

Development, *In Vitro* Testing, and Clinical Use of a 3.5 mm-diameter Zirconia Abutment

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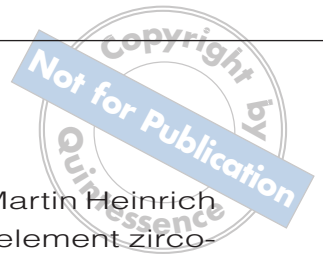
Abstract

The use of small-diameter implants is indicated when small missing teeth have to be replaced, especially in esthetic zones. Nevertheless, the small diameter can pose a limiting factor with respect to what materials can be used for the final crown. In most cases, full-ceramic crowns in combination with a ceramic abutment are usually the material of choice for final reconstructions. To date, based on mechanical considerations, a 3.5 mm implant diameter has been a contraindication for using ceramic abutments. The authors describe here the development, *in vitro* testing, and clinical use of a zirconium abutment with a 3.5 mm diameter.

The advantages of this small-diameter zirconia abutment include a minimum platform height that offers optimal prosthetic flexibility, and an accurate transfer of the implant position on to the master model. Furthermore, a precise rotational orientation for single-tooth restorations, optimal mechanical stability, and optimal fatigue resistance can be achieved. The microgap is minimized and protection against overload is afforded. In the reported case, high patient satisfaction was achieved due also to an esthetically pleasing final result.

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Introduction

The amount of space available is just one, albeit critical and limiting, factor in achieving optimal esthetic results with implant-supported restorations. A mesiodistal distance of more than 6 mm is required in the edentulous space to replace a single unit. This width is necessary because a minimum 1.5 mm distance is needed between an implant and a natural tooth to avoid attachment loss of the natural tooth.^{1,2} Most of the so-called “small diameter” implants that are clinically shown as being successful³⁻⁶ are between 3.25 and 3.5 mm in diameter.

For thin ridges also, the use of standard- or large-diameter implants is associated with esthetic risks because it is imperative to avoid placing the buccal edge of the implant shoulder too far buccally. Otherwise, the appearance of a soft tissue recession is guaranteed.⁷

When using such small-diameter implants, there are also limitations regarding the superstructure components. Metal abutments are usually used to avoid fractures. It has been shown previously that at least 3 mm of soft tissue is required to ensure that no color change will be visible when using a titanium abutment, whereas only 2 mm of soft tissue thickness is needed for zirconia abutments.⁸ In addition, the visibility of a grayish color is less attractive than a whitish color. Using a full-ceramic crown in combination with a titanium abutment is not recommended because the grayish color will be visible in the crown. The best esthetic results can be achieved when a full-ceramic abutment is used in combination with a full-ceramic crown.^{9,10}

The German chemist Martin Heinrich Klaproth discovered the element zirconium (Zr) in a semiprecious stone from Ceylon in 1789. Two hundred years later, high-tech industries are exploiting this important discovery. Today, Zr, with its high strength and longevity, is used in aerospace technology, the motor vehicle industry, medicine, and dentistry.

Abutments made of yttrium-stabilized zirconium dioxide (Y₂O₃-ZrO₂, ie, zirconia), also called yttrium tetragonal zirconium polycrystals (Y-TZP), have been introduced for clinical application and described in a few clinical studies as well as case reports.^{11,12} In addition to the high degree of biocompatibility, low corrosion potential, low bacterial adhesion, and plaque accumulation,^{13,14} Y-TZP demonstrates superior physical properties as a material for implant abutments compared with aluminum oxide (Al₂O₃). For example, Y-TZP has twice the degree of flexural strength and fracture toughness.¹⁵

To date, there have been no long-term clinical studies published that examine the behavior of small diameter zirconium abutments. Therefore, the development and clinical use of a small-sized zirconia abutment represents a new approach to implant restoration procedures. The goal of the present article is to describe the development, *in vitro* testing, and clinical use of a zirconia abutment with a 3.5 mm diameter that will enable esthetically pleasing results in demanding cases.



Material and methods

Development of a 3.5 mm-diameter zirconia abutment

The implant-abutment connection lies at the heart of any implant system. There are currently more than 20 different implant-abutment connections available on the market, and some satisfy the various requirements for an optimal implant-abutment connection better than others. These requirements can be summarized as follows:

- minimum platform height for optimal prosthetic flexibility
- accurate transfer of the implant position to the master model
- precise rotational orientation for single-tooth restorations
- optimal mechanical stability
- optimal fatigue resistance
- minimized microgap
- overload protection.

