Metal-free implant-supported single-tooth restorations. Part I: Abutments and cemented crowns

Daniel Edelhoff, Prof Dr med dent/Josef Schweiger, CDT, MSc/Otto Prandtner, MDT/
Michael Stimmelmayr, Prof Dr med dent/Jan-Frederik Güth, PD Dr med dent

In many areas of restorative dentistry, metal-free materials offer an alternative to metal-based restorations while ensuring high levels of biocompatibility and esthetics. Rapidly evolving CAD/CAM technology has significantly expanded the range of materials available, providing access to materials classes and their combinations not previously available within conventional manufacturing, such as zirconia ceramics and hybrid ceramics. In addition, digital methods offer previously unavailable options in diagnostics, greater planning reliability, better material quality through standardization of the manufacturing process, and reproducibility – significant benefits that can be used to advantage, especially in oral implantology. Even though technological progress in the field of metal-free materials has given rise to considerable improvements in their mechanical properties over the decades, their clinical long-term success is still very much dependent on an appropriate indication and proper material selection, on the knowledge and skills of the dental practitioner and dental technician, and on an adequate occlusion concept. The high rate of innovation – both with regard to the materials themselves and to CAD/CAM technology – therefore requires an adequate level of prior knowledge to sensibly and successfully implement the wide range of possibilities now open. It is becoming more and more puzzling for users to find their way around the many different new techniques and materials. This review article provides an up-to-date overview of the possibilities and limitations of metal-free implant-supported single-tooth restorations. This first part discusses abutments and cemented crowns. Resultant treatment concepts are presented and evaluated based on clinical examples. *(Quintessence Int 2019;50:176–184; doi: 10.3290/j.qi.a41906. Originally published in German in Implantologie 2018;26(4):353–370)*

Key words: abutments, CAD/CAM, hybrid abutments, implant prosthetics, implant-supported crowns, lithium disilicate, lithium silicate, monolithic restorations, polymers, titanium adhesive bases, zirconia, zirconium oxide

The development of computer-aided design/computer-assisted manufacture (CAD/CAM) technology and the introduction of digital workflows have given rise to numerous new options in recent decades: in three-dimensional (3D) implant planning, in the manufacturing of implant abutments, and also in terms of the available range of superstructure materials.[1-5] The focus is primarily on materials such as titanium, zirconia ceramics, or lithium (di)silicate ceramics, and increasingly also on polymer-based materials.[6-9] Oral implantology and CAD/CAM technology are experiencing steady growth. Overlaps between these two disciplines have developed in diagnostics, 3D implant planning, template-guided implant placement, abutment production, implant superstructure design and materials, and not least with regard to new treatment strategies, workflows, and concepts.[4]

There are therefore many new ways to fabricate custom implant abutments and to restore them using metal-free single-tooth restorative designs.[5,7,8,10-12] Implant manufacturers and CAD/CAM providers offer different manufacturing options – analog or digital – using different materials or combinations of materials. Depending on the available skills and equipment, a digital process chain can be set up by sending the master cast to an external service provider, by sending model or design data to a production center, or by keeping production in-house throughout (Fig 1).

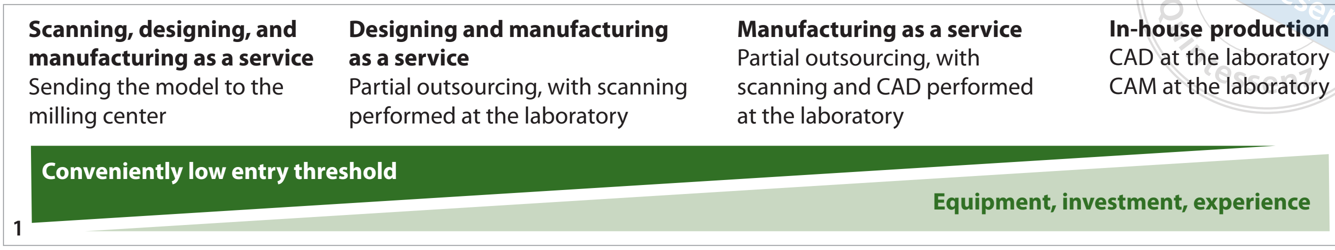


Fig 1 Entry-level options for digital abutments and restorations.

