All-Ceramic Restorative System for Esthetic Implant-Supported Crowns: In Vitro Evaluations and Clinical Case Report

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Abstract: ***Patient demands for improved esthetics have prompted the development of all-ceramic restorative systems for dental implants, but material strength and restorative costs have presented clinical challenges. Therefore, a new restorative system with tooth-shaped ceramic copings for the anterior and premolar jaw regions has been introduced to address these problems. Fatigue and 17° compression tests were conducted in vitro to assess the mechanical strength of the 6 tooth-shaped copings and several luting agents of the system. A case report on the clinical use of the components is presented. All 6 tooth-shaped copings significantly exceeded the range of forces associated with restoration in the anterior jaw. Crown-endurance limits for fatigue and 17° compression were 70% higher and 46% higher, respectively, than the established minimum-fatigue-endurance limits in those categories. In clinical evaluation, the ceramic restorative system performed well and produced excellent results; it has potential for implant restorations in the anterior and premolar regions of the jaw.***

Learning Objectives:

After reading this article, the reader should be able to:

- identify the esthetic challenges to restoring partially edentulous cases in the anterior maxilla with traditional ceramometal crowns.
- explain the steps for restoring dental implants with all-ceramic restorations in the anterior and premolar regions of the jaw.
- discuss current developmental trends in ceramic restorative systems.

Although ceramometal crowns have been widely used to successfully restore tooth form and function on dental implants, they have not always been able to meet patients' demands for natural-looking esthetics. When a thin porcelain veneer covers the underlying metal framework, the prosthesis can appear dull next to the adjacent natural dentition, and porcelain degradation from toothbrushing can cause this disparity in appearance to intensify with time.[1] The supporting prosthetic abutment also may create an unsightly metallic smile line that can become more pronounced with gingival recession and oxidation.[2,3] New labial margin designs and porcelain veneering techniques have helped to mitigate,[2,4] but not eliminate, the esthetic problems associated with ceramometal restorations on dental implants.

Recent innovations in the strengthening of dental ceramics[5-6] have led to the development of new ceramic restorative systems for the direct application of porcelain on an opaque ceramic base instead of on a metal framework. The various new ceramic restorative systems generally can withstand relatively high compressive forces and offer a range of flexural strengths.[2-5] Short-term studies[6,7] have demonstrated excellent esthetics and good survival rates.[6] One long-term, prospective study reported 5- and 10-year cumulative success rates of 97.7% and 92.2%, respectively,[8,9] which were comparable to reported results for ceramometal crowns.[9]

One drawback in the development of these new ceramic restorative systems has been the inability of ceramic materials to exhibit the same stress-

Table 1—PureForm™ Ceramic System Components

Item	Designs	Materials	
		Restorative	**Ancillary**
Tooth-shaped copings	Prepared premolar Prepared canine Prepared straight small incisor Prepared 17º angled small incisor Prepared straight large incisor Prepared 17º angled large incisor	Injection-molded, sintered ceramic copings: 70% alumina, 30% zirconia	Injection molded, ULTEM®,[b] plastic copings[1] (for surgical try-in)
Core abutments[2]	Cuff heights: 0.5 mm& 1.5 mm Diameters: 3.5 mm & 4.5 mm[3] or	Ti-6A1-4V (screw-retained base for cemented ceramic crown)	Color-coded Ti-6A1-4V 3.25 mm, 4 mm, & 5 mm[3] (laboratory analog for working cast)

[1]Includes surgical try-in pin (2.0-mm diameter, Ti-6A1-4V) for pilot drill hole.
[2]Includes retention screw (Ti-6A1-4V).
[3]Spline® Implant System[a].

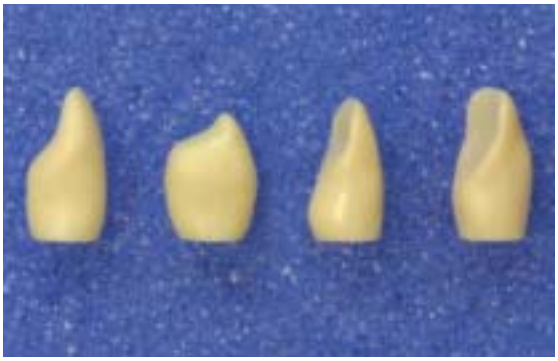

Figure 1—Tooth-shaped ceramic copings serve as the underlining of the ceramic crown.

