Titanium oral implants are still considered “state of the art” in implant dentistry, with well-documented survival rates. However, their grayish color and high prevalence of peri-implant infections have resulted in controversial discussion as to whether tooth-like–colored, metal-free zirconia ceramic implants provide sufficient potential to be considered equal regarding treatment outcomes. The present position paper has been composed upon invitation by the European Association of Osseointegration in order to provide an update on the current level of evidence regarding zirconia implants in clinical trials. To date, most available and scientifically documented zirconia implant systems are one-piece implants that require an experienced surgeon and prosthodontist due to the restricted flexibility in cases of compromised angulation or vertical positioning. Taking this limitation into account, there is evidence of a comparable outcome for one-piece zirconia implants compared to titanium implants for the fixed replacement of one to three missing teeth. In contrast, currently available clinical data evaluating two-piece zirconia implants with an adhesively bonded implant-abutment interface suggest an inferior outcome. Data evaluating the clinical applicability of screw-retained solutions, even if revealing sufficient fracture resistance in laboratory investigations, are still missing. High survival rates were reported for all-ceramic reconstructions supported by zirconia implants, but with increased technical complications; ie, fractures of the ceramic veneer in the case of bilayered restorations. Sufficient clinical evidence for recommending monolithic approaches is limited to single crowns.


Commercially pure titanium implants are considered the gold standard in implant dentistry, with documented survival rates of over 90% after 10 years or more. However, the potentially compromising effects of titanium as implant material, such as discoloration of the soft tissues in patients with localized bone loss and thin gingival biotype, material hypersensitivities, and a causal relationship with the development of peri-implant infections, have been discussed. Although studies have demonstrated a potential for titanium particles to cause inflammatory reactions in peri-implant tissue, hard evidence for this phenomenon is yet to be provided.

In the search for metal-free alternatives to titanium, the ceramic zirconium dioxide (ZrO₂, or zirconia) appeared as a potential material candidate for oral implants and abutments and for prosthetic reconstructions. Due to the tooth-like color of zirconia, its use as material for oral implants and abutments may be
advantageous, especially for rehabilitations in the esthetic zone. However, clear facts and scientific evidence for proving the esthetic advantages of ceramic over titanium implants are still lacking. In addition to aesthetic considerations with the use of zirconia in implant dentistry, reduced bacterial and plaque adhesion on zirconia in comparison to titanium is another point of discussion. The first generation of zirconia implants displayed obviously insufficient surface and material characteristics, as they provided inferior osseointegration and removal torque values as well as higher fracture rates than titanium controls. It seems that recent surface and material modifications have helped to overcome these issues, as manufacturers today recommend similar surgical and restorative protocols for both zirconia and titanium implants.

The majority of published clinical data on zirconia implants report on one-piece designs due to the difficulty of realizing screw-type connections with ceramic components. However, a drawback of one-piece implants of either material is the reduced prosthetic versatility caused by a lack of options for abutment angulation, which could potentially lead to compromised implant positioning. The available clinical data on two-piece zirconia systems are promising but still scarce and mostly report only on laboratory and clinical short-term outcomes.

In spite of lacking long-term evidence on the application of zirconia as an implant material and its potential advantages over titanium, certain patients and dentists seem to desire use of this material for metal-free reconstructions and implants. However, this desire has not been scientifically evidenced as a patient-reported outcome to date.

Other aspects to be considered and further covered in studies are the evaluation of restorative concepts with zirconia implants. Besides laboratory studies evaluating cementation techniques and types of abutment materials and connections, there are few data available reporting on the clinical performance of all-ceramic single crowns (SCs) and three-unit fixed dental prostheses (FDPs) supported by zirconia implants.