While different types of all-ceramic materials have been clinically used for implant-supported restorations for many years, current interest is focusing on polymer-based materials for use in implant abutments or in superstructures.[13,14] All this can be traced to a desire to compensate for the lack of abutment mobility (compared to natural teeth) that is an unavoidable side effect of the osseointegration of implants. The resulting stress concentrations are meant to be reduced by the damping behavior of polymer-based restorative materials, whose modulus of elasticity is considerably lower than that of ceramic materials.[15-20]

The present article intends to provide an up-to-date overview of the current state of the art in metal-free implant-supported single-tooth restorations.

Metal-free implant abutments

In the context of multi-part implants, implant abutments – generally simply referred to as "abutments" where the context is obvious – constitute the interface between osseointegrated implants and prosthetic restorations. They span the sensitive transition zone between the peri-implant soft tissue, the oral cavity, and the implant superstructure. The specific requirements of a given abutment are characterized by functional and esthetic aspects, but also by the type of restoration planned (fixed or removable). It is highly dependent on the location of the implant. These requirements include high stability and fatigue strength, chemical resistance, and biocompatibility. The ability to customize shapes, margin positions, and axial alignment must be ensured. In the esthetic zone of the maxilla in particular, the implant position itself, a customizable emergence profile, and a tooth-like shade and translucency are important factors in restoring satisfactory esthetics.[21,22] Metal-free materials offer certain advantages in this zone in the event that unfavorable conditions result in the exposure of abutment surfaces. In view of the esthetic risks involved, attempts had been made at an early stage to compensate for the unfavorable shade of titanium abutments by using sintered ceramics to obtain a tooth-colored foundation for all-ceramic crowns (Fig 2).[23]

In 1993, Prestipino and Ingber[24] were the first authors to introduce a densely sintered monolithic alumina abutment with an external implant connection – intended as an all-ceramic alternative to metal-based abutments in the anterior region. After taking a direct impression of the osseointegrated implant, a corresponding prefabricated cylinder made of high-purity densely sintered alumina was prepared at the laboratory to accommodate an all-ceramic crown – a very time-consuming process. Any adjustments required were made intraorally by finishing once the implant had been inserted with a torque wrench, followed by a second precision impression for the crown itself. This procedure offered only insufficient control of the minimum thickness requirement for ceramic abutments. Customization to achieve an adequate emergence profile was performed by adding and sintering veneering ceramics – another time-consuming procedure. In combination with glass-ceramic crowns, however, these metal-free implant restorations achieved previously unseen esthetics thanks to their tooth-like translucency (Fig 3).

The first experimental monolithic abutments made of partially stabilized zirconia were introduced shortly after the alumina abutments.[25,26] Like the alumina variant, these first had to be customized manually, starting from a prefabricated cylindrical geometry – once again in a very time-consuming laboratory procedure. Compared to the alumina option, these implant abutments were highly radiopaque and achieved roughly 2.5 times the fracture resistance of abutments made of monolithic alumina in an in-vitro study.[27] Long-term clinical studies also showed zirconia abutments to be more stable than alumina abutments.[10,12] The trend toward metal-free materials was also reinforced by a study that demonstrated less bacterial adhesion

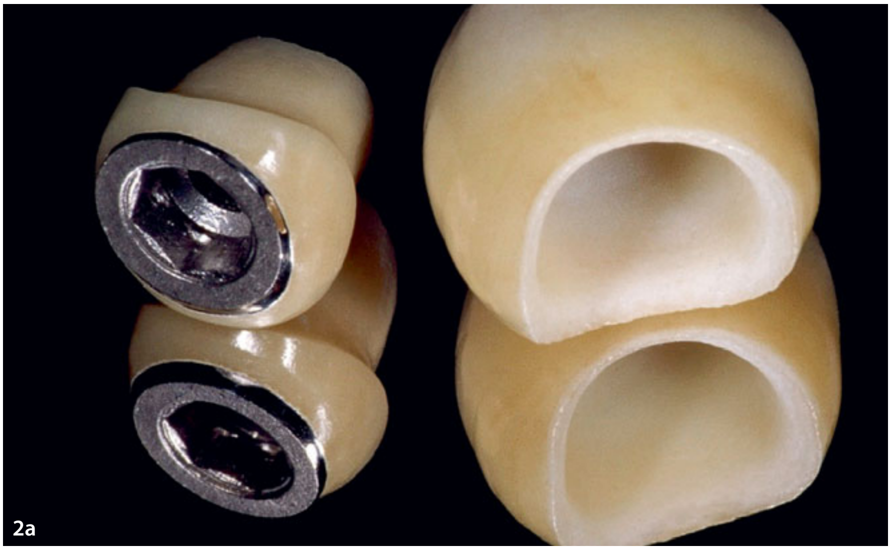


Fig 2a The prefabricated titanium abutment with an external connection (Steri-Oss Implant System, Nobel Biocare) was manually customized more than 15 years ago and coated with veneering ceramic to mask the dark shade of the titanium under the all-ceramic restoration delivered later.

