceramic as well as to zirconia was found. There were only little differences between zirconia and glass ceramic with regard to streptococci adhesion.

Ra = surface roughness; SEM = scanning electron microscopy.

The long-term effect of plaque accumulation on zirconia and titanium abutments was investigated by Bollen et al.⁴⁸ Abutments of the two materials were placed intraorally in six patients receiving implant-supported overdentures. Clinical and microbiologic examinations after 12 months failed to reveal any major differences quantitatively or qualitatively between supra- and subgingival plaque from the abutment material surfaces. Conclusions from these findings suggest that zirconia might reduce early bacterial adhesion (< 24 hours) compared to titanium. However, it is still unclear whether this characteristic of zirconia is of any clinical benefit.

Group 4

Only three papers in the fourth group were found to fulfill the criteria for the present review (Table 4).⁵⁴⁻⁵⁶ Two of them were prospective clinical trials^{54,55} and the remaining was a randomized controlled trial (RCT).⁵⁶ Although another RCT was found,⁵⁷ it was excluded because the same population was studied and reported in another paper.⁵⁶ The results of the two prospective studies showed good clinical performance in the anterior and premolar regions for zirconia abutments without fracture and peri-implant lesion during the

Table 4 Clinical Studies on Stability of Zirconia Abutments

Study	Materials	Prosthesis type	Survival rate	Follow-up	Results
Glauser et al ⁵⁴	27 patients with 54 experimental all-zirconia abutments No control group	Implant-supported single-tooth restorations in the incisor, canine, and premolar regions	100%	48 mo	No abutment fractures were observed and the peri-implant mucosa was healthy.
Canullo ⁵⁵	25 patients with 30 zirconia abutment complexes No control group	Implant-supported single-tooth restorations in the incisor, canine, premolar, and molar regions	100%	40 mo (mean)	Neither abutment fracture nor peri-implant soft tissue lesion was reported during clinical loading.
Zembic et al ⁵⁶	22 patients with 20 zirconia and 20 titanium abutments (RCT)	Implant-supported single-tooth restorations in the canine, premolar, and molar regions	100%	36 mo (mean)	At 3 years, zirconia and titanium abutments exhibited the same survival and technical, biologic, and esthetic outcomes.

RCT = randomized controlled trial.

observation periods (40 and 48 months, respectively). In addition, the RCT showed that zirconia abutments could also function well in the molar region without technical problems, such as abutment fracture, screw loosening, and loss of crown retention.⁵⁶

Glauser et al⁵⁴ evaluated both peri-implant hard and soft tissue reactions to experimental zirconia abutments made by an individualization process of densely sintered yttrium-stabilized zirconia ingots, supporting single crowns in the esthetic zone, and technical problems related to the abutment materials. Twenty-seven patients (16 women, mean age: 42 years; 11 men, mean age: 46 years) received 54 implants with experimental zirconia abutments (all-zirconia abutments) and all-ceramic crowns (Empress I, Ivoclar Vivadent). Following 1, 12, and 48 months postinsertion, clinical evaluations including assessment of the condition of the peri-implant mucosa were performed. Over the course of this study, no abutment fractures were observed, resulting in a survival rate of 100%. The peri-implant mucosa was judged as healthy with regard to Plaque Index and Gingival Index. However, at the 48-month follow-up, a patient/restoration dropout rate of 33% was recorded, which inevitably lowered the impact of the 48-month results.

In studying the clinical efficacy of zirconia abutments cemented with a composite resin cement to a titanium substructure (zirconia abutment complex), Canullo⁵⁵ evaluated 25 patients (14 women, 11 men; mean age: 52 years) requiring 30 zirconia implants provided with zirconia abutments and single implant-supported all-ceramic crowns. No detailed information about the type of all-ceramic crowns used was given. The crowns replaced anterior teeth (eight in the maxilla and eight in the mandible) and premolars (eight in the maxilla and two in the mandible) but only a few molars (two in the maxilla and two in the mandible). The patients were followed for a mean observation period of 40 months. No abutment fracture or screw loosening was reported during clinical loading, resulting in a cumulative survival

rate of 100%. Since no information was disclosed on patient/restoration dropouts, the reported survival rate must be evaluated cautiously. The Plaque Index and the Gingival Index indicated that the soft tissues around the abutments were considered healthy.