### ONE-PIECE ZIRCONIA IMPLANTS

Due to the difficulty of realizing two-piece ceramic implant systems with results comparable to the present standards of titanium implants (ie, screw retained at the bone level), the first implants available on the market were fabricated as one-piece implants (Fig 1). In the early days of ceramic implantology, the one-piece ceramic implant made from yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) was the first to overcome concerns of an insufficient fracture resistance. These concerns were raised from earlier evaluations focusing on one-piece ceramic implants made from mono- or polycrystalline aluminum oxide. According to a systematic review and meta-analysis that included available in vitro studies, one-piece zirconia implants in general still need to be considered more fracture resistant compared to the included two-piece systems, even if some two-piece systems available on the market proved to have sufficient fracture resistance to be recommended for clinical evaluation. However, in vitro data, even if gathered from meta-analyses, cannot serve as a basis for clinical recommendations. To achieve a high level of evidence (at least level III according to the U.S. Agency for Health Care Policy and Research), a systematic review published in the year 2017 (with literature screening until November 2, 2015) was limited to RCTs and prospective clinical trials reporting the survival rate and marginal bone loss to determine success of zirconia implants restored with SCs or three-unit FDPs. Furthermore, at least 15 patients per study were required as a supplementary inclusion criterion. According to these inclusion criteria, 9 studies including a total of 326 patients restored with 398 implants were included. Out of these included zirconia implants (made from Y-TZP and alumina-toughened zirconia/ATZ), 97% (n = 382) were fabricated in a one-piece design, and only 3% (n = 16) were currently noncommercial two-piece implants. All implants were followed up for 19.7 months. The survival analysis of this systematic review resulted in a 1-year survival estimate for zirconia.
implants of 95.6%. Limited to the short-term prognosis of this estimate, it was concluded that this outcome can be considered comparable to titanium implants supporting SCs and FDPs.\textsuperscript{27,28} Moreover, studies included in this analysis exceeding a 1-year follow-up period were used to calculate an expected decrease in survival of only 0.05% per year after the first year of observation, although this finding was based on a limited amount of data. In the included studies, MBL was measured on standardized radiographs, revealing a range from 0.44 to 1.95 mm after 12 months,\textsuperscript{29,30} with the latter measurement occurring in an early one-piece implant system that has never been commercialized. Meta-analysis resulted in 0.79 mm MBL after 1 year of observation, which was comparable to immediately temporized titanium implants at the same time of follow-up. However, a major drawback of this dataset might be seen in the observation periods of the included studies, which only allowed for the calculation of short-term (12-month) statistical estimates.\textsuperscript{5} When applying identical inclusion criteria and an identical search strategy more recently (ie, 6 years later), only one additional patient cohort could be included in the analyses,\textsuperscript{31} likewise evaluating a one-piece zirconia system over a period of 7.8 years. In this investigation, implant survival was shown to be 100%, though one implant presented with profound peri-implantitis resistant to therapies. However, five of the nine studies already included for analyses 6 years earlier were meanwhile validated, with increased observation periods of mostly 60 months.\textsuperscript{17,32–35} Focusing on commercially available one-piece systems, no changes regarding implant survival and bone level stability were registered after an additional 2\textsuperscript{33} to 4 years\textsuperscript{34,35} of observation. These results substantiate the comparability of those one-piece zirconia implant systems with the gold standard two-piece titanium implant systems regarding midterm implant survival and bone level stability. Of the two updated investigations evaluating noncommercial zirconia implant systems, one also reported an additional 2 years of observation, resulting in a follow-up period of 3 years.\textsuperscript{32} However, in this study, three more implants were lost between the 12- and 36-month follow-ups, decreasing the survival rate from 95.4% to 90.8%. Considering the surviving implants after 3 years, MBL was close to stable (increasing from 1.31 to 1.45 mm).

If a metal-free restorative complex is requested, it can be concluded that one-piece zirconia implant systems with scientifically reported and clinically successful mid- to long-term outcomes that are currently available on the market can be recommended for the replacement of one to three missing teeth to be restored with SCs and FDPs.\textsuperscript{34–36} Within this indication and taking the prostheticotic limitations/difficulties of a monobloc into account, no drawbacks compared to titanium implants should be expected regarding implant survival or bone level stability. The disadvantages of one-piece implants in general are that the implant placement has to be accurate since the abutment can only be adapted to a certain degree when the implant is misaligned.\textsuperscript{37} The adaptation of the abutment part is performed via grinding, which might impair the integrity of this part and is therefore a limitation in prosthetic reconstruction.\textsuperscript{18,38} Furthermore, placement of the integrated implant shoulder in the vertical direction is challenging. For esthetic reasons, the shoulder should be placed more submucosally for the development of an optimal emergence profile in the visible areas. This, however, entails the risk of cement entrapment when inserting the prosthetic reconstruction with possible impairment of tissue health (ie, peri-cementitis).\textsuperscript{39,40} When the implant shoulder is placed closer to the mucosal margin, the cement entrapment can be avoided; however, with the problem of esthetically unpleasing restoration contours.