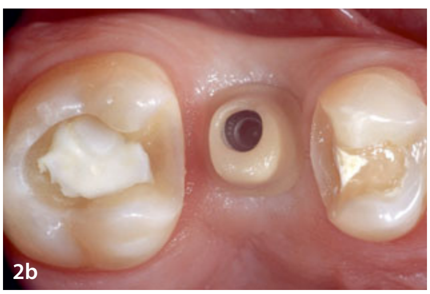


Fig 2b The ceramic-coated titanium abutment after insertion with a torque wrench. The adjacent teeth were prepared for all-ceramic inlays, with later removal of the temporary cementing agent of the provisional restorations. A precision impression was then taken. (Surgical procedures: Professor M. Yildirim, Düren, Germany).

Fig 2c Situation following adhesive connection of an experimental crown made of lithium disilicate (build-up technique using a prototype of IPS e.max Press, Ivoclar Vivadent) and two inlays made of IPS Empress (staining technique; Ivoclar Vivadent). (Laboratory procedures: Volker Weber, MDT, Aachen, Germany).

Fig 3a First generation of a one-piece (monolithic) ceramic implant abutment made of alumina ceramics on a Brånemark implant with an external connection to the maxillary right central incisor. (Surgical procedures, 1998: Dr Sascha Jovanovic, Los Angeles, USA). The prefabricated ceramic abutment (1st generation) was prepared on a plaster cast at the laboratory and carefully finished intraorally after delivery, followed by a precision impression for an all-ceramic single crown.

Fig 3b Situation following adhesive connection of an all-ceramic single crown made of IPS Empress (build-up technique; Ivoclar Vivadent) in 1999. (Laboratory procedures: André Rübben, CDT, RWTH Aachen, Germany.)

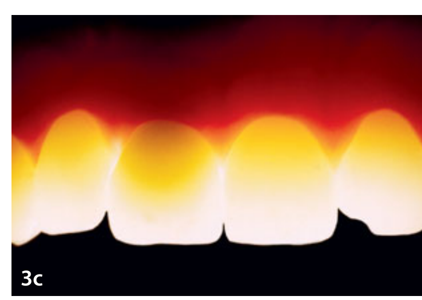
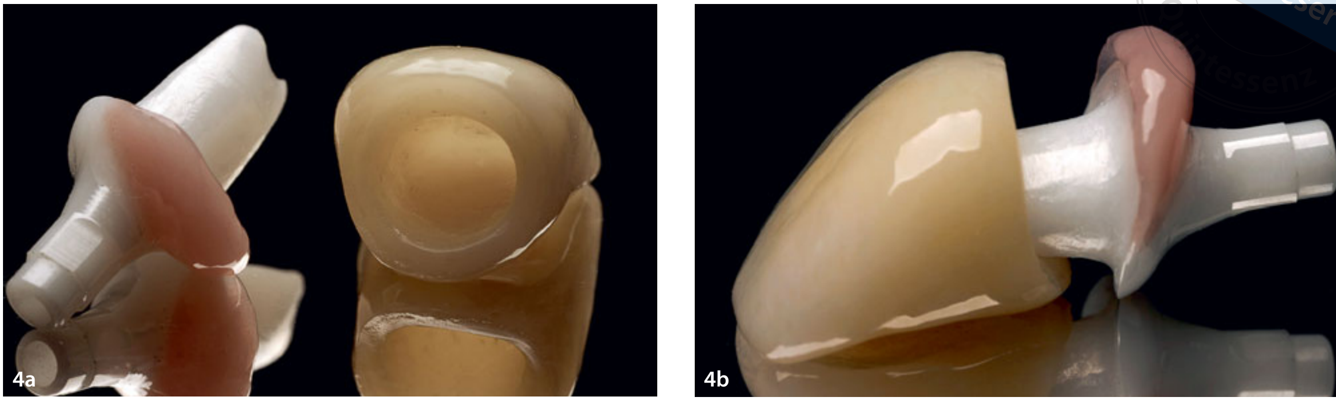


Fig 3c Transillumination of the clinical situation in Fig 3b. Around that time (1999) a level of light transmission comparable to that of natural teeth was achieved for the first time. The perceptible shadow was caused by the abutment screw used.