Figure 2—The ceramic coping attaches to the metal base component before porcelain application.

relieving properties as ductile metals. Moreover, brittleness sometimes limited the effectiveness of early ceramic crowns in the molar region. Newer blends of ceramic materials have been introduced to help reduce cracking and chipping. This article presents the results of in vitro evaluations of one new ceramic restorative system for creating tooth-shaped ceramic copings in the anterior and premolar jaw regions and a case report on its clinical use.

In Vitro Evaluations

Materials and Methods

The ceramic restorative system (PureForm™,[a]) consists of 6 ceramic (70% alumina, 30% zirconia) copings shaped like prepared natural teeth and titanium-core abutments that provide a machined interface with the implants for the finished crowns (Table 1; Figures 1 and 2). Porcelain is applied directly to the ceramic coping without waxing or casting, and the finished, all-ceramic crown is cemented onto a titanium core, which provides a precision-machined interface with the implant. The system also includes a try-in kit to help guide implant placement (Figure 3).

In vitro fatigue and 17º compression tests were conducted to assess the mechanical strength of individual restorations using each of the 6 ceramic-coping designs of the system (Figure 4). Two independent laboratories (Centre City Dental Lab, Escondido, CA; Rocco's Dental Studio, Escondido, CA) prepared and restored the test copings according to the manufacturer's specifications. For the evaluation of strength and heat generation in worst-case conditions, diamond grinding wheels[c] were used without irrigation to prepare each coping to a minimum wall thickness of 0.5 mm. Porcelain

[a]Centerpulse Dental Inc, Carlsbad, CA 92008; (800) 854-7019

[b]GE Plastics, Pittsfield, MA 01201-3662; (413) 448-7569
[c]DIADUR TOOLS S.L., Barcelona, Spain; (+34) 93 714 25 22

Table 2—Product Samples Used for In Vitro Testing

Sample	Coping Design	Porcelain	Crown Cement	Test
1	Small incisor	Procera®,[d]	Zinc phosphate[1]	Fatigue and 17° compression
2	Small incisor	Procera®	Zinc phosphate	17° compression
3	Small incisor	VITADUR® ALPHA	Zinc phosphate	Fatigue and 17° compression
4	Small incisor	VITADUR® ALPHA	Zinc phosphate	Fatigue
5	Small incisor	VITADUR® ALPHA	Zinc phosphate	Fatigue
6	Small incisor	VITADUR® ALPHA	Zinc phosphate	Fatigue
7	Large incisor	Procera®	Zinc phosphate	Fatigue
8	Large incisor	VITADUR® ALPHA	Zinc phosphate	Fatigue and 17° compression
9	Large incisor	Procera®	Zinc phosphate	17° compression
10	Large incisor	Procera®	Zinc phosphate	Fatigue
11	17° small incisor	Procera®	Glass ionomer[2]	Fatigue
12	17° large incisor	Procera®	Glass ionomer	Fatigue and 17° compression
13	Canine	Procera®	Glass ionomer	Fatigue
14	Premolar	Procera®	Glass ionomer	Fatigue

[1]Fleck's® Cement[e]

[2]Ketac™-Cem[f]

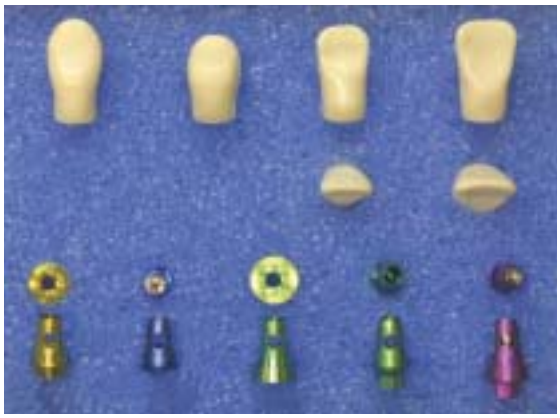

Figure 3—Try-in kit. Plastic tooth copings with color-coded base components facilitate selection of the appropriate components.

Figure 4—Setup for compression and fatigue is accomplished.

was applied directly to the ceramic copings without preliminary waxing and casting according to the manufacturers' instructions (Table 2).

