Ceramic implants — an **exotic novelty item** or a useful addition to the treatment armamentarium?

Rationale and case report

Titanium implants continue to represent the gold standard in implant dentistry. Zirconium dioxide (zirconia) is an alternative to titanium that promises improved esthetics and better biocompatibility. Initial short and medium-term results have been promising in terms of the clinical prognosis; however, the current lack of long-term clinical evidence must be addressed through additional clinical studies.

Since the first titanium implants for dental use were introduced in 1965 [1], consistent advances in materials and surface designs as well as a market consolidation in favor of two piece screw-retained implants have resulted in impressive success rates [2].

Ceramic implants were first presented almost at the same time, by Professor Sami Sandhaus in 1967 [3]. However, given the materials (aluminum oxide) used at that time and their lack of surface structure, these implants long suffered from low success rates [4] of a magnitude no longer acceptable today. Ceramic implants were a metal-free compromise and therefore mainly reserved for use in holistic dentistry. But with the introduction of zirconia as a reliable implant material, this started to change.

Today's ceramic implants have increasingly lost their reputation as niche products and are finding their way into "conventional" implantology procedures.

This is in part due to increased popular health awareness and a resulting increase in demand for metal-free restorations [5]. Another major reason may be an increasing acceptance on the part of implant dentists. Rapid technological advances in terms of materials, surface designs, and restorative concepts have made it possible to harness the clinical advantages of zirconia in daily practice.

Considering only the indications that we can currently consider evidence-based, namely single-tooth restorations and three-unit bridges [6], the survival rates for most ceramic systems are already on a par with those of titanium systems [7]. However, long-term data are still needed to confirm the favorable short-term and medium-term results.

Why ceramic implants?

One of the most frequently mentioned advantages of ceramic implants is esthetics.

Ceramic implants can help avoid the grayish discoloration so often seen in the context of titanium implants. It is true that titanium implants can also achieve excellent esthetics. However, this requires the presence of a peri-implant mucosa at least 2 mm in thickness that prevents the grayish discoloration caused by the titanium implants [8].

If the thickness of the mucosa is insufficient, it should be augmented with a connective-tissue graft. But this creates an additional burden for the patient. All-ceramic abutments could be an alternative; however, micro-movements of a hard zirconia abutment on the softer titanium implant can lead to surface wear and even destroy the implant/abutment interface [9]. This problem can be circumvented with a titanium base. Here, the

interface between the implant and abutment is metallic on both sides. This combination helps avoid the risk of a visible metal discoloration by the abutment, but not by the implant body [10].

The body of a ceramic implant can also shimmer through, but only if the thickness of the mucosa is less than 1.5 mm — and even so, the color will be white and is hardly noticeable [11].

While additional scientific evidence is still needed, clinical experience has shown that the main argument in favor of ceramic implants is the resulting excellent, almost completely inflammation-free peri-implant soft-tissue situation **(Fig. 1)**. Initial studies have indicated that the reasons for this observed improved peri-implant soft-tissue situation may include the favorable biological properties of the ceramic material. Compared to titanium, ceramic materials exhibit lower plaque accumulation and less bacterial adhesion [12,13] as well as a lower thickness of the deposited biofilm [14].

The blood circulation within the soft tissue around ceramic implants more closely resembles the situation around natural teeth, while it is significantly reduced around titanium implants [15]. Better blood circulation is known to result in healthier soft tissue, which in turn makes for improved treatment results — not just esthetically.

Although ceramic implants still lack appropriate long-term evidence, initial 3-year and 5-year results are now available, reinforcing the trends supported by preclinical studies and clinical experience: Zirconia is associated with the same — and in some studies, less — marginal bone loss as titanium implants. No reports on peri-implantitis are as yet available at these follow-ups [1,16–19].