In the RCT,⁵⁶ 22 patients (14 women, 8 men; mean age: 41.3 years) who were in need of implant-supported single crowns ($n = 40$) in the canine, premolar, and molar regions were included. At abutment connection, 20 customized all-zirconia abutments (Procera, Nobel Biocare) or 20 customized titanium abutments (Procera, Nobel Biocare) were assigned randomly. All-ceramic crowns were either fabricated out of glass ceramic or out of high-strength ceramic (alumina or zirconia) for the zirconia abutments, while metal-ceramic crowns were fabricated for the titanium abutments. During the follow-up period, no technical problems were observed despite the fact that 27% of zirconia abutments supported crowns in the molar region. Hence, the abutment survival rate was 100%. Furthermore, no biologic complications were found at zirconia abutments as well as titanium abutments. Thus, custom-made zirconia abutments might be useful for anterior and premolar implant-supported fixed prostheses regardless of whether they are all-zirconia abutments or zirconia abutment complexes. In addition, zirconia abutments might also function well in molar regions.

Discussion

Systematic reviews are often useful in the evaluation of various materials and treatments since they extract the best evidence from the scientific literature.⁵⁸ Concerning zirconia abutments, no systematic review has been performed thus far. The reason for this may be that zirconia abutments have been used for only a short period of time and data are still limited. Still, the interest in zirconia abutments is increasing due to their

favorable mechanical and esthetic properties. In that respect, this systematic review was performed as an attempt to evaluate the available data on zirconia abutments. Difficulties were experienced in that only a few studies focused on zirconia abutments. Only one RCT was identified. RCTs are regarded as the highest level of evidence. Since few RCTs have been performed on zirconia abutments to date, it should be recognized that the results of the studies reviewed in this article do have limited evidence and clinical relevance.^{59,60} In this review, *in vitro* studies and *in vivo* animal studies were included because they are well accepted for supplying basic scientific knowledge, although their clinical relevance may be questionable.⁶¹

Two main factors might cause failure in implant therapy, one of which is related to mechanical failure and the other to biologic complications. The former includes implant fracture, abutment fracture, and fracture of the superstructure, whereas the latter includes failure and loss of osseointegration.⁶²⁻⁶⁴ In addition, the esthetic requirements for implant abutments are or will be more strict in the esthetic zone.

In vitro, the mechanical flexural strength of zirconia (disks or bars) has been recorded from 900 to 1,200 MPa, which is approximately twice that of alumina.¹⁷ Concerning zirconia abutments, it was also confirmed that the fracture load of zirconia was more than twice that of alumina.³⁰ However, it was observed that the strength of the zirconia abutment decreased after cyclic loading. This could be attributed to the aging process. Still, it remains to be determined whether cyclic loading is responsible for the decline in strength and what clinical consequences will result.

The mechanical strength of zirconia abutments can also be affected by the method of fabrication.⁶⁵⁻⁶⁷ Furthermore, zirconia abutments can be adjusted chairside using a high-speed dental handpiece with a diamond bur.⁴⁰ Although these factors must be taken into account for the strength of the abutment, they were difficult to assess in the present review due to lack of valuable information in a majority of the articles. Although chairside adjustment of zirconia abutments might be possible,⁴⁰ further studies on the subject are needed.

It was apparent from the reviewed literature that even if the mechanical strength of zirconia was reduced by cyclic loading, the zirconia abutment would probably have enough mechanical strength clinically. The all-zirconia abutment and the zirconia abutment complex were found to be comparable regarding mechanical strength.

The peri-implant soft tissues around titanium abutments have been well documented.^{1,2,68-72} According to histologic studies, peri-implant soft tissues and periodontal tissues are composed of junctional epithelium and connective tissue attachment and act as barriers

between the oral environment and the internal structures of the body. Although the dimensions of the soft tissue barrier around implants and teeth are similar, the connective tissue attachment is different.^{68,73,74} Four histologic studies included in the present systematic review demonstrated that the peri-implant soft tissues around zirconia are similar to those around the titanium abutments. Furthermore, human histologic analysis⁴⁴ indicated that peri-implant soft tissues around zirconia might heal faster than when in contact with titanium.

According to the articles reviewed, zirconia appeared to be superior to titanium with less initial plaque accumulation when there were no differences in surface topography. Examination of only the surface roughness value was performed despite other surface parameters existing, such as the skewness factor, which offers valuable information on details of the topography. Due to lack of information, such as the surface free energy value and the surface elemental composition, it is difficult to draw any valid conclusions from the referred articles. The complex evaluation of the importance of plaque in relation to solid abutment surfaces calls for thorough analyses of which bacterial strains constitute the plaque. Also, the importance of the surface free energy as a causative factor for bacterial adhesion on zirconia abutments warrants further investigation.

