PROCERA® AllCeram Bridge

Brien R. Lang[1], Paulo Maló[2], Carlos M. Guedes[2], Rui-Feng Wang[1], Byungsik Kang[3], Lisa A. Lang[4], Michael E. Razzoog[1]

[1]Center For Excellence, Department of Biologic and Material Sciences, Division of Prosthodontics, School of Dentistry, The University of Michigan, Ann Arbor, MI, USA

[2]Department of Oral Surgery, Department of Prosthodontics, Maló Clinic, Portugal

[3]Mechanical Engineer, Vice-President, Hoff & Associates, Ann Arbor, MI, USA

[4]Department of Prosthodontics, School of Dentistry, University of Colorado, Denver, CO, USA

This paper reports on the in-vitro test requirements and results for the all ceramic bridge. Clinical application demonstrates that the esthetic and functional outcome satisfies patient needs and exceeds the biomechanical demands suggested for all ceramic fixed partial dentures.

INTRODUCTION

The Procera® AllCeram crown developed by Dr. Matts Andersson and Dr. Agneta Odén (Nobel Biocare, AB, Sweden) has enjoyed tremendous success throughout the world as an all-ceramic single unit restoration that is both beautiful and strong (Andersson & Odén 1993, Russel et al. 1995, Hegenbarth 1996, Andersson et al. 1998). Procera AllCeram crowns have been used in every location in the dental arches and this system of crown fabrication has become an unparalleled standard of care for the all-ceramic single tooth restoration. Nobel Biocare has now expanded its vision for the Procera system to include an all-ceramic 3-unit fixed partial denture as illustrated in Figure 1.

The Procera AllCeram bridge combines Procera AllCeram copings with an all-ceramic pontic. The aluminum oxide copings are joined to the aluminum oxide pontic substructure using specially formulated Procera Connecting and Fusing materials. The entire three-units of the bridge are then covered with Procera AllCeram veneering porcelain to complete the anatomic form of the bridge and to satisfy the esthetics and occlusion requirements of the patient. Treatment success with the Procera AllCeram bridge has created greater enthusiasm among clinicians who have long been looking for an all-ceramic fixed partial denture that is strong and predictable. The following patient presentation demonstrates the utility of the Procera AllCeram bridge used in restoring a single tooth edentulous space as well as its usefulness in combination with the Procera AllCeram crowns in full mouth rehabilitations.

Fig. 1. The Procera AllCeram 3-unit fixed partial denture.

The patient presented with teeth that had numerous large fillings placed in almost every tooth, and teeth that demonstrated significantly different colorations throughout the mouth and the patient was missing tooth #25. The supporting tissues demonstrated a generalized periodontal condition that required some therapy to reach a maintenance phase. The treatment plan developed for this patient involved both individual Procera AllCeram crowns and the 3-unit Procera bridge to restore the edentulous space for the missing tooth #25. This treatment plan provided the opportunity to achieve an excellent esthetic result whereby all teeth were restored with color and transparency that was natural and life-like in appearance (Figs. 2-4a, 4b).

Historically, the strength of most all-ceramic bridges has been a major concern that has limited their use to very few clinical situations. Restoration of anterior missing teeth and in some instances missing premolars has been satisfactorily managed with some all-ceramic bridges. Yet even in these clinical conditions, the question of strength limitations and the ability of any all-ceramic bridge to withstand the forces of functional and nonfunctional patient activities have resulted in skepticism among the dental profession.

The need for such scientific creditability in support of the Procera 3-unit fixed partial denture resulted in the initiation of a study by the authors to compare load to fracture mechanical test data with finite element analysis to determine the strength of the Procera AllCeram bridge. Additionally, the study was designed to evaluate the strength of the Procera AllCeram bridge when cemented using three different cements. The study results would provide information on the strength of the bridge that would withstand scientific scrutiny and assist the clinician in his/her decision on which luting agents to use in cementing the bridge.

MATERIALS AND METHODS

This study consisted of two parts: 1) Mechanical strength test of the Procera AllCeram bridge when cemented with a resin modified glass reinforced ionomer cement (Fuji Plus, GC America, Alsip, IL), and 2) Finite element analysis of the bridge when cemented with Zinc Phosphate (Kulzer, Dormagen, Germany), Fuji Plus and a resin cement (Panavia 21, J Morita USA, Irvine, CA).