Figs 4a and 4b One-piece all-ceramic implant abutment, second generation, with internal connection (Internal Interface, Bone Level; Straumann). The zirconia abutment, which had been customized from a semi-finished CAD/CAM product, was modified with a gingival mask made of sintered ceramics and then restored with a lithium disilicate ceramic crown (build-up technique, IPS e.max. Press; Ivoclar Vivadent). (Laboratory procedures: Oliver Brix, CDT, Bad Homburg, Germany).

Fig 5a One-piece (monolithic) implant abutment made of zirconia (second generation) with an internal implant connection (Internal Interface, Replace Select; Nobel Biocare). The implant was inserted in an immediate-placement procedure. (Surgical procedures: Dr Christian Hammächer, Aachen, Germany). The abutment screw was in direct contact with the ceramic material.

Fig 5b Situation following the insertion of a lithium disilicate crown (build-up technique, IPS e.max Press; Ivoclar Vivadent). (Laboratory procedures: Oliver Brix, CDT, Bad Homburg, Germany).

Fig 5c Situation from Fig 5a after insertion of the custom one-piece zirconia abutment (second generation).

Fig 5d Situation from Fig 5b after insertion of an all-ceramic lithium disilicate crown. (Laboratory procedures: Oliver Brix, CDT, Bad Homburg, Germany).

to zirconia than titanium in healing caps.[28] The many advantages of the alternatives notwithstanding, the highest fracture strengths have been demonstrated for metal-ceramic and all-ceramic crowns on titanium abutments.[8,25,29]

The introduction of modern production processes in dentistry and dental technology has yielded many improvements, which also benefited abutments. These include better diagnostic options for deciding the best material to use, the standardization of manufacturing processes, the use of industrially prefabricated high-quality restorative materials, the possibility of using software tools to monitor compliance with minimum wall-thickness requirements, and gentler processing and time savings compared to manual procedures. It has become increasingly difficult for users to find their way around this abundance of new production and design options.

In general, implant abutments can be classified by the way they are produced, distinguishing between prefabricated abutments, cast-on/pressable abutments, and CAD/CAM abutments.[23] Prefabricated abutments are available in various sizes, shapes, and angulations; some can be adjusted by grinding while others cannot. Since prefabricated abutments can only be customized to a very limited extent, users had been hoping for a way to give abutments the exact shape they were looking for. Since the introduction of CAD/CAM abutments a number of years ago, it has been possible to design individual shapes and to determine restoration margins for single crowns, based on

6a

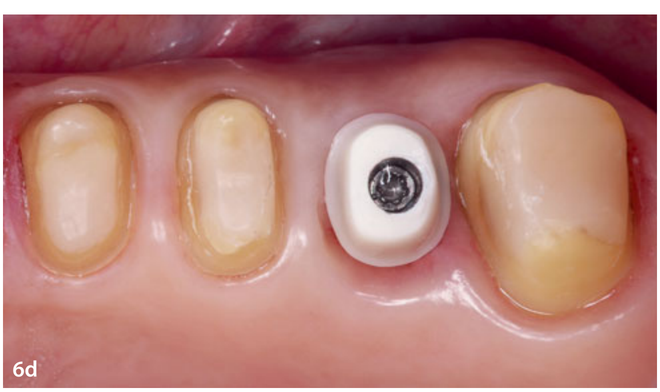
Fig 6a Two-piece hybrid ceramic abutment (third generation) consisting of a Cerec titanium base (Dentsply Sirona for Straumann Tissue Level; Straumann) and a custom CAD/CAM abutment (InCoris ZI, Dentsply Sirona) made of zirconia. After mechanical pretreatment (moderate airborne-particle abrasion) of the titanium and zirconia surfaces, both components were adhesively connected at the laboratory. The screw had no direct contact with the ceramic abutment, which avoided unwanted stress concentrations within the ceramic material.

6b

6c

Fig 6b Two-piece hybrid abutment with corresponding all-ceramic crown (maxillary left first molar, one premolar width) made of lithium disilicate (staining technique, IPS e.max Press; Ivoclar Vivadent). (Laboratory procedures: Oliver Brix, CDT, Bad Homburg, Germany).

Fig 6c Situation following provisional placement of the all-ceramic crown on the hybrid abutment. The sensitive areas of the internal connection are mapped by the titanium base and provide greater stability and better protection against excessive abrasion at the implant connection thanks to the metal structure (Straumann Tissue Level; Straumann).