It has been reported that although slightly less plaque accumulation on zirconia rather than titanium abutments offers no general clinical advantage, plaque adherence and plaque removal might be influenced. In a series of studies, Bollen et al⁴⁸ and Quirynen et al^{75,76} determined the threshold surface roughness value of plaque accumulation on titanium. The threshold value was proposed to be $Ra = 0.2 \mu\text{m}$, below which no or only minor influence of the surface topography occurred on plaque accumulation. However, Wennerberg et al⁷⁷ failed to find any clinical or histologic differences between surface roughness of titanium abutments and soft tissue inflammatory responses after an evaluation period of 4 weeks. It remains to be determined whether there might be a relationship between surface factors, plaque accumulation, and soft tissue inflammatory responses.

In the prospective clinical studies, it was observed that zirconia abutments would not cause technical or biologic problems, at least over short or intermediate observation periods (40 to 48 months).^{54,55} This was confirmed by the RCT at the 36-month follow-up.⁵⁶ A prospective study on alumina abutments supporting short-span FPDs displayed a cumulative success rate of 98.1% over 5 years.¹² Based on the reviewed studies, it can be hypothesized that zirconia abutments, with superior mechanical properties compared to alumina, will function as abutments for anterior FPDs with a success rate that corresponds to or is better than alumina. Additionally, the possibility of zirconia abutments for

restorations in the molar region has been shown.^{55,56} Still, the small sample size and the relatively short observation period (36 to 40 months) justify further studies for supporting a decision to possibly expand the indications for zirconia abutments.

It is difficult to recommend an appropriate design of zirconia abutments (eg, dimension) because of a lack of data. Only one clinical study reviewed in the present paper mentioned a minimum thickness of zirconia abutments (0.5 mm).⁵⁴ When computer-aided design/computer-assisted manufacture is used to mill a presintered zirconia block for the fabrication of restorations, it is recommended to not reduce the thickness below 0.5 mm.²⁰ Therefore, it is reasonable to assume a minimum thickness of zirconia abutments to be 0.5 mm or more to withstand a functional load. Concerning the height of the abutment and the collar, it apparently varies from patient to patient, and further studies may be needed.

Albeit only a few clinical studies reported the outcome of zirconia abutments, zirconia appears suitable as an abutment material. For future improvements to ceramic abutments, however, two issues require focus: color and the long-term stability of zirconia.²⁷ The color of zirconia is too white compared to natural teeth. This might cause another problem in esthetic dentistry, at least in the esthetic zone. Therefore, a tooth-colored zirconia abutment that matches the cervical portion of the natural teeth has been developed recently.^{78,79}

Regarding long-term stability, the aging of zirconia has become an issue for implants used in orthopedics.⁸⁰⁻⁸² Aging is suggested to be a progressive transformation of the metastable tetragonal phase into the monoclinic phase, causing degradation of the mechanical properties.^{80,83} Aging of zirconia might also be a critical problem in the field of dentistry. Further studies should verify if the aging process causes critical damage to zirconia abutments. It is expected that this will be addressed in the future.

Conclusions

On the basis of the available data, the following conclusions can be drawn:

- Mechanical properties of zirconia abutments: Based on in vitro studies, zirconia abutments are applicable to the anterior region equally as much as alumina abutments. Additionally, evidence from clinical studies has shown that zirconia abutments functioned up to 4 years without mechanical problems. However, it is still necessary to prove that zirconia abutments will be safe for posterior restorations.
- Peri-implant soft tissue responses around zirconia abutments or implants: From the animal and human

histologic studies reviewed, it can be concluded that zirconia is as suitable a material for dental implant abutments as titanium concerning biocompatibility. This has also been confirmed in clinical studies addressing the maintenance of healthy peri-implant soft tissues.

- Plaque accumulation onto zirconia: Further research is warranted before the clinical relevance concerning the differences in plaque formation on titanium and zirconia abutment surfaces can be concluded. Zirconia appears to have a lower tendency for surface-bound bacterial plaque at early stages.
- Clinical results on zirconia abutments: Since only three studies addressing the clinical outcome of zirconia abutments passed the inclusion criteria, the conclusions based on those studies should be interpreted with caution. The two prospective studies and the RCT indicated that zirconia abutments function without fracture and peri-implant lesions for up to 4 years. From this review, it is suggested that more RCTs comparing zirconia with titanium abutments using a large population should be conducted to evaluate the benefits of zirconia abutments.

Due to the limited number of well-performed scientific studies published to date, this systematic review concludes that at present, zirconia abutments should be used with caution for single implant-supported restorations in the esthetic zone. Concerning mechanical and biologic properties, zirconia abutments seem to be as applicable as titanium or alumina. It remains to be determined whether this assumption will hold true for follow-up periods over 5 years in prospective randomized controlled clinical trials. To optimize esthetics further, development of tooth-colored zirconia is necessary. To expand on the data on zirconia restorations in the future, it is of crucial importance to elucidate the influence of the aging process on zirconia.

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