Zimmer® Contour Ceramic Abutments

Precision-engineered for strength, esthetics and clinical versatility

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Introduction

The ability of modern dental ceramics to rival the translucency[1-2] and subtle shade gradations[2-3] of natural dentition continues to fuel clinical demand for all-ceramic restorations. No longer limited to the esthetic zone, high-strength ceramic core materials with porcelain veneers are now widely used for both anterior and posterior restorations.[4-5] In implant dentistry, however, the use of a titanium abutment can compromise the translucency of an all-ceramic crown and result in a prosthetic tooth that appears dull next to adjacent natural dentition.[6-8] The titanium abutment may also cause a darkened or metallic appearance along the gingival crevice, which can become more pronounced over time.[6-9] Attempts to overcome these challenges have included concealing the abutment beneath opaque material[10] or a densely sintered coping,[11] or replacing the stock titanium abutment with a custom-cast, porcelain-veneered abutment.[10] Clinical and esthetic results have been mixed with each of these procedures, and extensive preparations can significantly increase laboratory time and overall expense. Zimmer Dental's zirconia abutments provide a versatile esthetic solution to these traditional challenges, and offer the stability, strength and esthetics to restore any tooth location. This paper will provide a basic overview of the product.

Design

Zimmer Contour Ceramic Abutments for the *Tapered Screw-Vent*® Implant System are pre-contoured to minimize or eliminate the need for additional preparations. The abutment (patent pending) consists of a solid zirconia body, titanium alloy seating ring, and titanium alloy retention screw [Fig. 1]. During the manufacturing process, the abutment body and seating ring are press-fit together and remain in place through contact pressure between the two components.

Fig 1. *Zirconia abutment body with titanium alloy seating ring (abutment screw not shown).*

The retaining screw passes through the abutment body and rotates freely to engage the internal threads of the implant and secure the abutment in place. Contour Ceramic Abutments feature a selection of cuff heights designed to position the contoured restorative margin at or slightly below the gingival margin for esthetics and hygiene.[12]

Abutment seating ring and retention screw The mating hexagon of the zirconia abutment achieves an intimate, non-interference-fit connection with the *Tapered Screw-Vent* Implant's internal hexagon. Material differences in flexural properties (deformation) precluded development of a friction-fit connection between the zirconia abutment and titanium alloy implant. The desire to provide maximum screw-joint stability and protect the interfacial integrity of the abutment-implant junction led to development of the abutment seating ring.

When an abutment screw is threaded into an implant, the machined flanks of the screw threads form tight, interfacial contacts with the machined flanks of the implant's internal threads.[13] As the abutment screw is tightened, the generated torque places the implant-abutment assembly into compression (axial preload).[14] This clamping force improves the ability of the implant-abutment joint to maintain its integrity over time (fatigue resistance) and helps the abutment to resist rotational micromovements and occlusal shear loads.[13] Maintenance of axial preload is crucial for the long-term stability of the implant-abutment assembly.

Several known factors can reduce axial preload, however, and potentially lead to screw loosening and component fracture. Under prolonged occlusal loading, for example, the machined irregularities on the interfacial surfaces of the mated thread flanks may begin to flatten or wear, which has been reported to reduce the initial preload clamping force from 2% to 10%.[13-16] Such settling or embedment relaxation of the threads may reduce the axial preload and result in the type of rotational micromotion by the abutment that can lead to screw loosening.[13] In addition, the relationship between deformation (change in shape) when an implant-abutment assembly is subjected to loading can be expressed as a stiffness factor (loading-elongation ratio).[17] A system with a high degree of stiffness will experience small deformations when subjected to high loads, but small deformations can also rapidly eliminate the preload of a relatively stiff abutment screw.[17] Deformations can be induced by stress relaxation or enhanced by crack propagation as well as external mechanical loads.[17]

The titanium abutment seating ring is an axially deformable washer with relatively low stiffness that is positioned between the abutment body and implant.

Finite Element Analysis (FEA)[17] has shown that an elastic deformable element with relatively low stiffness can significantly increase the elastic energy stored in a system. The result is that the screw seating surface remains more in contact with the head of the retaining screw, which preserves the preload and thereby enhances abutment stability and helps to prevent screw loosening.[17]

A second comparative FEA study[18] was conducted to assess the stability of the abutment-implant interface with and without the titanium seating ring [Figs. 2-3] when subjected to (1) *pretension* (axial preload) [Fig. 4] and (2) *pretension + physiological loading* conditions [Fig. 5].