To overcome some of the limitations of a one-piece system (eg, predefined angulation of the abutment axis and position of the cementation line), virtual/prosthetically driven implant planning and a digital workflow might be recommended prior to and after surgery.\textsuperscript{37,41} Moreover, previously established cementation techniques, like oral venting or precentementation, can be recommended in order to avoid cement remnants despite a restoration margin location that has not been tailored to the individual without compromising the stability and integrity of the dental restoration.\textsuperscript{42,43}

**TWO-PIECE ZIRCONIA IMPLANTS**

The advantage of bone-level two-piece implants is that they can be placed close to the bone margin, thereby allowing the development of an optimal emergence profile (Fig 2).\textsuperscript{44} Furthermore, with bone-level placement, surgical interventions like guided bone regeneration can be performed as with conventional two-piece titanium implants by applying a primary flap closure.\textsuperscript{45} Angulated abutments that allow for implant misalignment to be overcome can also be used, and different abutment designs increase the prosthetic flexibility. Using screw retention of abutments/crowns instead of cementation allows them to be retrieved without destroying the reconstruction.\textsuperscript{46} Although two-piece implants have their advantages over one-piece implants, their production is much more difficult due to the demanding construction of the joining parts of implants and abutments including the retention mechanism.\textsuperscript{22,47} The clinical evidence for the two-piece (bone-level) implant design is by far not as broad and solid as for the one-piece implants, and only very limited evidence-based data exist.\textsuperscript{5,16} Currently, six clinical investigations on two-piece zirconia implants can be found in the literature.\textsuperscript{17,26,48–51}
including two follow-up reports.\textsuperscript{17,51} All studies evaluated two-piece implants placed supracrestally or at the tissue level, with luted/cemented abutments made from fiberglass\textsuperscript{48,50} or zirconia.\textsuperscript{17,51} There are no clinical data available for screw-retained and/or bone-level ceramic implant systems.

Brüll et al retrospectively evaluated the clinical performance up to 3 years.\textsuperscript{48} Of 121 implants, 66 were two-piece implants. Two of these failed during the mean observation period of 18.4 months. The calculated survival rate was 97\%. Regardless of the implant design, a mean bone loss of 0.1 mm after 3 years was calculated. Becker et al assessed an initial cohort of 60 patients including 60 implants.\textsuperscript{50} The implant type of this investigation was similar to the investigation of Brüll et al.\textsuperscript{48} The authors reported that 8 implants failed to osseointegrate. Four patients were additionally lost to follow-up, leaving 48 patients for further evaluation. The mean observation time was 26 months. Two implants were lost after prosthetic reconstruction after 8 months. Therefore, the calculated survival rate was reduced to 83.3\% after 26 months. Regarding MBL, the authors stated that the “implants merely revealed minor crestal bone level changes not exceeding the upper 25\% of the implant length.” However, the authors also stated that 18 patients were diagnosed with initial peri-implantitis between 12 and 24 months, and the Kaplan-Meier estimates of biologic complications amounted to 37.5\%.

Koller et al published a prospective randomized pilot trial of two-piece zirconia and titanium implants after 80 months.\textsuperscript{17} The original cohort comprised 22 patients with 31 implants (16 zirconia and 15 titanium). Over the course of 80 months, 2 zirconia implants and 1 titanium implant were lost, resulting in 87.5\% and 93\% survival rates for zirconia and titanium, respectively. The zirconia implants showed a mean MBL of 1.38 mm compared to 1.17 mm for titanium implants. The difference was not statistically significant.

In the investigation of Cionca et al, 32 patients received 49 implants.\textsuperscript{51} The implants were restored with single-unit all-ceramic crowns. After an average time of 82.2 months after loading, 24 patients with 39 implants were available for examination. The cumulative implant survival rate was 83\%. Eight implants were lost over the examination time: 1 implant was removed because of nonosseointegration (primary failure), 1 implant fractured, 1 failed due to peri-implantitis, and 5 implants in 5 patients were explanted due to “aseptic loosening” at different time points within the first year of loading. Furthermore, 6 abutments in 6 patients fractured at the level of the implant platform. The authors reported that, at the implant level, a cumulative mechanical complication rate of 17.5\%, a cumulative technical complication rate of 13\%, and a biologic complication rate of 8\% occurred, leading to a reduced success rate of 63\%. Bone loss evaluation was performed between 1 year and 6 years after loading and amounted to a mean gain of 0.05 mm. Unfortunately, there was no information provided regarding the bone loss between implant placement and insertion of the reconstructions.

Whereas the implants from the investigations of Brüll et al and Becker et al are still available on the market,\textsuperscript{48,50} the implants included in the studies of Koller et al and Cionca et al have both been withdrawn.\textsuperscript{17,51}

When critically assessing the results of the latest clinical investigations on zirconia two-piece implants, it must be concluded that the short to mid-term survival results are inferior to one-piece zirconia implants and to two-piece titanium implants.