6d

6e

Fig 6d Situation prior to the placement of lithium disilicate crowns (staining technique, IPS e.max Press; Ivoclar Vivadent). The screw of the hybrid abutment has only contact with the titanium base.

Fig 6e Situation from Fig 6d after adhesive placement of lithium disilicate crowns (staining technique, IPS e.max Press; Ivoclar Vivadent) on abutments at the maxillary left first and second premolar and second molar (24, 25, and 27 according to FDI notation). The crown on implant 26 (maxillary left first molar) was cemented conventionally with a glass-ionomer cement to facilitate the removal of excess cement. (Laboratory procedures: Oliver Brix, CDT, Bad Homburg, Germany).

the soft-tissue situation for better control and easier removal of excess cement. All-ceramic abutments are available with or without an adhesive base.

One-piece (monolithic) zirconia abutments

One-piece ceramic CAD/CAM abutments without an adhesive base are fabricated from monoblocks, like titanium abutments. Today, semi-finished zirconia blanks are the raw material almost exclusively used for this purpose; the interface between the implant and abutment will already have been created during the industrial manufacturing process. The external geometry of the abutment is custom-milled from the blank based on the design data or wax-up. In some cases, a certain amount of modification using, for example, matching sintering ceramics can still be performed.

One-piece monolithic CAD/CAM ceramic abutments without an adhesive base are clearly indicated for use in the esthetic zone. Their translucency is similar to that of natural dentin.[30,31] Combining them with glass-ceramic crowns achieves very attractive esthetics (Figs 4 and 5). Compared to metal-supported implant superstructures, however, their strength is significantly lower.[32,33] This is as true of reference two-piece zirconia abutments on a titanium adhesive base as of one-piece titanium abutments with an identical shape.[34,35] The required design of the abutment screw also results in a higher incidence of screw loosening.[36] As a result, micromovements of the monolithic zirconia abutment may occur that can cause permanent damage to important implant structures and geometries.[36,37]

Clinically, the restorative vertical height (RVH, measured from the implant shoulder to the maximum height of the superstructure) and the design of the implant connection (external or internal) seem to be important success factors.[13,34,38] In a retrospective clinical study of 965 zirconia abutments, a significantly higher fracture rate was observed over an average 6 years for monolithic zirconia abutments with internal implant connections.[13] In addition, the authors identified a RVH above 13 mm as risky, especially when combined with parafunctional habits. A RVH of more than 13 mm often occurs in the anterior region; it is more common with bone-level than with tissue-level implants.[13]

Advantages

- Limited or no reworking of the ceramic abutment required – low risk of damage to the material.
- Consistently tooth-colored abutments are advantageous in the esthetic zone.
- Excellent tissue compatibility in the sensitive transition area from implant to superstructure.

Disadvantages

- Increased risk of fracture due to stress concentrations, especially with internal implant connections.
- Possible stress concentrations induced by direct contact between the abutment screw and the ceramic material.
- The need for a specific screw design with a flat geometry on the underside of the screw head increases the risk of premature screw loosening.
- Direct contact of the extremely hard ceramic with the sensitive titanium structure of the implant carries the risk of permanent damage to important aspects of the implant geometry.

Two-piece ceramic abutments with an adhesive base

Hybrid abutment with separate crown part

To avoid direct contact between the extremely hard zirconia of the abutment (Vickers hardness: approx. 1,200) and the sensitive titanium structures of the implant (Vickers hardness: approx. 384), alternative concepts were quickly developed that facilitated titanium-to-titanium interfaces without having to relinquish the option of using a ceramic abutment.[34,36,37] All-ceramic CAD/CAM abutments on a titanium adhesive basis (so-called hybrid abutments) are usually fabricated at the dental laboratory or production center (eg, Bego Medical) from pre-sintered zirconia. Partially prefabricated "meso" blocks made of pre-sintered zirconia can be used for this purpose; these are semi-finished products that already include the connection geometry between the abutment and the adhesive base. In a first step, the outer geometry of the pre-sintered zirconia block is milled and then densely sintered, to be carefully bonded to the adhesive base in a second step to obtain a custom zirconia abutment.[39] The adhesive bases themselves are manufactured from titanium and therefore have the same precision of fit as prefabricated titanium abutments. The interface between the titanium base and the zirconia abutment is usually equipped with an anti-rotation device that prevents the abutment from turning and getting bonded to the titanium base in the wrong position. In a third step, a separate lithium disilicate crown (for example) can be fabricated on the hybrid abutment and connected intraorally (Fig 6).