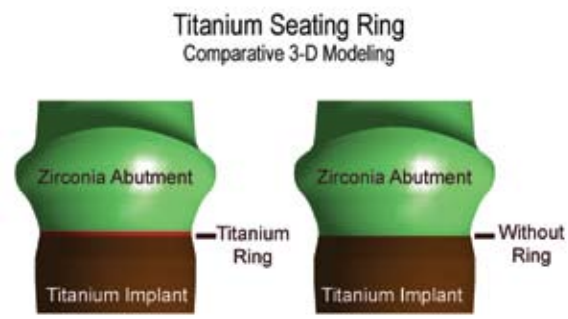

Fig 2. *FEA modeling of zirconia abutments on implants with (left) and without (right) a titanium seating ring.*

Fig 3. *FE mesh for the zirconia abutment and titanium seating ring model.*

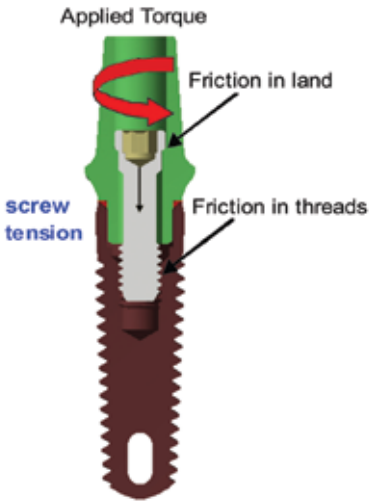

Fig 4. *Pretension loading: schematic of screw with 364.91 N of pretension generated by 30 Ncm of generated torque.*

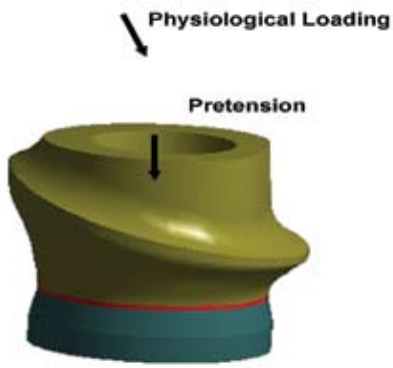

Fig 5. *FE model of the abutment with titanium seating ring under pretension + physiological loading.*

These components represented a masticatory force of 118.2 N at an angle of approximately 75° to the occlusal plane. The interfacial contact area or *sticking zone* of the seating ring and titanium implant [Fig. 6] extended 360° around the entire circumference of the implant with approximately seven times greater resistance to dislodging (greater sticking zone)

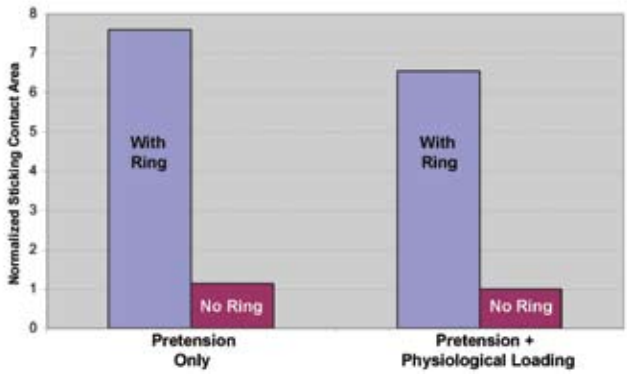

Fig 6. *Normalized sticking contact area for each test case.*

under both loading conditions as compared to the interfacial sticking zone of the zirconia abutment and titanium implant without the titanium seating ring.[18] This can be explained by differences in the coefficient of friction between the two interfacing materials: 0.5-0.6 for the titanium-to-titanium interface (i.e. abutment with the titanium seating ring on the titanium implant), and 0.2-0.3 for the zirconia-titanium interface (i.e. abutment without the titanium seating ring on the titanium implant).[18] Under the *pretension + physiologic loading* condition, the larger sticking contact zone of the abutment with the titanium seating ring increased the seating between the abutment system and the implant and thereby reduced the possibility of microbial leakage at the implant-abutment interface.[18] In contrast, the abutment without the titanium seating ring under the *pretension + physiologic loading* condition exhibited sticking contact at only one-quarter of the abutment-implant circumference compared to the abutment with the titanium seating ring model, which suggested the presence of interfacial microgaps.[18] The ring thus provides better friction and contact between the abutment system and the implant than the abutment without the ring, and the press-fit between the ring and the abutment provides very strong contact.