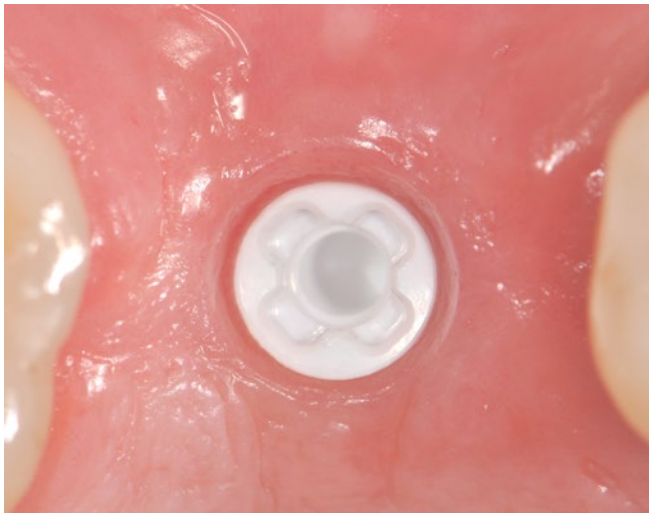


Fig. 1: Inflammation-free soft tissue favors ceramic implants.

Zirconia as a dental material

There are good reasons for directing our attention to the use of ceramic implants in oral implantological practice. Particularly rapid developments have characterized implant materials [20], implant surface designs [21], and restorative concepts, with success rates of up to 98%, depending on the implant system and study design, which is similar to the results for titanium implants [22,23]. Even the fracture rates — which used to be quite high — have improved, according to the results of static and dynamic fracture resistance testing according to ISO 14801. Thus, recent ceramic systems can be classified as suitable for clinical use with regard to fracture resistance [24,25]. However, as we know from dental technology, we have to remember that two zirconia materials are not always alike. There are still major differences in manufacturing processes, material selection, surface design, and restorative concepts and handling, so having the appropriate deep background knowledge is essential when working with ceramic implants.

Material composition and properties

Current ceramic implants are made of TZP ceramics (tetragonal zirconia polycrystals) with an average flexural strength of 1,100 MPa. To increase the flexural strength to 1,200 MPa and to exert a beneficial influence on the aging process (hydrothermal degradation), up to 0.5% v/v alumina has been added (TZP-A). Increasing the share of alumina to 20% v/v yields novel hybrid ceramics are produced that can achieve a flexural strength of up to 2,000 MPa [26]. These ATZ (alumina-toughened zirconia) ceramics reduce the risk of fracture even further than the already highly resistant TZP-A. Thanks to these modifications, aging caused by hydrothermal degradation now has hardly any clinical relevance [27,28].

Whether TZP, TZP-A, or ATZ — what counts is the downstream processing of the material. Grain size, purity, and density all have a determining influence on hardness and quality. Two basic manufacturing processes can be distinguished. In the first process (CIM, ceramic injection-molding; CIP, cold isostatic pressing), the molding is first carried out by injection or green-body processing, followed by a sintering process for annealing. In the second process (hard machining), the process is reversed: first, a block is compacted and annealed in a HIP procedure (hot isostatic post-compaction) at a high pressure of up to 2,000 bar and temperatures of up to 2,000 °C. Only then is the desired shape ground from the finished blank, which requires a considerable effort at the production stage. Both processes can achieve very high-quality and precise results.

Surface design

Whereas early ceramic implants featured smooth machined surfaces exclusively, various modified contemporary processing methods have resulted in rougher implant surfaces. High-grade corundum abrasion, thermal acid-etching, laser modulation, or pre-structuring of the pressing mold have created a surface roughness achieving a bone-to-implant contact (BIC) almost equivalent to that of titanium implants, reaching the same level of osseointegration [29,30].

Renaissance of the ceramic implant

Recent developments within the field of ceramic implants — as described here — and their increasing relevance in the treatment setting have not failed to attract the attention of the dental industry. Almost all renowned implant manufacturers currently include ceramic implants in their portfolio, and sizeable research expenditures have resulted in ever better product quality and a "renaissance" of ceramic implants.