Mechanical Strength Test

Five Procera AllCeram test bridges were provided to the investigators from the manufacturing facility (Nobel Biocare, Fairlawn, New Jersey USA). All five bridges were similar in design and dimensions, having been fabricated from a master set of dies and articulated casts using the Procera method of scanning the dies and assembling the bridge as previously described. In addition to the test bridges, special dies machined from the master dies scanned data file were provided (Nobel Biocare, Fairlawn New Jersey, USA) in a resin material with properties similar to human dentin. A resin die was positioned in each bridge crown and examined for fit prior to mechanical testing. An acceptable fit was observed between all of the dies and their

Fig. 2. The treatment plan developed for this patient involved both individual Procera AllCeram crowns and a posterior Procera bridge to restore tooth #25.

Fig. 3. The anterior teeth fully restored with Procera AllCeram crowns.

Fig. 4 a. The rehabilitation combined both Procera AllCeram crowns and a Procera bridge in restorations of the anterior and posterior teeth.

Fig. 4 b. The posterior edentulous space was restored with a Procera bridge to replace missing tooth #25.

individual copings in the five test bridge assemblies. For each bridge, dies were positioned within their respective crowns and secured with sticky wax. A cast was poured in improved stone with the dies and bridge oriented with the occlusal surfaces of the 3-units parallel with the base of the cast. After a controlled time for stone hardening, each Procera AllCeram test bridge was cemented onto their respective dies using Fuji Plus. After ten minutes for cement hardening, the cemented test bridges and their stone casts were stored in an environment similar to oral conditions for five days. After five days, each test bridge was positioned in a specially designed holder and placed in a Universal Instron machine. An Instron loading rod with a tip 2.0 mm in radius was positioned in the center of the occlusal surface of the all-ceramic pontic and a load in Newtons (N) was applied till fracture of the test bridge occurred (Fig. 5).

Finite Element Analysis

The specific design for the abutment teeth, the all-ceramic coping and pontic, cement space, and the junction area between the copings and pontic units are illustrated in Fig. 6 for the Procera AllCeram test bridge. The abutment teeth were modeled with a chamfer finish line and an 8-10 degree axial wall taper. The design was circular and dimensioned similar to what one would achieve preparing a maxillary 1st molar. A cement space between the tooth and the copings was modeled with a uniform thickness of 0.060 mm. The abutment teeth were 12.0 mm in diameter and positioned on either side of the pontic. The copings were modeled with a uniform thickness of 0.600 mm. The pontic was designed with a width of 6.0 mm and a height of 6.0 mm. The length at the inferior border of the pontic was 6.0 mm and the superior border was 10.5 mm. The junction between the copings and the pontic was modeled with a specific design that was required when using the Procera Connecting/Fusing material. The slope of the junction formed an angle of approximately 25 degrees with the vertical wall of the pontic. The area of the junction was 12.0 mm^2. The space between the coping and the pontic in the junction area was 0.050 mm. The finite element model for the Procera AllCeram test bridge illustrated in Fig. 6 was created using the software program HyperWorks®. The teeth in Fig. 6 were allowed to move slightly at their base horizontally to simulate a not-so-firm relationship in the jawbone. To achieve this function "springs X and Y" finite elements with a stiffness = 2 (N/mm) were used at the interface between the base nodes of the teeth and the supporting constraints. Spring elements were also used between the tooth and cement and cement and coping in the model. It had been previously determined by the authors that using spring elements created more exacting mechanical test results in strength testing of a Procera coping (Wang

Fig. 5. A loading rod was positioned in the center of the occlusal surface of the all-ceramic pontic and loaded until fracture of the test bridge occurred.