**RESTORATIVE CONCEPTS FOR ZIRCONIA IMPLANTS**

In cases where a completely metal-free restoration concept is desired, it should be considered appropriate to restore zirconia implants with all-ceramic reconstructions. The clinical performance of all-ceramic...
implant-supported single-unit and multiple-unit fixed implant reconstructions was addressed at the 5th EAO Consensus Conference in 2018.\textsuperscript{52} The consensus report on this topic was based on two systematic reviews.\textsuperscript{53,54} However, the large majority of the included studies investigated reconstructions supported by titanium implants. The data on the clinical behavior of zirconia implant-supported reconstructions is still very limited and restricted to the publications of only a handful of research groups.\textsuperscript{18,55–57}

A recently published systematic review with the aim of analyzing the clinical outcomes of all-ceramic SCs and three-unit FDPs supported by zirconia implants could therefore only include eight clinical studies.\textsuperscript{36} All included investigations reported on cemented/adhesively bonded reconstructions. Out of these, five studies reported on monolithic lithium disilicate SCs,\textsuperscript{17,49,50,56,58} two on veneered zirconia SCs and FDPs,\textsuperscript{18,55} and one on veneered zirconia FDPs.\textsuperscript{57} No further studies with other material compositions or screw-retained reconstructions could be identified in this review. The major findings\textsuperscript{36} were that the overall 5-year survival rate of cemented reconstructions can be considered high (95%). SCs and FDPs made of zirconia showed comparable survival rates. Chipping of the ceramic was a very frequently reported technical complication, although it did not occur with equal frequency in all material compositions. While almost no chipping occurred after 5 years with monolithic lithium silicate or disilicate crowns, veneered zirconia restorations showed significantly higher chipping rates (SCs 38%, FDPs 57%).\textsuperscript{36}

However, the clinical impact of the occurrence of chipping is controversial. In one study with veneered zirconia SCs, 23% of the SCs had to be replaced during the 5-year observation period due to major chipping, which significantly diminished the survival rate.\textsuperscript{18} In contrast, another study was able to show that chipping, when in the posterior region, did not influence patient satisfaction, and the SCs were still able to fulfill patient needs in terms of function and esthetics.\textsuperscript{55} Due to the high chipping rate, screw-retained reconstructions would be preferable, as they allow for intervention in case of technical complications. Currently, there are no investigations reporting on screw-retained reconstructions on ceramic implants; thus, the clinical performance of such reconstructions cannot be assessed.

For SCs, monolithic reconstructions should be preferred due to the relatively high chipping rate of veneered reconstructions. No clinical comparison between different monolithic materials is available at the moment, and therefore no conclusive material recommendation can be given. For FDPs, no clinical data for monolithic reconstruction are available.

Surface roughness of the ceramic should also be considered, as it is regarded as a precursor for chipping\textsuperscript{57} and supports plaque adhesion. The occurrence of occlusal roughness over time has been reported in several studies and seems to occur in monolithic\textsuperscript{56} and veneered reconstructions.\textsuperscript{55,57} Framework fracture, on the other hand, seems to be a very rare event. A solitary fracture of a framework was reported only in the investigation of Cannizzaro et al.\textsuperscript{58} In the same study, one decementation of a crown from a monotype implant was noted, although the crown had been adhesively bonded.\textsuperscript{58,59} A study investigating the outcome of two-piece implants reported six losses of retention of the adhesively bonded abutment-crown complex with a mean period of 47.6 months.\textsuperscript{51} In the remaining studies, decementation was not reported as a complication to be expected.

At present, no clinical evidence is available for removable reconstructions on zirconia implants.

**CLINICAL RECOMMENDATIONS**

Taking the limitations of a one-piece implant system into account, one-piece zirconia implants can be recommended for the fixed restoration of one to three adjacent missing teeth.

Two-piece systems currently available on the market have not yet been clinically evidenced to be unconditionally recommended for clinical application.

Regarding survival, all-ceramic SCs and FDPs cemented/bonded to zirconia implants can be considered to be a valid treatment. No clinical data are available for screw-retained restorations. To avoid chipping of ceramic veneers, monolithic reconstructions should be preferred.

Due to missing clinical data, zirconia implants cannot yet be recommended to support removable dental prostheses.

**RECOMMENDATIONS FOR FUTURE RESEARCH**

To allow for comparison with titanium at the implant level, more randomized clinical trials that include the evaluation of patient-reported outcome measures (PROMs) are needed. Clinical investigations should be performed evaluating screw-retained two-piece zirconia implant systems. Material selection for monolithic reconstructions should be clinically investigated, especially if exceeding single units.

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