One-piece ceramic implants

Currently, the evidence for one-piece ceramic implants is still better than for two-piece systems; most studies examine one-piece systems, as they have been on the market for longer. In one-piece systems, abutment and implant consist of a single piece (monoblock), which are considered to be hermetically sealed (no abutment required, no separate abutment connection, no

implant interface). They have the advantage that they closely replicate the dentist's usual way of taking impressions and cementing crown restorations on a natural tooth. However, they not the same as natural teeth — they are still implants, which differ from natural teeth in terms of flexibility, emergence profiles, crown-to-root/implant diameter ratios, or gingival/mucosal sulcus anatomy.

Restorations on one-piece implants are exclusively cemented. The height of the implant shoulder defines the position of the crown margin and corresponds to the cementing gap. Since cement removal is no longer reliable beyond 1.0 to 1.5 mm subgingivally [31], the implant shoulder — and with it the crown margin — should be placed at tissue level wherever possible. In the anterior region, however, tissue-level placement of the implant shoulder is successful only in rare cases, for esthetic reasons. If the implant shoulder is placed subgingivally or if the implant axis for the prosthetic restoration is incorrectly aligned, this can be corrected to a minor extent by adjusting the implant. However, this involves a risk of damage to the material structure (phase transformation by microcracks) and thus to the entire implant body.

Two-piece bonded ceramic implants

In "titanium" implantology, two-piece implant systems are the state of the art. They cover almost all indications, allow an unloaded healing phase, primary wound closure, single-stage augmentation procedures. However, with zirconia implants, the combination of a hard, non-elastic zirconia abutment with a hard, non-elastic zirconia implant still represents one of the greatest challenges of two-piece ceramic implants. With all two-piece systems, adhesively connecting the abutment to the implant is still widespread today. Monomer-based cements should be used for this purpose. Cementation with glass-ionomer or phosphate cements should be avoided due to the risk of abutment loosening. Impressions can be taken after the abutment has been connected — or before, which allows extraoral adjustment of the abutment by grinding.

The two-piece implant is effectively turned into a one-piece implant after the abutment has been connected. Consequently, the restoration must be cemented and is no longer as flexible in the event of a necessary adjustment. Only screw-connected abutments and implants, as with titanium implants, are flexible and easily removed with the screw. The advantages are many: no risk of excess cement, simplified soft-tissue management, the option of shaping the emergence profile, and simple repair and reentry options.

Two-piece screw-retained ceramic implants

Connecting two-piece ceramic implants with metal screws made of gold or titanium, as commonly used for titanium implants, has its own challenges. Ceramics are known to be more resistant to compression forces than to tensile forces. However, a screw connection can introduce tensile forces that are hard on the ceramic material, leading to internal stress peaks. Micromovement of the screw — which is softer than the ceramic material — within the hard internal thread of the implant can result in additional wear and abrasion of the screw. The manufacturing precision of the implant/abutment interface and the fit of the screw are likely to be the decisive factor; further pertinent studies are therefore required. The insertion torque specified by the manufacturer should always be respected.

Two-piece metal-free screw-retained ceramic implants

Nobel Biocare is pursuing a new approach in this respect with the NobelPearl implant system and the use of carbon fiber-reinforced abutment screws (Vicarbo) **(Fig. 2)**. The Vicarbo screw is embedded in a PEEK matrix containing more than 60% v/v carbon fibers, which allows particularly high insertion torques of up to 85 Ncm. Actually, only a 25 Ncm insertion torque is required for a permanent connection, which is why this torque is specified by the guidelines for abutment connection. The threads of the screw are rounded on their flanks and distribute forces evenly within the implant body.