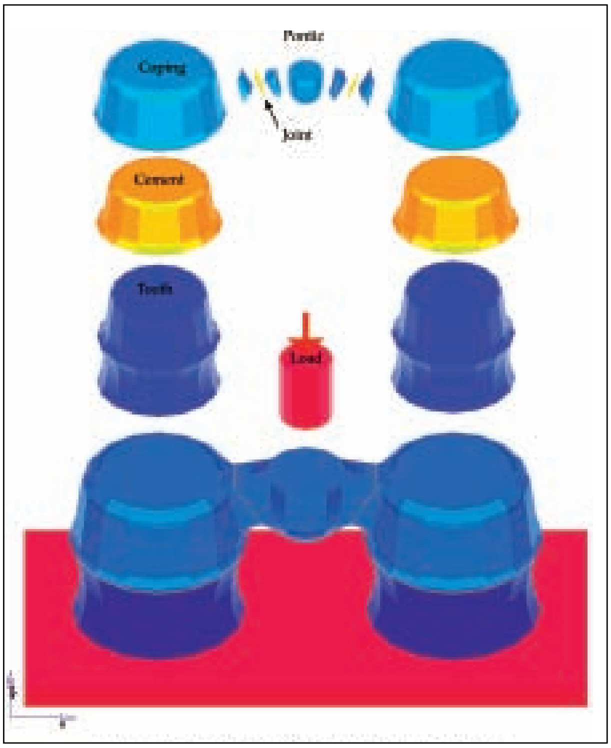

Fig. 6. The finite element model for the Procera AllCeram test bridge was created using the software program HyperWorks®.

	Density mg/mm³	Modulus of Elasticity MPa	Poisson's	Ultimate Tensile Stress MPa
Aluminum Oxide	3.97E-09	380000	0.25	508
Dentin	2.1~2.2E-9	12~14000	0.3	240
Zinc Phosphate	3.94E-09	13400	0.35	4.5
Fuji Plus	2.52E-09	6400	0.25	33.9
Panavia 21	2.52E-09	7500	0.25	45
Connecting and fusing materials	3.72E-09	104000	0.3	260

Table 1. The physical properties of the specific materials used in the finite element models.

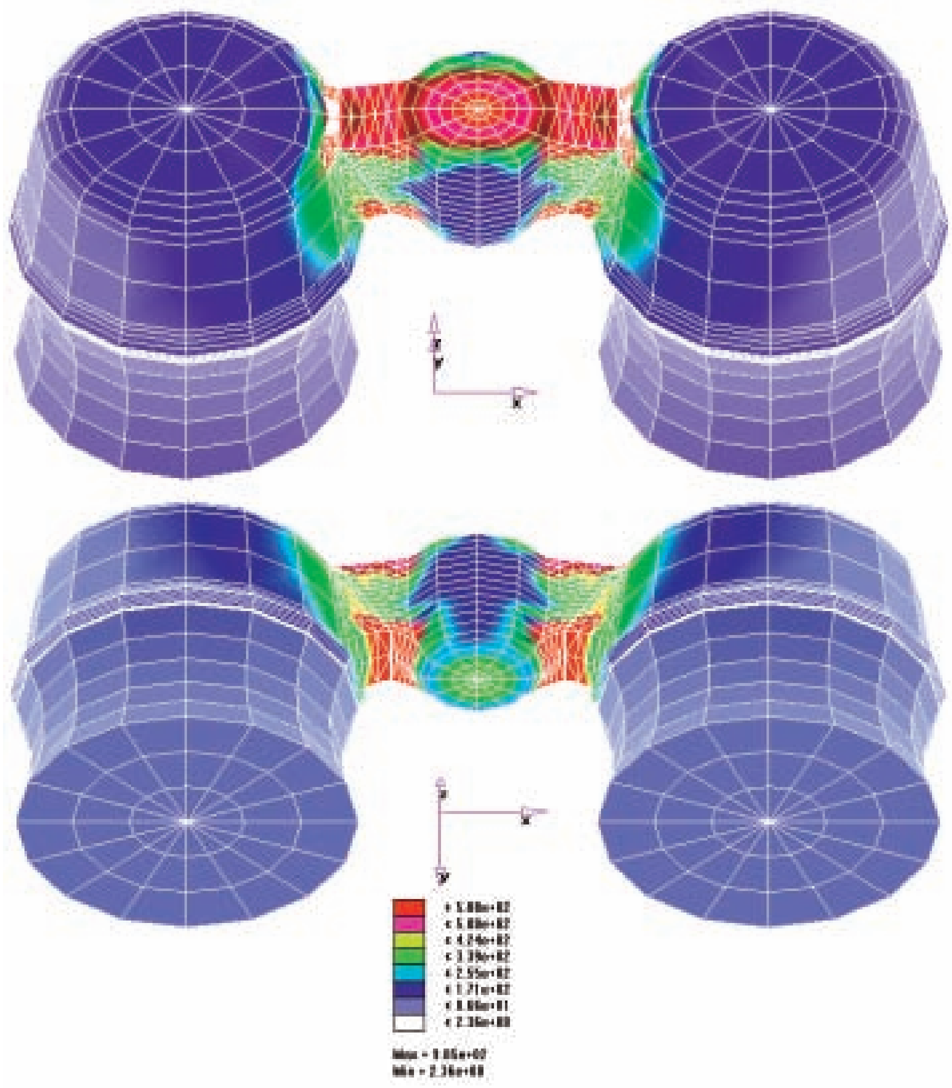

Fig. 7. von Mises stress distributions for the Procera test bridge model.