For each test sample, a dental implant (Spline™ Twist™,[a]) was stabilized in a bed of bone cement. A titanium-core abutment was placed directly onto the implant and secured with a retaining screw tightened to a torque of 28.25 Ncm (2.5 in-lbs). The finished porcelain crown was sterilized in an autoclave at 250° for 60 minutes and cemented onto the core abutment with either zinc phosphate or glass-ionomer cement (Table 2). An independent engineering laboratory mounted the completed assembly in MTS equipment (MTS Equipment Corporation, Eden Prairie, MN) and subjected it to fatigue or 17° compression testing (Engineering Materials Laboratory, Santa Fe Springs, CA). Failure of the retaining screw or implant was defined as any distortion, bending, or breakage of the component, and crown failure was defined as any chipping or cracking of the porcelain or cement failure resulting in the detachment of the crown from the core abutment.

Fatigue testing was conducted with a load cycle of 22.2 N to 244.7 N (5 lbs to 55 lbs) at 5 million cycles. Three consecutive restorations were required to withstand a minimum loading of 22.2 N to 142.3 N (5 lbs to 32 lbs) for 5 million cycles without any sign of restoration failure. The 142.3 N (32 lb) maximum endurance load was based on the reported mean bite force component for implant-supported dentures.[10] A visual inspection of the

[d]Nobel Biocare, Yorba Linda, CA 92887; (800) 322-5001

[e]Mizzy, Inc (a division of Keystone Industries), Cherry Hill, NJ 08002; (856) 663-4700

[f]3M ESPE, St. Paul, MN 55144; (800) 216-9502

Table 3—Results of Fatigue Testing

Sample	Cycles	Load	Failure	Comments
1	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
2	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
3	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
4	1,845,800	22.2 N – 289.1 N (5 lbs – 65 lbs)	Abutment screw bent	Ceramic restoration remained intact without any signs of chipping or detachment.
5	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
6	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
7	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
8	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
9	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Porcelain chipped at incisal edge of crown because of contour that concentrated the full test load on a single incisal edge. Coping was intact.
10	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.
11	5 million	22.2 N – 244.7 N (5 lbs – 55 lbs)	No failure	Ceramic restoration remained intact without any signs of chipping or detachment.

ceramic restoration for signs of cracking, chipping, or detachment of porcelain was performed every 1,000,000 cycles. Compression tests were conducted until the first sign of failure. The crowns were required to meet a 400.3 N (90 lb) load requirement based on the statistical analysis of 3 anterior bite studies.[11-13]

Ten of the crowns tested were worst-case configurations for strength; 6 small incisors had the thinnest incisal sections, and 4 large incisors had the tallest configurations that generated the most bending stresses on the coping base. Many factors were evaluated in determining the overall strength of the crowns, the strength of the ceramic materials, the coping strength after minimum wall preparation, and the effect of heat generated from grinding. Other evaluated areas were the bond strength of the applied porcelain to the ceramic coping and the bond strength of different crown cements to the ceramic copings and titanium cores.

Results

The results of in vitro fatigue and 17° compression tests are presented in Tables 3 and 4, respectively. The former did not determine the actual fatigue endurance limit of the restored test samples because the core-abutment retaining screw failed (Table 3). In an evaluation of conditions of extreme overload, 1 sample, tested at 22.2 N to 289.1 N (5 lbs to 65 lbs), failed when

Table 4—Results of 17° Compression Tests

Sample	Coping Design	Mode of Failure	Failure Load N (lbs)
1	Small incisor	Porcelain fractured, coping intact	747.3 (168)
2	Small incisor	Porcelain and coping fractured	622.8 (140)
3	Small incisor	Porcelain fractured, coping intact	765.1 (172)
4	Large incisor	Porcelain and coping fractured	818.5 (184)
5	Large incisor	Porcelain and coping fractured	618.3 (139)
6	17° large incisor	Porcelain fractured, coping intact	880.7 (198)
			Mean 742.9 (167)

Table 5—Indexing the Implant Buccally for Optimal Crown Positioning

Implant System	Implant Connection	Fixture Mount	
		No. of Flat Surfaces	Portion to Orient Buccally
Tapered Screw-Vent® MTX™,[a]	Internal hexagon	1	Flat surface
Spline™ Twist™	External spline	6	Corner junction of any 2 flat surfaces

the abutment screw fractured at 1,845,800 cycles. At a 17° compression, the mean fatigue load failure was 46% greater than the minimum requirement of 329.4 N (90 lbs). Each sample was closely observed during the test. At the first sign of failure the test was stopped, and the load was recorded. The results of fatigue testing showed the crown endurance limit was 70% higher than the established minimum fatigue endurance limit of 142.3 N (32 lbs). All of the remaining test samples withstood 5,000,000 cycles without failure.