Also new is the Inter-X internal implant connection. The four interlocks attached to the abutment are not in contact with the implant body under vertical or horizontal loading. They serve exclusively to prevent abutment rotation on the implant. Vertical compressive forces are absorbed by the slightly beveled implant shoulder, while lateral forces are absorbed by the Vicarbo screw.

Thanks to this two-piece concept, all the workflows we know from titanium implants can now be employed for ceramic implants, both in the dental practice and in the dental laboratory: unloaded and submerged healing, open or closed impressions, precise model fabrication, custom abutments, and metal-free and reversible screw connections for a wide range of indications. This also includes one of the most widely used restorative approaches in implantology today, namely restorations with a cement-free, screw-retained adhesive base. With the Vicarbo screw concept, this is now also possible with ceramic implants, making the use of metals unnecessary. This will be illustrated by the following clinical case in which the NobelPearl implant system was used.

Fig. 2: The NobelPearl implant system with its carbon fiber-reinforced Vicarbo screw.

Clinical case

A 54-year-old female patient presented at our clinic with a desire for metal-free restorations for her upper second premolars (FDI teeth 15 and 25). The teeth had been extracted six months before. The horizontal and vertical bone supply at the prospective implant sites was sufficient.

Preoperative planning

The implant was selected using a 3D planning software. Two NobelPearl implants, each with a diameter of 4.2 mm and a length of 10 mm, were chosen for implant sites 15 and 25. The specified length corresponds to the endosseous portion of the implant. It should be noted that in addition to the endosseous portion there is a tapered etched neck area with a height of 1.6 mm to take into account the biological width. Consequently, a 10-mm implant has a total length of 11.6 mm. The lower shoulder of the profile drill corresponds to the endosseous length of the implant without the neck area **(Fig. 4)**. However, in patients with a thin mucosa, the implant can be placed up to 1 mm deeper, so that only a supracrestal neck area of 0.6 mm will remain and the endosseous portion will be now 11 mm.

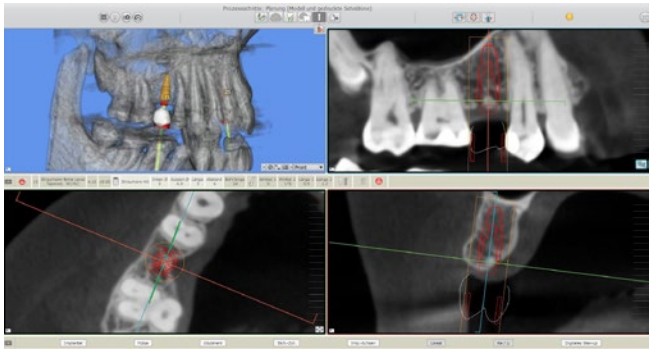


Fig. 3: Digital planning.

Fig. 4: Due to its extra length, the implant can be placed up to 1 mm lower.

Surgical phase

Under local anesthesia and following a crestal incision, a flap was raised **(Fig. 5)** and the implant bed prepared according to the surgical protocol for NobelPearl, using the drills of the NobelPearl surgical tray. After marking with a round bur, the first hole was drilled with the 2.3 mm cylindrical pilot drill to the planned length of 10 mm, observing the correct implant axis. Shape-congruent profile drills are available for subsequent preparation steps. For example, the "small" profile drill (diameter, 3.3 mm; length, 10 mm; purple color-coding) is used next to expand the implant bed, followed by the "regular" profile drill (diameter, 4.2 mm; length, length, 10 mm; yellow color-coding, here with drill stop) **(Fig. 6)**. Since the NobelPearl implant is not self-tapping and the ceramic material does not dissipate heat like a titanium implant does when the implant is screwed in, the threaded tap must be used as the last instrument for implant-bed preparation over the entire implant length.