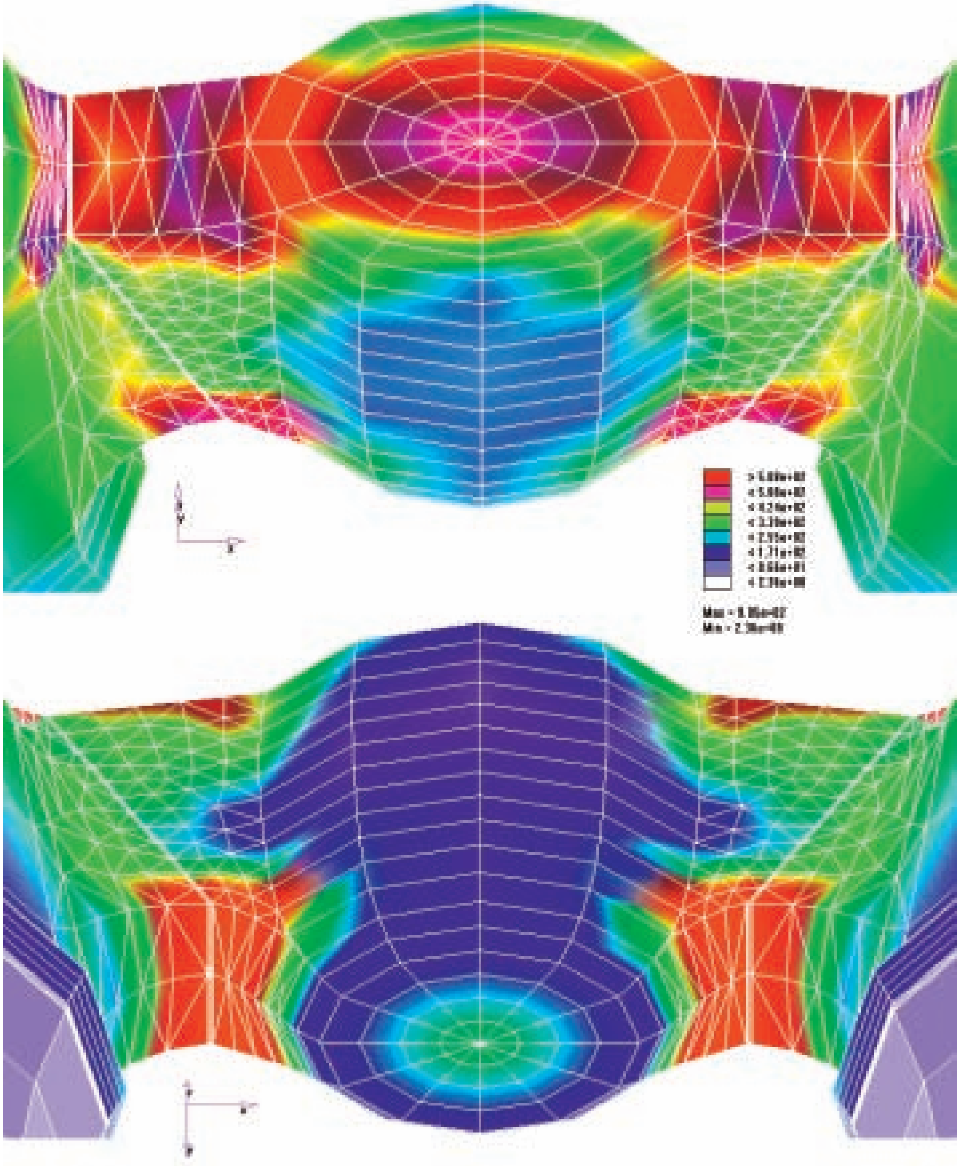

Fig. 8. Von Mises stress concentrations in all models extended from the pontic through the joint to the sides of the copings.

& Lang 2002). The remaining contact interfaces in the model were 'Node to Surface' at the interfaces between the copings and pontic in the junction space. A loading rod with a tip 2.0 mm in radius was modeled and positioned in the center of the occlusal surface of the all-ceramic pontic. Using the program ABAQUS Standard 3D 6.2 software the rod was load in increments up to 3000 N and a finite element analysis was performed. The model in Fig. 6 was replicated to create three models; one for each of the three cements being examined to determine the load to fracture or strength of the Procera AllCeram test bridge. The physical properties of the specific materials used in the finite element models are presented in Table 1.