Internal connections have a great advantage over external connections in that they reduce the implant platform height. This allows more flexibility in designing the emergence profile of the final restoration.

Thanks to its large indexed contact surface, the internal hexagon also provides precise rotational orientation and stability for single-tooth implant restorations. The reinforcement collar on the implant platform carries all non-axial forces and gives optimal mechanical stability to the implant-abutment connection. The reinforcement collar reduces the lateral area between implant and abutment so that there is higher surface compression in the critical perimeter area of the

connection with the same torque used on the abutment screw. This results in a minimal microgap between the implant and the abutment that, in turn, reduces the occurrence of bacterial contamination.

One typical complication of implant-abutment connections is that the screw may loosen due to non-axial forces that, in turn, may cause relative motions between the screw head and abutment. A conical screw seat (conical angle of 60°) precludes such relative lateral motions and minimizes the risk of the screw becoming loose. The same concept has been used for decades in the automobile industry to prevent wheel screws from loosening.

The abutment screw utilizes a proven reduced-diameter shaft (anti-fatigue shaft), a common component in engineering found in connections that are subject to strong dynamic loads. An anti-fatigue shaft screw differs from a normal screw in that the shaft is subject to deformation when exposed to tension and acts like a spring. Tightening the abutment screw presses the abutment onto the implant to generate a stable connection. The correct torque is therefore of critical importance, otherwise the concept does not function properly. The appropriate pre-load of the abutment screw is attained by applying the correct tightening torque, which is usually lower than that found in standard screws.

The mechanical properties of zirconia theoretically allow the manufacture of an all-ceramic abutment with a 3.5 mm diameter that is suitable for clinical applications. Extensive finite element calculations were undertaken in order to

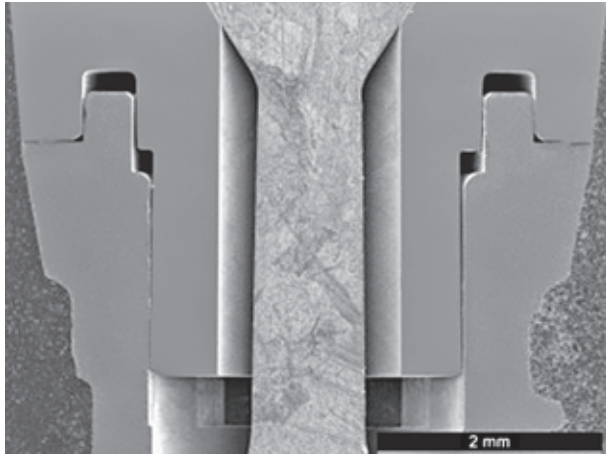


Fig 1 Polished micrograph section of the implant-abutment connection.

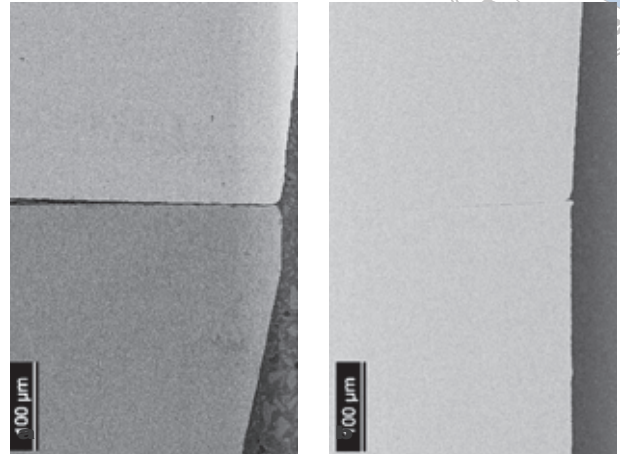


Fig 2 Polished micrograph section of the implant abutment for microgap measurements: **(a)** zirconia/titanium, **(b)** titanium/titanium.

demonstrate that an all-ceramic abutment is feasible with a reasonable safety factor. Prototypes were then produced using milling and injection molding production methods.

The prototypes had to fulfill two main requirements:

- at least the same degree of precision as found in titanium abutments
- at least the same degree of fatigue resistance as found in titanium abutments.

In vitro testing

Precision

Only milled zirconia abutments achieved the required precision. In order to verify the marginal fit, polished micrograph sections were produced with the abutments mounted on implants (Figs 1 and 2). The microgaps between zirconia abutments as well as titanium abutments (both Thommen Medical, Waldenburg, Switzerland) were measured by scan-

ning electron microscopy (SEM). The microgaps for both implant/abutment combinations were far below 4 µm.