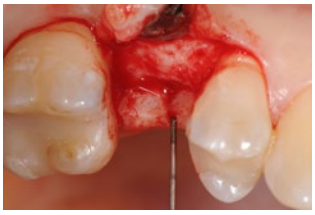
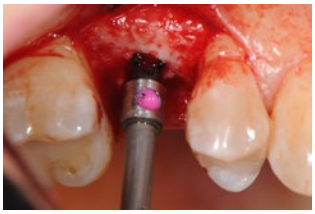
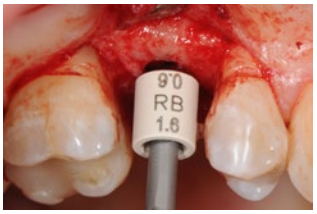


Fig. 5: Preparing the implant bed.

The implants were subsequently placed with a sufficient primary stability of 30 Ncm and a supracrestal portion of 0.6 mm. This supracrestal positioning is simplified by a drill stop **(Fig. 7)** that can be attached to the profile drill if necessary. A new positive-lock insertion tool **(Fig. 8)** for the Inter-X internal connection is available for inserting the implants, which ensures optimum force transmission when inserting the implant **(Fig. 9)**. The healing caps are visibly flattened and allow simple primary wound closure **(Figs. 10 and 11)**. In the present case, the wounds healed without complications. After a healing period of three months, which is the usual time for ceramic implants today, the implants presented with stable osseointegration in the control radiograph **(Fig. 12)**. Inflammation-free soft-tissue conditions were found at both implant sites, so that the prosthetic restoration of the implants could be started.





Figs. 6 and 7: Preparation with the profile drills.

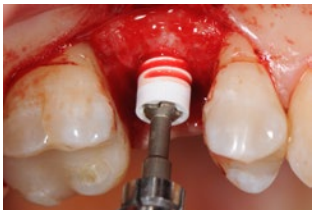


Fig. 8: Implant placement with the Inter-X insertion tool.

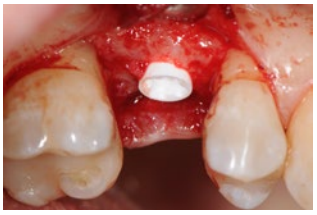


Fig. 9: Slightly supracrestal implant in situ.

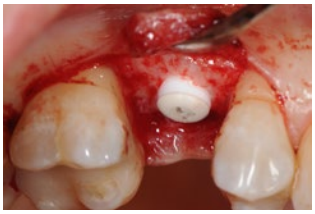


Fig. 10: The flat healing cap

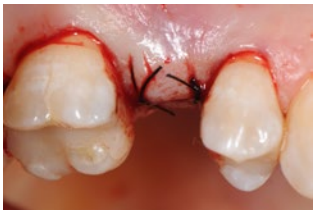


Fig. 11: Primary wound closure.

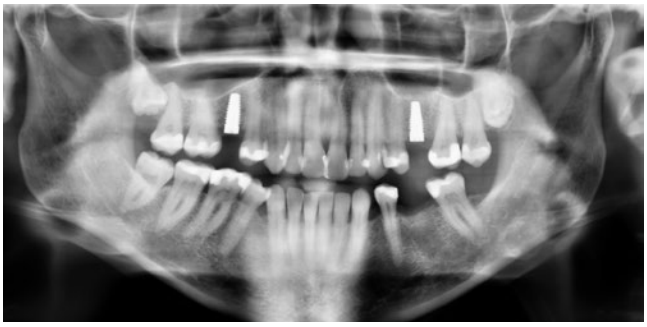


Fig. 12: Three months postoperatively.

Prosthetic phase

For reentry, a minimal crestal incision was made for inserting the healing abutment **(Fig. 13)**. Two weeks later, once the soft tissue had healed **(Fig. 14)**, a closed impression was taken with a repositioned impression post **(Fig. 15)**, and the master model was fabricated. Since this is a two-part implant system and the abutments are also made of high-strength ATZ ceramic, they can be customized by grinding — if necessary — either in the dental surgery or in the laboratory **(Fig. 16).** Both straight and 15° angled abutments with 1 mm and 3 mm of gingival height are available for NobelPearl. A monolithic zirconia crown with an occlusal screw access channel was fabricated using a CAD/CAM procedure (Dentallabor Studio für Zahntechnik, Dirk Tartsch).