Each test sample was microscopically examined for signs of porcelain cracking or chipping and detachment of the porcelain crown from the metal core. The canine restoration exhibited porcelain failure at the incisal edge because of poor contour that delivered the entire test load to a single point on the incisal edge of the crown. No signs of loosening between the porcelain crown and core abutment were observed in any of the samples.

Clinical Case Report

A 48-year-old white woman presented with a missing mandibular left cuspid. A diagnostic workup was performed to evaluate the functional and esthetic needs of the patient, as well as the volume and location of available bone. Medical and dental histories were reviewed to determine the presence of any diseases or conditions that might pose risks to surgery or osseointegration. Radiographic (panoramic and periapical) and physical examinations were conducted to assess the vertical height of available bone and adjacent anatomical structures relative to the proposed implant sites and to identify any undiagnosed diseases, destructive parafunctional habits, or oral pathologies that would require treatment before implant surgery. A working cast was fabricated to determine the proposed implant position, crown-to-root ratio, occlusion, and potential complications. This allowed the creation of a prosthetic wax-up and fabrication of a surgical template to guide placement of the implant relative to the planned prosthesis. All treatment options and alternatives were thoroughly discussed, and a signed informed consent was obtained from the patient.

Antibiotic prophylaxis (500 mg of amoxicillin) was begun 2 hours before surgery and continued for 3 days after. The patient was prepared for aseptic surgery, and anesthesia was administered via local infiltration. A primary midcrestal incision and 2 releasing incisions were made with a scalpel (#15 BD Bard-Parker™,[g]). The soft tissues were elevated to expose the underlying alveolar process. Using the sterile surgical template for positioning, a guide hole was drilled into the bone under copious external irrigation, and the template was removed. A sterile, surgical try-in pin was inserted into the guide drill hole, and a plastic try-in coping was attached to the pin to evalu-

[g]BD Medical Systems, Franklin Lakes, NJ 07417; (888) 237-2762

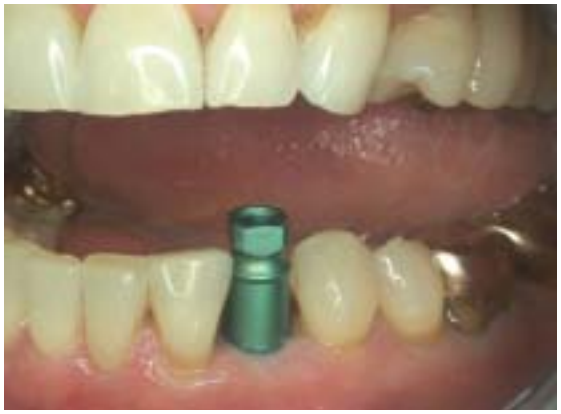

Figure 5—The impression post is attached to the implant. Note that the flat surface is oriented toward the buccal for an internal hexagon implant.

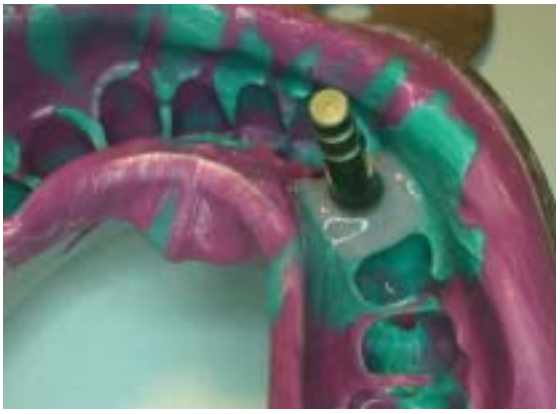

Figure 6—Soft-tissue replication material is injected around the assembled impression post and implant analog before pouring the impression in dental stone.