Under *pretension + physiological loading* conditions, the abutment with the titanium seating ring also showed 13.4% lower maximum principal stress in the abutment structure and lower contact pressure at the implant-seating ring interface than the abutment without the seating ring [Figs. 7 and 8].[18] The location of the stress concentration was exactly the same as the fracture location of the zirconia abutment during fatigue testing [Fig. 9]. This may provide less chance of wear and fracture of the abutment during

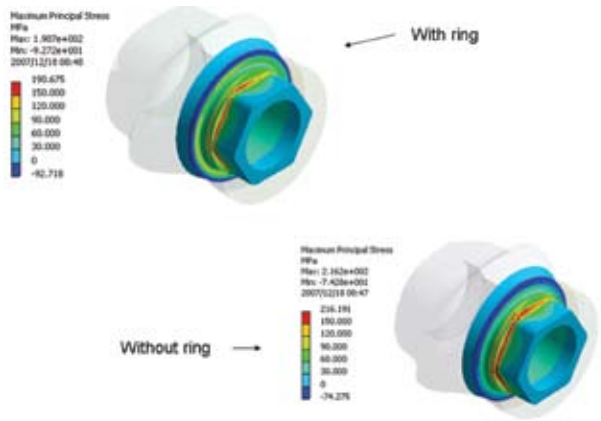

Fig 7. *Comparison of abutment stress distributions under the* pretension + physiological loading *condition. The abutment without a titanium seating ring showed approximately 13.4% higher stress concentrations.*

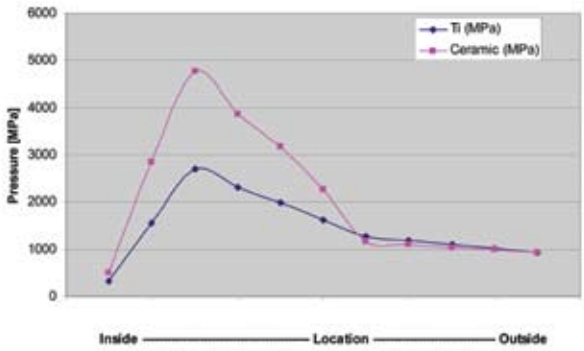

Fig 8. *Contact pressure distribution along the interfacial region.*

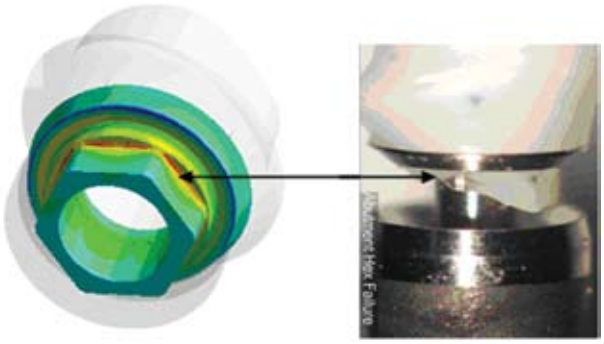

Fig 9. *The location of stress concentration for the abutment + seating ring was identical to the fracture location of the abutment without seating ring during fatigue testing.*

functional loading.[18] It was concluded that the significantly better interfacial contact and the lower maximum stress and contact pressure exhibited by the abutment with seating ring design may provide greater resistance to abutment micromovements and tilting during functional loading, and thereby reduce the possibility of microbial leakage, screw loosening, wear, and abutment fracture compared to the abutment without the seating ring.[18] Further research is needed to fully evaluate these findings.

Repeated micromovements at the implant-abutment interface can also cause abrasive wear over time, but the effects of that wear will vary according to nature of the interfacing surfaces. In a study of ceramic-to-titanium interfacial wear patterns, it was the metallic surface that tended to wear and abrade.[19] This has also been observed clinically by ceramic abutments rounding and smoothing the corners of external hexagon implants as a consequence of seating and reseating the abutments during the fabrication process.[20] Since ceramic abutments cannot be machined to the same degree of precision as metal abutments, an imprecise fit between an abutment and implant can lead to screw loosening, bone loss subsequent to microbial infection, and other clinical problems.[9, 21] In contrast, the titanium seating ring provides a precision-machined interface between the implant and zirconia abutment [Fig. 1], and metal-to-metal surfaces tend to self-polish through continued contact if abrasive scratches occur,[22] thereby enhancing long-term stability. Abutment retention and stability are thus enhanced by interaction between the abutment's retention screw and titanium seating ring.