RESULTS

The mean load to fracture during the mechanical test of the Procera AllCeram bridges was 697 ±102 N. During loading, the first signs of fracture occurred along the lower border of the junction area in the Procera AllCeram porcelain. A total fracture of the junction involving the Procera Connection/Fusing material followed the initial failure. Once the junction began to fail, a fracture moved up through the junction ma-

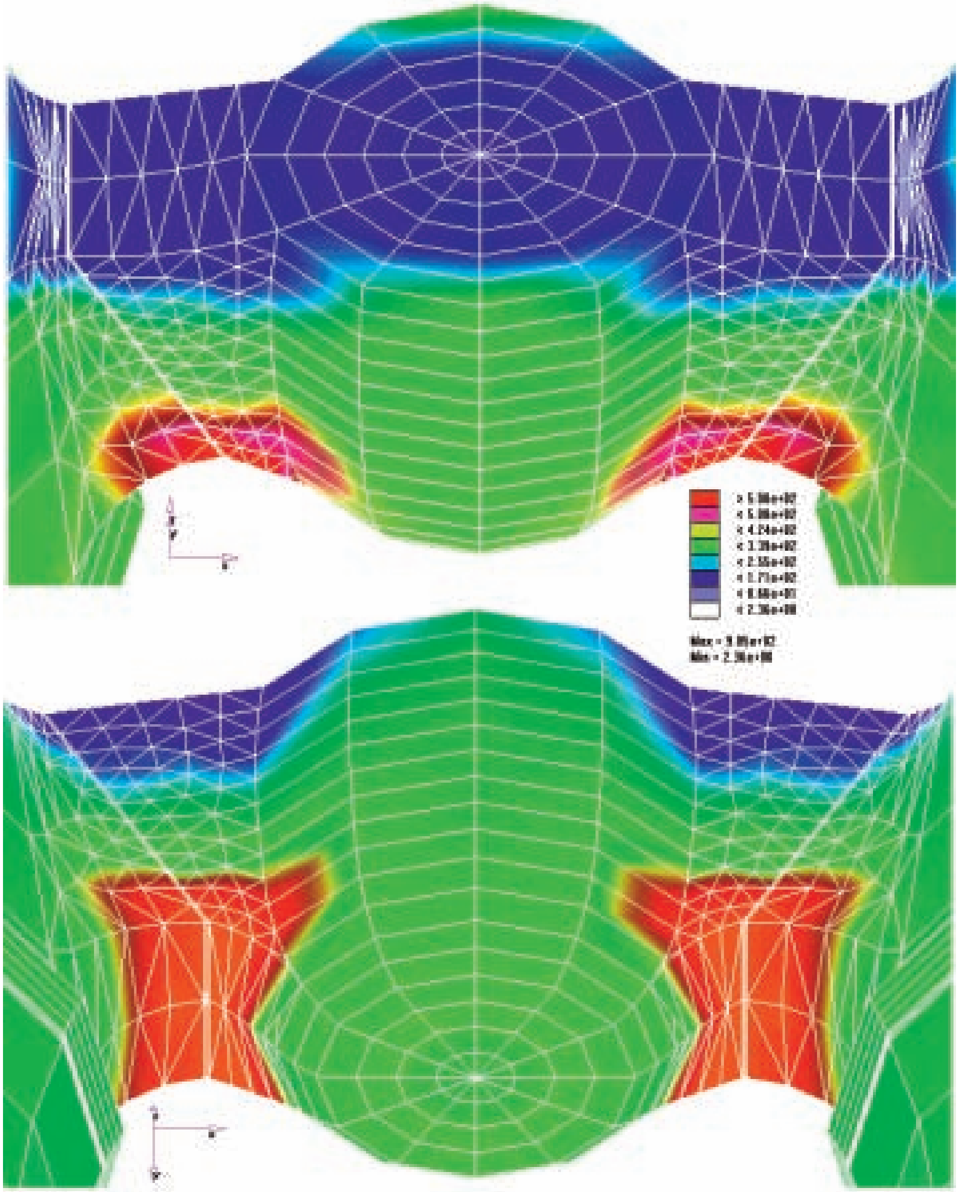

Fig. 9. Loading was uniaxial in direction and the normal stress component in the XX-axis was the major contributor to the stress patterns.

terial and continued laterally from the top of the junction across the occlusal surface of the pontic.