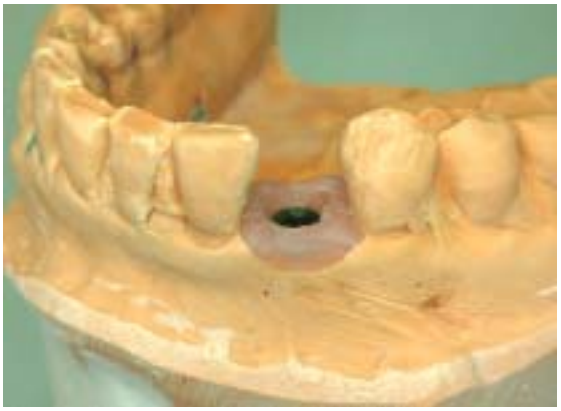

Figure 7—Removal of the impression post reveals the internal hexagon interface of the embedded implant analog in the working cast.

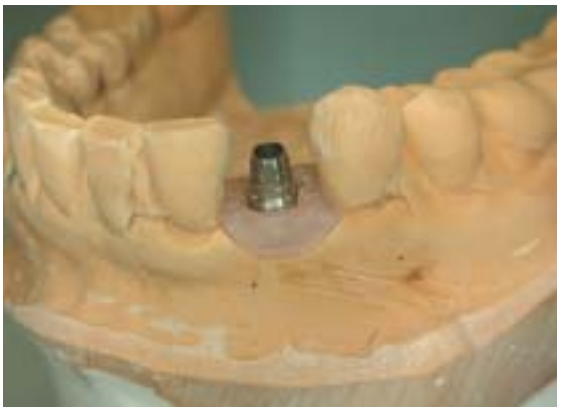

Figure 8—The core abutment is attached to the implant analog in the working cast with its retention screw. Note the buccal orientation of the flat side of the abutment.

ate its angulation and positioning relative to the adjacent dentition.

The try-in components were removed from the patient's mouth, and the osteotomy was completed using the template according to the manufacturer's protocol for the implant system. A self-tapping, screw-type implant (Tapered Screw-Vent® MTX™) was placed into the prepared receptor site, and the fixture mount was oriented toward the buccal aspect to establish optimum positioning for the crown (Table 5). The fixture mount was removed, the surgical cover screw was attached, and the implant was submerged beneath the soft tissue for 3 months of healing.

No complications arose during healing, and clinical osseointegration was confirmed at the second-stage surgical uncovering. A healing collar was attached to the implant, and the soft tissues were closed around it with 3-0 sutures (VICRYL®,[h]). The sutures were removed 5 days later, and the soft tissues were allowed to mature before prosthetic procedures continued.

[h]ETHICON, Inc. (a Johnson & Johnson Company), Somerville, NJ 08876; (800) 255-2500

At patient recall the healing collar was removed, an impression post was attached to the implant (Figure 5), and a full-arch impression was made. After setting, the impression was removed from the patient's mouth, and the area surrounding the posthole was lubricated with petroleum jelly. The impression post was unthreaded from the implant in the patient's mouth, threaded into an implant analog, and the assembly was inserted into the corresponding impression hole (Figure 6). Soft-tissue replication material (IPS Express®,[i]) was injected around the transfer assembly, the impression was poured in dental stone, and the working cast was separated after setting (Figure 7). The healing collar was reattached to the implant, and the patient was dismissed until delivery of the definitive prosthesis.

The impression post was removed from the working cast in the laboratory. A core abutment with a 1.5-mm cuff height was seated on the implant analog in the working cast with the flat side of the abutment oriented buccally and

[i]Ivoclar Vivadent®, Amherst, NY 14228; (800) 533-6825

Figure 9—The plastic try-in coping is placed on the core abutment to verify its emergence profile relative to the adjacent dentition.

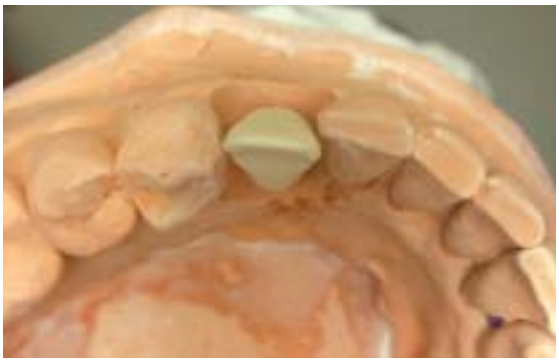

Figure 11—Occlusal view of the premolar ceramic coping shows excellent contours for fabrication of the ceramic crown.