Fatigue resistance

In determining the fatigue resistance of zirconia abutments, particular attention has to be paid to the different types of loading: the zirconia abutments must be able to withstand occlusal forces under different loading situations and have optimal fatigue resistance. For this reason, two different test setups were used to test the implant-zirconia abutment connection (one complying with ISO 14801 and one with Thommen internal standards; Figs 3 and 4, respectively). The prototypes were tested thoroughly on hydropulse equipment with 2 million load cycles at 2 Hz, in physiological saline solution at 37°C. After testing, the parts were inspected for cracks or deformation. The removal torque of the abutment screw was measured as an indicator of screw loosening. Both the



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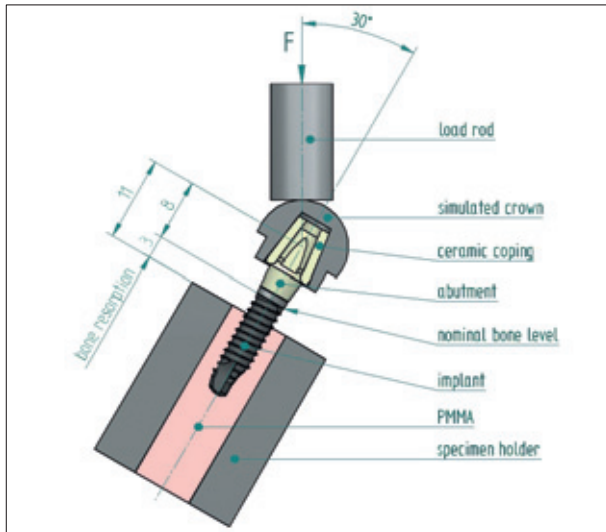


Fig 3 Test setup complying with ISO 14801.

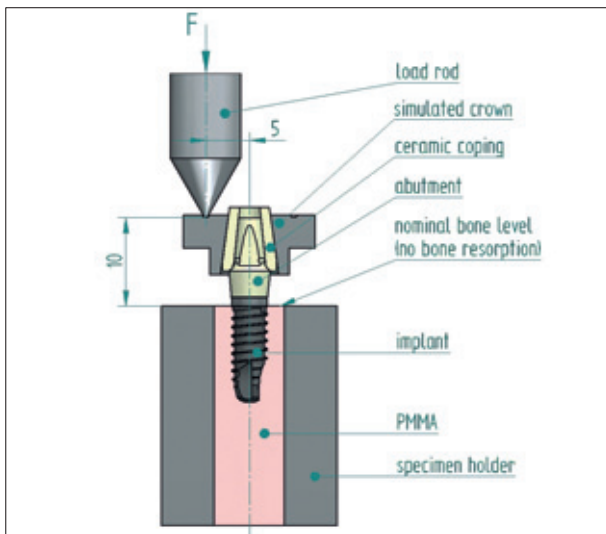
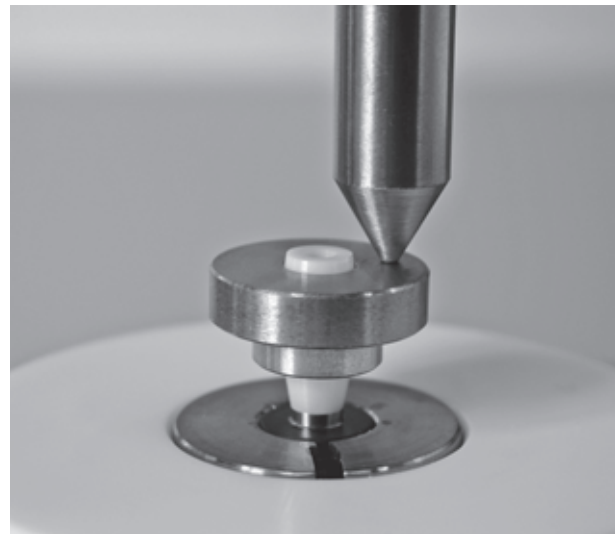


Fig 4 Test setup complying with internal standards of Thommen Medical.



load level achieved with the ceramic abutments and its removal torque were equivalent to the titanium abutments.

These tests demonstrated that both the requirements for fatigue resistance and precision could be achieved by a

targeted selection of the raw material and the production method. The mechanical performance and the precision were tested on the final product developed for clinical use.



Fig 5 The space in the area of the congenitally missing lateral incisors in the maxilla was limited.



Fig 6 Due to the high smile line of the patient, a full ceramic restoration on small-diameter implants was planned.