Advantages

- Reduced risk of screw loosening due to the conical geometry of the underside of the abutment screw head.
- Reduced risk of tensile stress inside the ceramic abutment, as there is no direct contact between the abutment screw and the ceramic component.
- The complete manufacturing process of an individual CAD/CAM abutment can be performed at the laboratory or the dental office if preferred and does not require the services of a milling center.
- Protection of implant geometry and structures, as the interface is designed to put titanium against titanium.

Disadvantages

- Additional time and effort is required for manually bonding the custom ceramic abutment on the titanium adhesive base with a correct alignment.
- Risk of retention loss due to improper bonding.
- The composite adhesive joint between the titanium adhesive base and the zirconia abutment is placed in the sensitive peri-implant transition area (but can be polished under laboratory conditions).

The separate tooth-colored crown can be fabricated immediately, together with the hybrid abutment, in the dental laboratory. Alternatively, it can be fabricated in a second step once the abutment has been inserted in situ and a precision impression has been taken. The second procedure may be more complex, but it is safer, as the marginal preparation margin can be re-checked in the presence of the actual soft tissue and corrected if necessary, and any transfer errors that may have occurred during the first impression can be corrected, improving the occlusal and proximal fit of the crown. For the final cementation of the definitive crown, the authors prefer classic glass-ionomer cements (such as Fuji Cem by GC, Ketac Cem by 3M, or Vivaglass Cem by Ivoclar Vivadent)[40] because they allow excess material to be safely removed. Glass-ionomer cements have been shown to provide sufficient retention for crowns on implants in in-vitro studies.[41,42]

Conclusion

Monolithic crowns made of lithium (di)silicate or zirconia frameworks with a sintered lithium (di)silicate veneer appear to be suitable as definitive superstructures cemented on titanium or zirconia hybrid-abutments. These materials appear to have a failure mode that protects the implant, as their strength is lower than that of monolithic zirconia.[8,43] The authors also recommend that the interface between abutment and implant should be made out of titanium, to protect the weaker osseointegrated titanium implant from destruction and inhomogenous wear. For cementation, a classic cement (eg, glass-ionomer cement) should be preferred for the definitive connection of a ceramic crown, as it facilitates the removal of excess cement.[40] Sufficient long-term clinical data are not yet available for polymer-based materials for this indication. However, preliminary clinical results appear to cast doubt on the use of CAD/CAM composites for crowns.[44]

The second part of the article focuses on screw-retained hybrid abutment-crowns as well as the material selection criteria, and discusses the pros and cons of different treatment options and forms of metal-free implant-supported single-tooth restorations.

Acknowledgments

The authors thank the following persons for their laboratory support: Volker Weber (Aachen, Germany), case shown in Figure 2; André Rübben (RWTH Aachen, Germany), Figure 3; and Oliver Brix (Bad Homburg, Germany), Figures 4, 5, and 6.

References

1. Blatz MB, Bergler M, Holst S, Block MS. Zirconia abutments for single-tooth implants: rationale and clinical guidelines. J Oral Maxillofac Surg 2009;67(11 Suppl): 74–81.

2. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J 2008;204:505–511.

3. Beuer F, Schweiger J, Eichberger M, Kappert HF, Gernet W, Edelhoff D. High-strength CAD/CAM-fabricated veneering material sintered to zirconia copings: a new fabrication mode for all-ceramic restorations. Dent Mater 2009;25:121–128.

4. Güth JF, Stimmelmayr M. Digitale Konzepte in der Implantologie. Wissen Kompakt 2017;11:43–52.

5. Schubert O, Beuer F, Güth JF, Nold E, Edelhoff D, Metz I. Two digital strategies in modern implantology: root-analogue implants and the digital one-abutment/one-time concept. Int J Comput Dent 2018;21:115–131.

6. Koutayas SO, Vagkopoulou T, Pelekanos S, Koidis P, Strub JR. Zirconia in dentistry: part 2. Evidence-based clinical breakthrough. Eur J Esthet Dent 2009;4:348–380.

7. Preis V, Hahnel S, Behr M, Bein L, Rosentritt M. In-vitro fatigue and fracture testing of CAD/CAM-materials in implant-supported molar crowns. Clin Oral Investig 2017;33: 427–433.

8. Rosentritt M, Hahnel S, Engelhardt F, Behr M, Preis V. In vitro performance and fracture resistance of CAD/CAM-fabricated implant supported molar crowns. Clin Oral Investig 2017;21:1213–1219.