Emergence profile A slightly convergent or concave emergence profile extending from the bottom of the contoured margin to the base of the abutment is designed to facilitate mucosal development around the top of the implant. Numerous studies have reported the importance of achieving adherent peri-implant soft tissue to function as a biologic barrier against bacterial invasion and the ingress of food debris into the implant-abutment interface.[23] Abutments that diverge from the top of the implant have been observed to compress the peri-implant mucosa and result in a periodontal biotype that is relatively thin and fragile.[24] With the lack of true connective tissue fiber anchorage into implant and abutment surfaces, the compressive effect of this abutment divergence has been cited as a cause of soft tissue recession.[24] In contrast, a convergent, narrow and somewhat concave negative profile has been reported to induce thicker, more stable and tighter peri-implant mucosa.[24]

Design *Zimmer* Contour Ceramic Abutments [Fig. 1, Table 1] feature a contoured collar and a pre-defined offset margin that is lower on the buccal aspect and higher on the lingual aspect to minimize or eliminate the need for further preparations. Since the abutment is fully sintered, it may also be modified utilizing conventional porcelain instruments and external irrigation. Provisions for abutment modification are listed in its Instructions for Use.

Materials

Pure zirconia (zirconium oxide / ZrO_2) can exist in 3 crystalline forms: monoclinic, tetragonal and cubic.[25] Monoclinic crystalline structure is the stable phase of

Table 1. Zimmer Contour Ceramic Abutments

Catalog no.	Abutment emergence profile	Abutment dimension		
		Platform diameter	Emergence diameter	Cuff height
ZRA341S	Straight	3.5 mm	4.5 mm	1 mm
ZRA342S	Straight	3.5 mm	4.5 mm	2 mm
ZRA451S	Straight	4.5 mm	5.5 mm	1 mm
ZRA452S	Straight	4.5 mm	5.5 mm	2 mm
AH20S	Replacement screw for *Zimmer* Contour Ceramic Abutments			

pure zirconia at room temperature.[26] Zirconia transforms into the tetragonal phase when heated to 1000-1100°C, and then into the cubic phase when heated above 2000°C.[26-27] During monoclinic-to-tetragonal transformation, a 5% decrease in volume occurs as the zirconium oxide is heated.[26-27] As the material cools, there is a 3% to 5% increase in volume and the crystalline structure of the pure zirconia transforms back into the monoclinic phase.[26-27] Stresses generated by changes in volume can cause cracks in the zirconia material, but since the monoclinic crystal is 3% to 5% larger than the tetragonal crystal, it places the region around the cracks in compression and significantly adds to the overall strength of the zirconia ceramic material through the process of transformation toughening.[26-28]

The addition of a stabilizing agent, such as yittrium oxide (Y_2O_3) to a zirconium oxide (ZrO_2) base, will cause the material to stabilize at room temperature and generate a multiphase, primarily tetragonal ceramic called partially stabilized zirconia, which has high initial strength and fracture toughness.[27-29] The leading edge of a crack propagating through partially stabilized zirconia generates a high-energy stress state that causes the zirconia to transform from the tetragonal crystal configuration to a monoclinic configuration. This reverse transformation causes the zirconia to expand in volume to stop and partially close the crack while adding to the overall strength of the material in a localized form of transformation toughening.[25-26, 28]

After compounding the zirconia, the material is compressed with a hydrostatic press to create the abutment body blank, which is the pre-sintered green state. The abutment blank is machined to an intermediate form that has the same geometry as the finished product, and then it is sintered (fired). The sintering process causes the zirconia to densify with limited grain growth, which significantly enhances strength, and shrinks the abutment to its final form.[26] Sophisticated software management is required to compensate for the shrinkage from the milled intermediate abutment to its final clinical dimensions. Residual sprues left from the machining process are ground off the abutment body to complete the finished product.