Results

Clinical application

The replacement of two congenitally missing lateral incisors in an esthetically demanding case becomes more difficult if the mesiodistal distance of the neighboring teeth is less than 7 mm (Figs 5 and 6). In this particular case, the use of a small-diameter implant (eg, SPI® System, Thommen Medical) was indicated. When treating thin ridges, bone augmentation as well as soft tissue augmentation is needed (Figs 7 and 8) to avoid the appearance of recessions and shadows.^{7,16-19}

Prosthetic and laboratory considerations

One month after the second-stage procedure, an impression from the level of the implant shoulder was taken (Fig 9) and master casts were fabricated with soft tissue Gi-Mask® (Coltène Whaledent, Altstätten, Switzerland; Fig 10). The position and angulations of the implants as well as the interocclusal space that was

available for the entire restoration was evaluated and analyzed with respect to the use of a 3.5 mm-diameter zirconium abutment (SPI ART, Thommen Medical; Fig 11), since this small-sized zirconia abutment only allows minor modifications by grinding to correct for non-ideal positions and angulations.

Considering the root-crown contour of the restoration, a close-to-ideal implant-abutment configuration was required. Clinicians and dental technicians apply different components and materials to enhance esthetics. The esthetic advantage of all-ceramic abutments in cases with thin translucent tissue is widely recognized. To date, clinicians do not have any experience with small-diameter zirconia abutments, such as the 3.5 mm SPI ART abutment. The interproximal as well as the interocclusal space is decisive in ensuring long-lasting results where there is sufficient material strength of the abutment as well as the all-ceramic crown.

The interproximal space at the level of the cemento-enamel junction was 6.45 mm and 6.25 mm for the right and left lateral congenitally missing incisors, respectively.



Fig 7 Small-diameter implants were placed according to the prosthetic demands.



Fig 8 Bone augmentation was performed with demineralized perforated bone matrix (DPBM) and an expanded polytetrafluoroethylene (e-PTFE) membrane.



Fig 9 Eight months after implant placement and guided bone regeneration, or 2 months after the graft procedure and 1 month after abutment connection, an impression from the level of the implant shoulder was taken.



Fig 10 Master cast with removable peri-implant sulcus on soft tissue model (Gi-Mask) gave the technician the information needed to build the ideal anatomic contour, respecting the tissue and papillae support within the peri-implant sulcus.

Fig 11 Evaluation and try-in of the 3.5 mm SPI ART zirconia abutments on the master cast as delivered by the manufacturer (Thommen Medical) prior to modification.





Fig 12 The abutments were carefully prepared to match the silicon index from the anatomic waxup, with the crown finishing lines submerged approximately 1.5 mm below the gingival marginal crest.



Fig 13 Abutments ready for try-in after minor modifications following the manufacturer's recommendations concerning minimal transocclusal and shoulder height, as well as material wall thickness.

The Thommen 3.5 mm SPI ART zirconia abutments measure 4.5 mm at the shoulder, 3.65 mm at the prosthetic base of the coronal cone, and 2.55 mm at the incisal level of the cone, including the screw access channel of 1.60 mm with the minimal material wall of 0.80 mm. The IPS e.max[®] Press (Ivoclar Vivadent, Schaan, Liechtenstein), an all-ceramic crown, requires a minimum thickness of 1.0 mm at the shoulder and 1.5 to 2.0 mm at the body and the incisal area to guarantee sufficient strength and to allow the elaboration of an acceptable esthetic result. The pressed core material requires a minimum thickness of 0.6 mm. These configurations and measurements are decisive for the evaluation process of the all-ceramic versus metal-ceramic type of restoration.

After a diagnostic waxup on the master cast, followed by the evaluation of the spaces available to restore the two lateral incisors (Figs 11 and 12), the authors concluded that, according to the minimal requirements mentioned

above, there was sufficient space to fabricate these two lateral incisors using the small 3.5 mm-diameter SPI ART zirconia abutment (Fig 13) with an all-ceramic crown (Fig 15).

The abutments were carefully prepared in the laboratory with a high-speed turbine and diamonds to fit the silicon index of the anatomic waxup made on the master cast (Fig 12). No pressure during milling was to be exerted to avoid crack formation in the zirconia. The shoulder of the abutments was lowered 1.0 mm to 1.5 mm according to the soft tissue index on the master cast (Figs 12 and 15), in order to place the finishing lines of the crowns approximately 1.5 mm subgingival (Fig 16). According to the manufacturer's recommendations, the overall height of the abutment should not be lower than 4.0 mm, the interproximal height of the shoulder less than 2.5 mm, and the wall thickness of the prosthetic coronal cone should not be trimmed below 0.8 mm in order to guarantee sufficient strength



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Fig 14 Try-in of the abutments in the oral cavity, checking for excessive pressure on the tissue and the appropriate position of the shoulders and crown finishing lines.