9. Schubert O, Nold E, Obermeier M, Erdelt K, Stimmelmayr M, Beuer F. Load bearing capacity, fracture mode, and wear performance of digitally veneered full-ceramic single crowns. Int J Comput Dent 2017;20:245–262.

10. Andersson B, Glauser R, Maglione M, Taylor A. Ceramic implant abutments for short-span FPDs: a prospective 5-year multicenter study. Int J Prosthodont 2003;16: 640–646.

11. Silva NR, Teixeira HS, Silveira LM, Bonfante EA, Coelho PG, Thompson VP. Reliability and failure modes of a hybrid ceramic abutment prototype. J Prosthodont 2018;27:83–87.

12. Zembic A, Philipp AO, Hämmerle CH, Wohlwend A, Sailer I. Eleven-year follow-up of a prospective study of zirconia implant abutments supporting single all-ceramic crowns in anterior and premolar regions. Clin Implant Dent Relat Res 2015;17(Suppl 2): 417–426.

13. Fabbri G, Fradeani M, Dellificorelli G, De Lorenzi M, Zarone F, Sorrentino R. Clinical evaluation of the influence of connection type and restoration height on the reliability of zirconia abutments: a retrospective study on 965 abutments with a mean 6-year follow-up. Int J Periodontics Restorative Dent 2017;37:19–31.

14. Rosentritt M, Rembs A, Behr M, Hahnel S, Preis V. In vitro performance of implant-supported monolithic zirconia crowns: influence of patient-specific tooth-coloured abutments with titanium adhesive bases. J Dent 2015;43:839–845.

15. Gracis SE, Nicholls JI, Chalupnik JD, Yuodelis RA. Shock-absorbing behavior of five restorative materials used on implants. Int J Prosthodont 1991;4:282–291.

16. Kaleli N, Sarac D, Külünk S, Öztürk Ö. Effect of different restorative crown and customized abutment materials on stress distribution in single implants and peripheral bone: a three-dimensional finite element analysis study. J Prosthet Dent 2018;119:437–445.

17. Magne P, Silva M, Oderich E, Boff LL, Enciso R. Damping behavior of implant-supported restorations. Clin Oral Implants Res 2013;24:143–148.

18. Rosentritt M, Schneider-Feyrer S, Behr M, Preis V. In vitro shock absorption tests on implant-supported irowns: Influence of crown materials and luting agents. Int J Oral Maxillofac Implants 2018;33:116–122

19. Santing HJ, Meijer HJ, Raghoebar GcM, Özcan M. Fracture strength and failure mode of maxillary implant-supported provisional single crowns: a comparison of composite resin crowns fabricated directly over PEEK abutments and solid titanium abutments. Clin Implant Dent Relat Res 2012;14:882–889.

20. Schweiger J, Neumeier P, Stimmelmayr M, Beuer F, Edelhoff D. Macro-retentive replaceable veneers on crowns and fixed dental prostheses: a new approach in implant-prosthodontics. Quintessence Int 2013;44:341–349.

21. Jung RE, Sailer I, Hämmerle CH, Attin, T, Schmidlin P. In vitro color changes of soft tissues caused by restorative materials. Int J Periodontics Restorative Dent 2007;27: 251–257.

22. Müller HP, Eger T. Masticatory mucosa and periodontal phenotype: a review. Int J Periodontics Restorative Dent 2002;22: 172–183.

23. Schweiger J, Beuer F, Stimmelmayr M, Edelhoff D. Wege zum Implantatabutment. Dent Dialogue 2010;11:76–90.

24. Prestipino V, Ingber A. Esthetic high-strength implant abutments. Part II. J Esthet Dent 1993;5:63–68.

25. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Schärer P. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004;17:285–290.

26. Zembic A. Externally connected zirconia abutments with standard platform are successful long term in anterior regions. J Evid Based Dent Pract 2016;16:130–132.

27. Yildirim M, Fischer H, Marx R, Edelhoff D. In vivo fracture resistance of implant-supported all-ceramic restorations. J Prosthet Dent 2003;90:325–331.

28. Degidi M, Artese L, Scarano A, Perrotti V, Gehrke, P, Piattelli A. Inflammatory infiltrate, microvessel density, nitric oxide synthase expression, vascular endothelial growth factor expression, and proliferative activity in peri-implant soft tissues around titanium and zirconium oxide healing caps. J Periodontol 2006;77:73–80.