secured in place using a retaining screw tightened to 30 Ncm of torque to fully engage the friction-fit connection of the component (Figure 8). The cuspid plastic try-on tooth was seated on the core abutment in the working cast (Figure 9) to verify that the equivalent ceramic tooth was the optimum design for the restoration (Figures 10 and 11). Reduction and contouring of the ceramic coping was accomplished with high-speed diamond wheels and external irrigation to prevent excessive heat generation. The prepared ceramic coping was blasted with alumina at 38 psi and steam-cleaned for 45 seconds. Porcelain with a coefficient of thermal expansion that ranged from 6.9×10^{-6} to 8.1×10^{-6} (VITADUR® ALPHA[i]) was applied to the ceramic coping and finished according to the manufacturer's recommendations and conventional laboratory procedures.

In preparation for sterilization, the finished crown was removed, and the core abutment was unseated from the implant analog in the working cast with a tool that dislodged the friction-fit interface between the components. During the delivery appointment, the healing collar was removed from the implant, and the sterilized core abutment was attached to the implant under 30

[i]Vident™ (US Distributor of Vita Zahnfabrik Products), Brea, CA 92821; (800) 828-3839

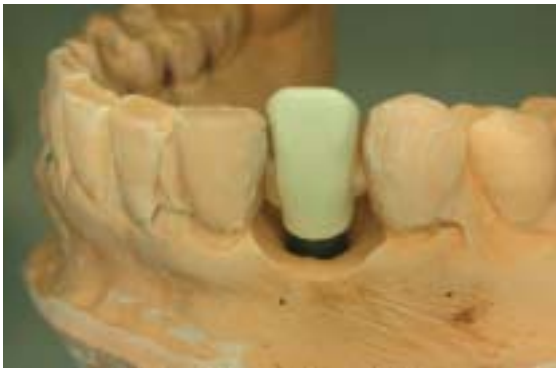

Figure 10—The premolar ceramic coping is seated on the working cast.

Ncm of applied torque (Figure 12). Full seating of the core abutment was verified radiographically. The access hole of the core abutment was occluded with a cotton pellet (Figure 13) and composite material to prevent the ingress of crown cement and facilitate future retrieval. The porcelain crown was cemented onto the core abutment with glass-ionomer cement (Ketac™-Cem). Excess cement was removed from the margin area, and the occlusion and bite were adjusted with conventional crown-and-bridge techniques (Figure 14).

Discussion

Although ceramometal restorations are still the dominant restorative choice for partially edentulous cases, cosmetic dentistry represents an emerging market driven by patient demand. In 2002, nearly 80% of dentists reported the use of metal-free crowns;[9] this is 36% more than what was reported in a 1995 survey.[10] Several implant manufacturers have offered ceramic restorative systems for several years, but the associated drawbacks of preparation time and less-than-optimal restorative materials have resulted in a slow market growth. The tooth shapes and ceramic restorative materials in this system offered a level of simplicity and strength that showed promising results.

In this case report, the ceramic restorative system was easy to use and achieved excellent esthetics. The internal hexagon connection consisted of a threaded shaft below a 1.5 mm deep internal hexagon and a beveled platform on the cervical portion of the implant.[14,15] During assembly, a self-locking taper on the male hexagon of the mating abutment created frictional resistance as it was seated into the female hexagon of the implant.[14,15] When fully assembled under 30 Ncm of applied torque, the mated com-

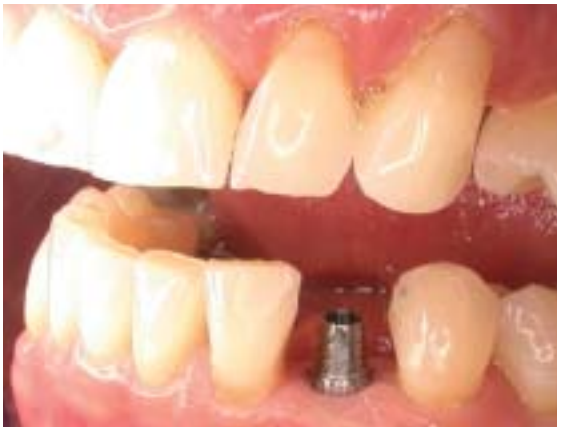

Figure 12—The core abutment is attached to the implant. Note the buccal orientation of the flat side of the component.