If it were desired to make the screws completely removable, the occlusal access hole of the crown would have had to accommodate a screw-head diameter of 2.8 mm. With molars, this dimension is usually not a problem, but it is often too much for a narrower premolar. In the present case, the screw was integrated into the abutment before the crown was bonded. An access hole of 2.2 mm was therefore sufficient, allowing screwdriver access, if only barely **(Fig. 17)**. In the case of ceramic veneering, care must be taken to provide framework support for any overhangs. If the inserted screw has to be replaced, the abutment/crown bond can be severed simply by heating the assembly to 120°C in a furnace; the bond can be re-created once the screw has been replaced.

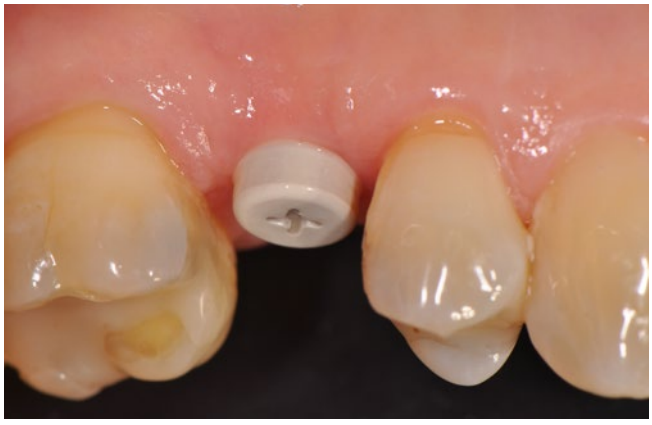


Fig. 13: Healing abutment.

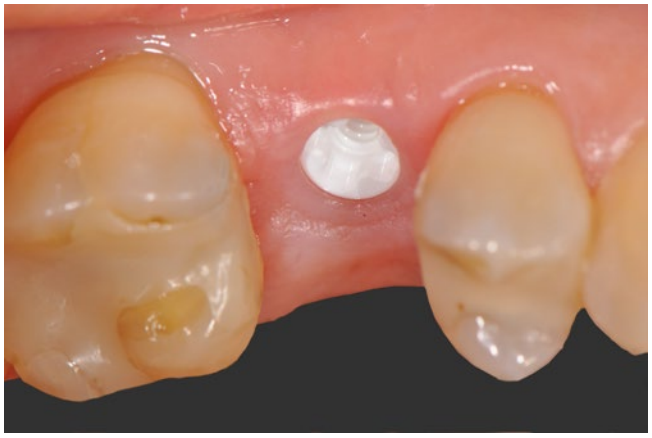


Fig. 14: No soft-tissue irritation is visible.

Fig. 15: Impression posts for open- and closed-tray impressions.

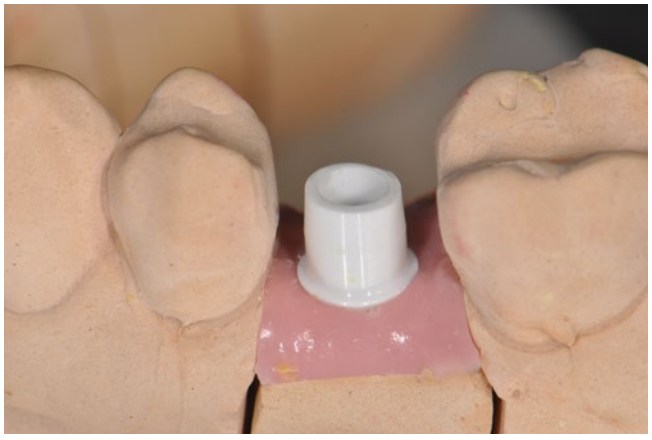


Fig. 16: Master cast with modified abutment.