Yttria-stabilized, tetragonal zirconia polycrystalline (Y-TZP) ceramic was first introduced for biomedical use as orthopedic hip replacements, and were successful because of the material's excellent mechanical properties and biocompatibility.[25] More than 400,000 Y-TZP hip implants were in use by 1985.[25] In the early 1990s, an early form of Y-TZP expanded into dentistry for endodontic dowels and implant abutments that offered a lower elastic modulus, higher strength, better wear properties and higher fracture toughness than alumina.[27-30]

All of Zimmer Dental's esthetic zirconia abutments are 3-piece assemblies manufactured in conformance with international standards for clinical use: the zirconia abutment body conforms to ISO 6872 Dental Ceramic and ISO 13356 Implants for Surgery, and the titanium alloy abutment seating ring and retention screw conform to ISO 5832-3 Implants for Surgery – Part 3: Wrought Titanium 6-Aluminum 4-Vanadium Alloy. All ISO documents are available online from the International Organization for Standards at http://www.iso.org/. The zirconia is made of 100% small, metastable, tetragonal grains that are densely sintered with minimal voids, flaws, cracks and are free of any glassy phase at the borders of the crystals that can lead to low-temperature degradation and adversely interact with moisture to degrade the ceramic. The resulting densely packed particles[31] and high flexural strength[32-33] allow zirconia abutments to be clinically prepared utilizing conventional techniques with ceramic burs and external irrigation. Comparative research has shown that material removal from fine-grained zirconia abutments resulted in a transgranular fracture pattern with smoother surfaces than the intergranular fracture pattern and rougher surfaces of alumina abutments.[34]

Strength and biocompatibility testing of Zimmer Dental's esthetic zirconia abutments were conducted according to ISO 14801:2003 Dentistry – Fatigue Test for Endosseous Dental Implants, and ISO 10993-1:2003 Biological Evaluation of Medical Devices – Part 1: Evaluation and Testing, respectively, and were found to provide excellent biocompatibility and a combination of stable mechanical properties [Table 2] for high-strength dental restorations.[35]

Abutments made with this process have less than 1% porosity and consistent physical properties that can be maintained from one abutment to the next.[35] *Zimmer* Contour Ceramic Abutments are indicated for use with *Zimmer*® Endosseous Dental Implants for the support of single- (freestanding) or multiple-unit (splinted) fixed partial dentures.

Table 2. Strength comparisons of implant-supported Y-TZP ceramic abutments[35]

Component	Feature	Zimmer Contour Ceramic Abutment 3.5 mm diameter	Zimmer Contour Ceramic Abutment 4.5 mm diameter	Competitor abutment 3.5 mm diameter
Abutment	Body	Y-TZP ceramic	Y-TZP ceramic	Y-TZP ceramic
	Seating ring	Ti-6Al-4V	Ti-6Al-4V	None
	Screw	Ti-6Al-4V	Ti-6Al-4V	Ti-6Al-4V
	Emergence	Contoured/curved	Contoured/curved	Cone
	Margin	Pre-machined	Pre-machined	None
	Cone	Tapered	Tapered	Tapered
	Crown anti-rotation	Irregular cone cross-section	Irregular cone cross-section	Flat on cylindrical cross-section
Implant	Diameter	3.5 mm	4.5 mm	3.5 mm
	Interface	Internal hexagon	Internal hexagon	Internal hexagon
	Material	Ti-6Al-4V	Ti-6Al-4V	Ti-6Al-4V
Test results	Compression bending (max. load)	408.9 N (91.93 lbs)	606.9 N (136.44 lbs)	309.4 N (69.56 lbs)
	Cyclic loading to fatigue (5 million cycles)	155.7 N (35 lbs)	222.4 N (50 lbs)	155.7 N (35 lbs)

Sterilization and shelf life

Zimmer Contour Ceramic Abutments are packaged in a cleanroom under low bioburden conditions, but the components are not sterilized. Dry heat sterilization instructions are provided in their Instructions For Use. Autoclaving is contraindicated in conformance with ISO 13356. The dry heat sterilization procedure was validated to provide a minimum sterility assurance level of 10^{-6}.[35] Testing was performed in accordance with AAMI TRI 12:2004, Designing, Testing, and Labeling Reusable Medical Devices for Reprocessing in Health Care Facilities: A Guide for Device Manufacturers; ANSI/AAMI ST40:2004, Table-Top Dry Heat Sterilization and Sterility Assurance in Health Care Facilities; ANSI/AAMI ST50:2004, Dry Heat Sterilizers.[35] Since Zimmer esthetic ceramic abutments are sold non-sterile, no expiration date is applicable for the product.

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Notes