29. Att W, Kurun S, Gerds T, Strub JR. Fracture resistance of single-tooth implant-supported all-ceramic restorations after exposure to the artificial mouth. J Oral Rehabil 2006;33:380–386.

30. Liebermann A, Freitas Rafael C, Colle Kauling AE, et al. Transmittance of visible and blue light through zirconia. Dent Mater J 2018;37:812–817.

31. Sailer I, Zembic A, Jung RE, Hammerle CH, Mattiola A. Single-tooth implant reconstructions: esthetic factors influencing the decision between titanium and zirconia abutments in anterior regions. Eur J Esthet Dent 2007;2:296–310.

32. Kim S, Kim HI, Brewer JD, Monaco EA Jr. Comparison of fracture resistance of pressable metal ceramic custom implant abutments with CAD/CAM commercially fabricated zirconia implant abutments. J Prosthet Dent 2009;101:226–230.

33. Martínez-Rus F, Ferreiroa A, Özcan M, Bartolomé JF, Pradíes G. Fracture resistance of crowns cemented on titanium and zirconia implant abutments: a comparison of monolithic versus manually veneered all-ceramic systems. Int J Oral Maxillofac Implants 2012;27:1448–1455.

34. Sailer I, Asgeirsson AG, Thoma DS, et al. Fracture strength of zirconia implant abutments on narrow diameter implants with internal and external implant abutment connections: a study on the titanium resin base concept. Clin Oral Implants Res 2018;29:411–423.

35. Stimmelmayr M, Sagerer S, Erdelt KJ, Beuer F. In-vitro fatigue and fracture strength of one-piece ziroconia implant abutments and zirconia abutments connected to titanium cores. Int J Oral Maxillofac Implants 2013;28: 488–493.

36. Stimmelmayr M, Edelhoff D, Güth JF, Erdelt K, Happe A, Beuer F. Wear at the titanium-titanium and the titanium-zirconia implant-abutment interface: a comparative in vitro study. Dent Mater 2012;28: 1215–1220.

37. Brodbeck U. The ZiReal Post: a new ceramic implant abutment. J Esthet Restor Dent 2003;15:10–23.

38. Sailer I, Sailer T, Stawarczyk B, Jung RE, Hämmerle CH. In vitro study of the influence of the type of connection on the fracture load of zirconia abutments with internal and external implant-abutment connections. Int J Oral Maxillofac Implants 2009;24:850–858.

39. Gehrke P, Alius J, Fischer C, Erdelt KJ, Beuer F. Retentive strength of two-piece CAD/CAM zirconia implant abutments. Clin Implant Dent Relat Res 2014;16:920–925.

40. Agar JR, Cameron SM, Hughbanks JC, Parker MH. Cement removal from restorations luted to titanium abutments with simulated subgingival margins. J Prosthet Dent 1997;78:43–47.

41. Garg P, Pujari M, Prithviraj DR, Khare S. Retentiveness of various luting agents used with implant-supported prosthesis: an in vitro study. J Oral Implantol 2014;40:649–654.

42. Sheets JL, Wilcox C, Wilwerding T. Cement selection for cement-retained crown technique with dental implants. J Prosthodont 2008;17:92–96.

43. Obermeier M, Ristow O, Erdelt K, Beuer F. Mechanical performance of cement- and screw-retained all-ceramic single crowns on dental implants. Clin Oral Investig 2018;22:981–991.

44. Schepke U, Lohbauer U, Meijer HJ, Cune MS. Adhesive failure of lava ultimate and lithium disilicate crowns bonded to zirconia abutments: a prospective within-patient comparison. Int J Prosthodont 2018;31:208–210.

Daniel Edelhoff

Daniel Edelhoff Director and Chair, Department of Prosthetic Dentistry, Munich University Hospital, LMU Munich, Munich, Germany

Josef Schweiger Certified Dental Technician, Head of Dental Laboratory, Department of Prosthetic Dentistry, Munich University Hospital, LMU Munich, Munich, Germany

Otto Prandtner Master Dental Technician, Plattform Laboratory, Munich, Germany

Michael Stimmelmayr Associate Professor, Department of Prosthetic Dentistry, Munich University Hospital, LMU Munich, Munich, Germany

Jan-Frederik Güth Associate Professor, Department of Prosthetic Dentistry, Munich University Hospital, LMU Munich, Munich, Germany

Correspondence: Prof Dr Daniel Edelhoff, Department of Prosthetic Dentistry, Munich University Hospital, LMU Munich, Goethestrasse 70, 80336 München, Germany. Email: daniel.edelhoff@med.uni-muenchen.de