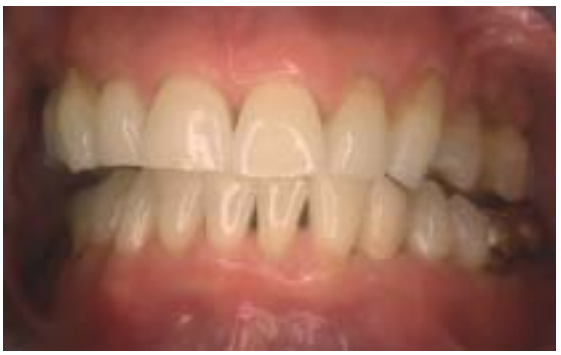

Figure 14—The finished crown is cemented onto the core abutment to complete the case.

ponents created a "virtual cold weld" frictional interface that has been documented to completely eliminate rotational micromovements.[15] To remove the abutment, a special tool was required to first disengage the tight frictional interface with the implant. The core abutment successfully withstood attachment and removal with the appropriate tools without any evidence of distortion or damage.

Conclusion

In vitro testing demonstrated that the strength of the restored ceramic coping exceeds the occlusal loads expected in the anterior and premolar regions when the coping is prepared according to the manufacturer's recommendations, and the applied porcelain has thermal expansion properties ranging from 6.9 to 8.1 $\times$ 10^{-6} Clinically, the system is user-friendly and achieves excellent esthetics.

Acknowledgments

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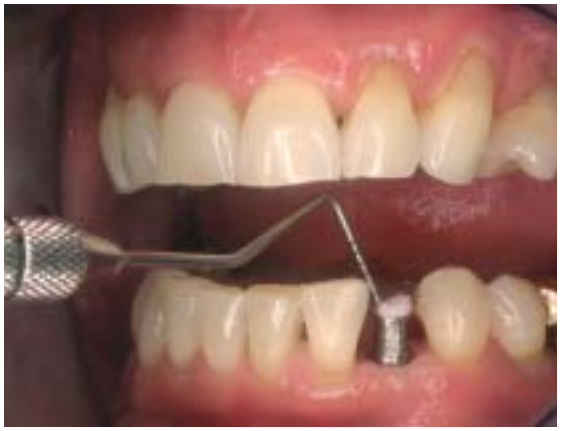

Figure 13—The core abutment is occluded with cotton and composite material to prevent the ingress of crown cement.

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Quiz 2

1. **A new restorative system, introduced in this paper, provides tooth-shaped ceramic copings for which jaw regions?**
   a. anterior and premolar
   b. posterior and premolar
   c. anterior and posterior
   d. posterior and premolar

2. **The ceramic restorative system Pureform™ consisted of how many copings?**
   a. 6
   b. 8
   c. 10
   d. 12

3. **What is the composition of PureForm™ copings?**
   a. 100% alumina
   b. 30% alumina, 70% zirconia
   c. 70% alumina, 30% zirconia
   d. 50% alumina, 50% zirconia

4. **The finished, all-ceramic crown is cemented to a titanium core, which provides what kind of interface with the implant?**
   a. processed porcelain
   b. precision-machined
   c. dental adhesive
   d. autopolymerizing acrylic

5. **A visual inspection of the ceramic restoration for signs of porcelain cracking, chipping, or detachment was performed every:**
   a. 100,000 cycles.
   b. 500,000 cycles.
   c. 1,000,000 cycles.
   d. 5,000,000 cycles.

6. **What was inserted into the guide drill hole?**
   a. surgical template
   b. try-in pin
   c. pilot drill guide
   d. both a and b

7. **A plastic try-in coping was attached to the pin to evaluate:**
   a. soft-tissue maturation.
   b. the stage-2 uncovering.
   c. provisional loading.
   d. its angulation and positioning.

8. **In 2002, what percentage of dentists reported the use of metal-free crowns?**
   a. 50%
   b. 60%
   c. 70%
   d. 80%

9. **Several implant manufacturers have offered ceramic restorative systems, but what associated drawbacks have resulted in a slow market growth?**
   a. cost and training
   b. preparation time and cost
   c. preparation time and less-than-optimal materials
   d. cost and materials

10. **When fully assembled under 30 Ncm of applied torque, the mated components create a:**
    a. "virtual cold weld" frictional interface.
    b. a tongue-and-groove interface.
    c. dowel-and-pin interface.
    d. chemical-bond interface.

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