Fig 15 The all-ceramic IPS e.max Press cores after fitting on the zirconia abutments.

of the zirconia abutment. In addition, a minimal prosthetic cone height of the abutment is necessary to enable enough retention after crown cementation. The use of the 3.5 mm zirconia abutments is contraindicated when the above minimum measurements cannot be fulfilled. This particularly applies to cases where space between the adjacent teeth is limited and there is poor occlusion, such as a deep vertical and horizontal overbite, as well as with non-ideal implant positions and angulations that could require severe modifications of the small-size abutment due to grinding.

A try-in of the abutments is necessary to make sure that the applied pressure on the soft tissue, especially on the buccal side, does not result in loss of soft tissue height (Fig 14). Once the abutments met the goals and did not require any modifications, the all-ceramic IPS e.max Press cores were fabricated (Fig 15), followed by an individual IPS e.max Ceram build-up according to the



Fig 16 Abutments and finished all-ceramic crowns after individual ceramic build-up with IPS e.max Ceram to fit the anatomical and esthetic needs of the patient.

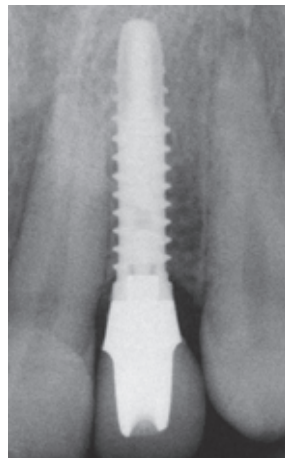
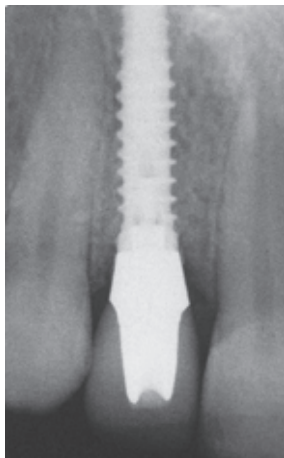
final anatomic and esthetic needs of the patient²⁰ (Fig 16). Finally, they were seated using a composite cement. Figures 17 to 26 show the impressive final result after restoration, and 2 years later.



Fig 17 The two lateral incisors, esthetically emerging implant-supported all-ceramic crowns, seated over the 3.5 mm SPI ART zirconia abutments luted with composite cement.



Fig 18 No grayish discoloration was visible in the final result. The patient showed a pleasant smile line.



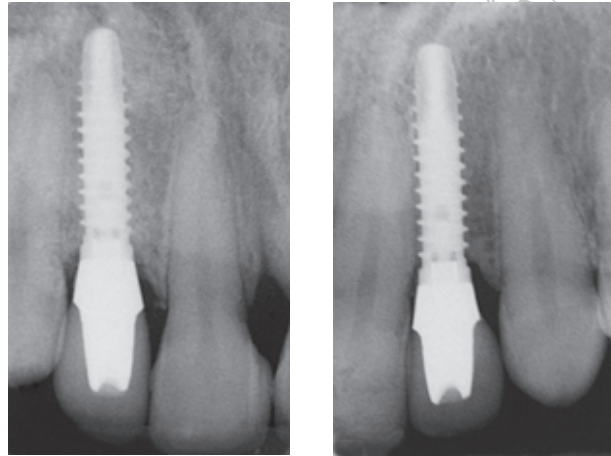
Figs 19 and 20 The final radiograph showed an ideal bone-to-implant relationship. The zirconia abutments have an opacity similar to metal.



Figs 21 and 22 Two years after inserting the final reconstruction.



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Figs 23 and 24 At the 2-year follow-up visit, no changes were seen on the radiograph.



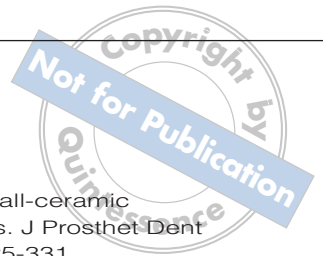
Figs 25 and 26 There were no major changes in the esthetic result after 2 years.

Conclusions

Within the limitation of lacking long-term clinical experience concerning the fracture strength of small-size zirconia abutments (3.5 mm SPI ART), the esthetic outcome was remarkable and contributed significantly to meeting the esthetic needs of the patient.

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