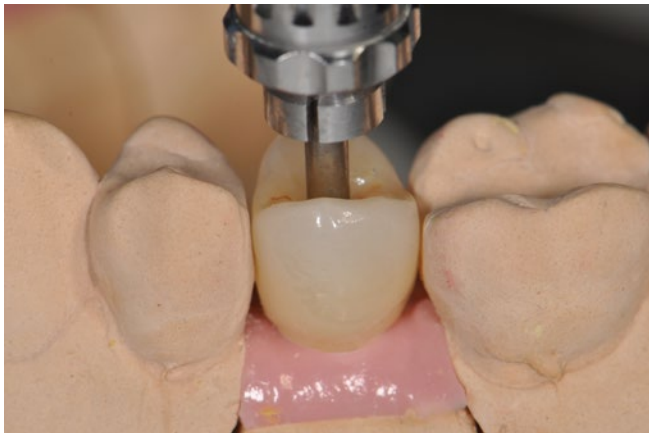


Fig. 17: Monolithic zirconia crown with a small occlusal screw access channel.

Adhesive bonding of the crown

Once the abutment and crown had been successfully tried in **(Figs. 18 and 19)**, they were bonded, which can be done either extraorally in the dental laboratory or, as in the present case, intraorally — just like a titanium adhesive base. The advantage of adhesive bonding in the patient's mouth is that any tension between abutment and implant can be compensated for. Such tensions can be caused by a not-quite-precisely returned impression post during closed impression-taking, by small inaccuracies in the design of the contact points, or by the backlash between the implant, impression post, laboratory implant, and abutment, which is always present to a greater or lesser degree, as with any implant system. Being an elastic metal, titanium can more easily compensate for this kind of "micro-tension" than hard, non-elastic ceramics. For bonding, the abutment is secured to the implant using the original screw, tightening it only hand-tight. In our clinic, we have successfully sealed abutments or screw access channels with PTFE tape **(Fig. 20)**.

The PTFE tape can be modelled almost in an almost plastic manner and seals off the access hole reliably. Overhangs or underfilling should, however, be avoided. After conditioning according to the manufacturer's specifications and the requirements of the material, the abutment and crowns were bonded with a resin cement. The procedure corresponds to the bonding of ceramic restorations with a titanium adhesive base. After bonding, the PTFE tape was removed through the access cavity **(Fig. 21)**.

Delivery of the definitive restoration

The restorations bonded to the abutment were now almost ready. Excess cement **(Fig. 22)** was safely removed and the crown-to-abutment transitions areas were polished. The 25 Ncm insertion torque specified for the abutment screw must be observed during the final insertion. After refilling the screw access channels with PTFE tape, they were sealed with composite resin in the usual manner. The result was two metal-free and cement-free screw-retained and reversible single crowns **(Fig. 23)**.

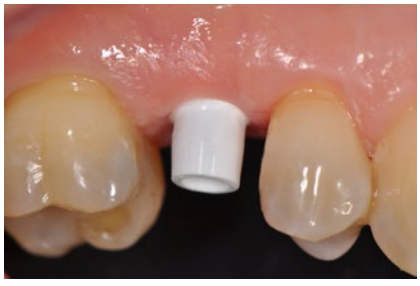


Fig. 18: The abutment in situ.

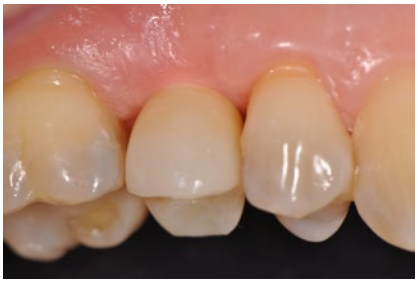


Fig. 19: Intraoral try-in.

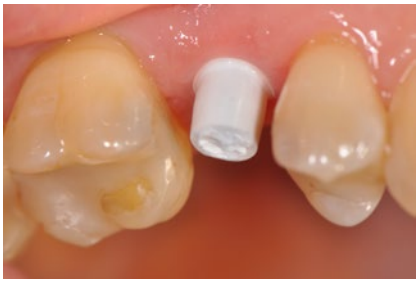


Fig. 20: Ready for bonding.

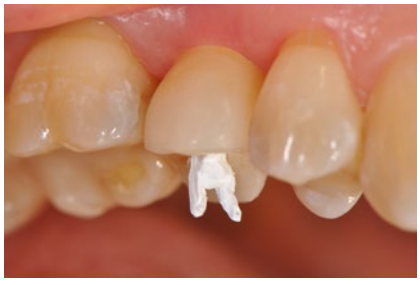


Fig. 21: Removing the PTFE tape through the screw access channel.

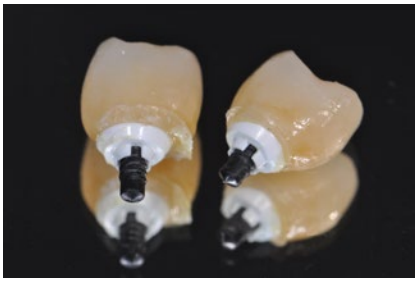


Fig. 22: Excess cement on the bonded restoration.

Fig. 23: Cement-free and metal-free screw-retained single crowns.

At the routine follow-up six months after placement, a non-irritated soft-tissue situation was found at both implant positions **(Figs. 24 a and b)**. The control radiographs showed stable peri-implant bone conditions **(Figs. 25 a and b)**.

Reversible and flexible

If, contrary to expectations, should problems such as chipping occur or shade adjustments become necessary, these can be easily corrected and handled in the same way as with titanium implants.

The DTX Studio software (Nobel Biocare) and the NobelPearl position locator have already paved the way for a digital workflow.

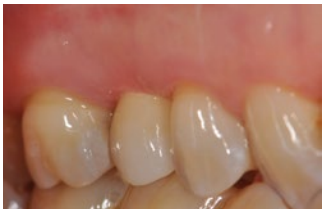


Fig. 24 a: Site 15, 6 months after loading.

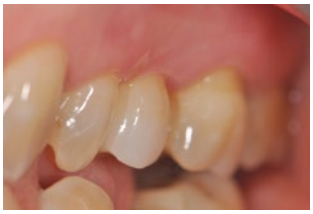


Fig. 24 b: Site 25, 6 months after loading.

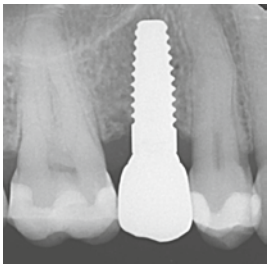


Fig. 25 a: Implant 15, 6 months after loading.

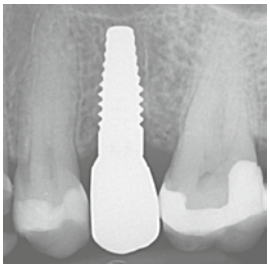


Fig. 25 b: Implant 25, 6 months after loading.

Conclusion

Compared with titanium implants, there is still less clinical evidence for ceramic implants. Further studies are required to confirm the promising short- and medium-term results. Nevertheless, within the limitations of the data available to date, we can state that ceramic implants have caught up with titanium implants in terms of handling and clinical prognosis. The surgical and prosthetic protocols that can be employed are now largely the familiar ones — a fact that, in addition to clinical evidence and reliability, will weigh heavily in favor of the future acceptance of ceramic implants in oral implantology. Contemporary ceramic implants thus represent a welcome addition to the treatment armamentarium in oral implantology, given suitable indications and proper handling, and will continue to gain in importance in the future.

Note: The author reports no conflict of interest.
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