The design of the finite element models provided information about stress patterns experienced by these materials and the overall strength of the bridge. The distribution of stresses in the various areas of the finite element models can be determined by matching the colors in each element to the scale in the FEA illustrations (Fig. 7). The standard eight color system was used in each illustration. The red color always represented the higher Von Mises value and the blue the lowest value. In the bridge models, high von Mises stress values were concentrated in the loading region and the area directly beneath the lowest part of the coping/pontic joint extending into the copings, cement and teeth.

This typical stress pattern was observed in all bridge models. The high von Mises stress concentrations in all models extended from the pontic through the joint to the sides of the copings (Fig. 8). In the bridge models, the loading was uniaxial in direction and the normal stress component in the XX-axis was

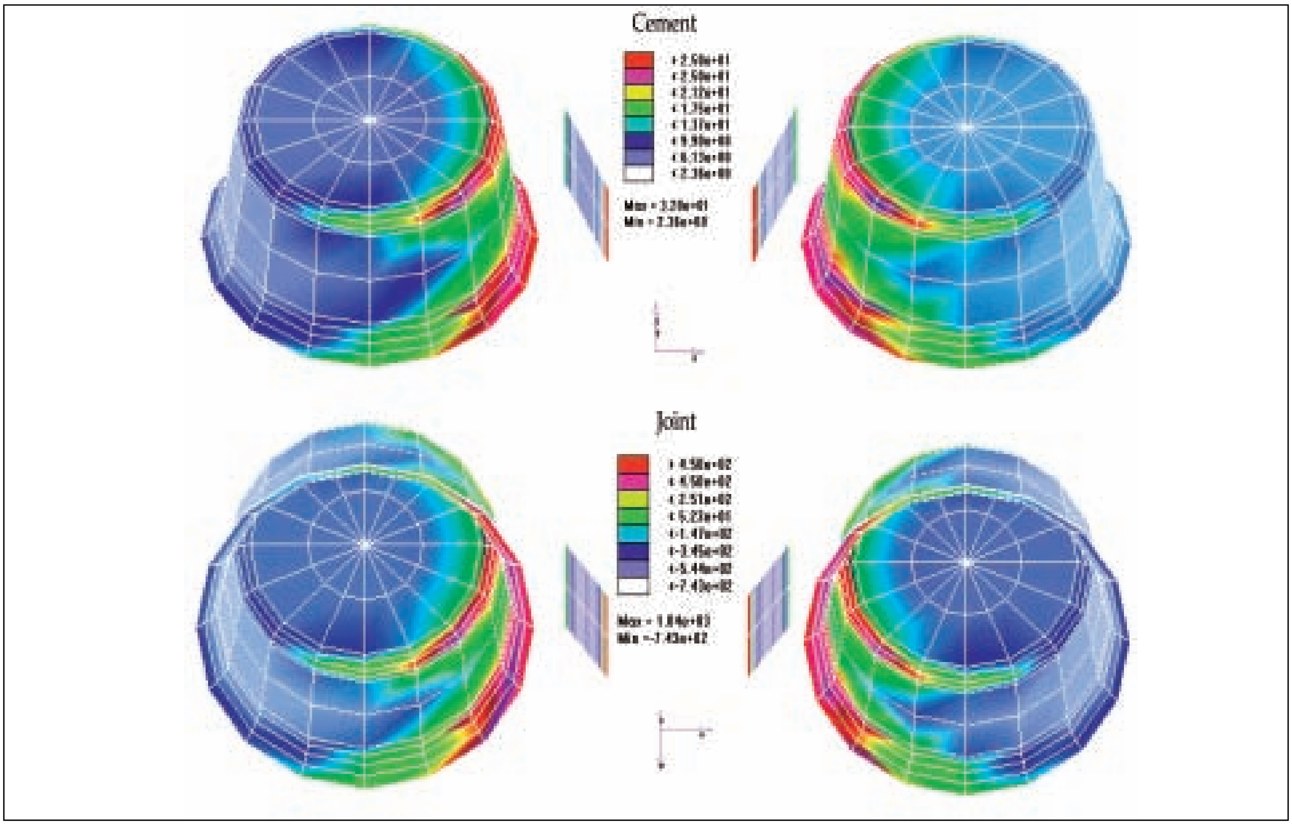

Fig. 10. The Von Mises stress distributions for the cement and joint.

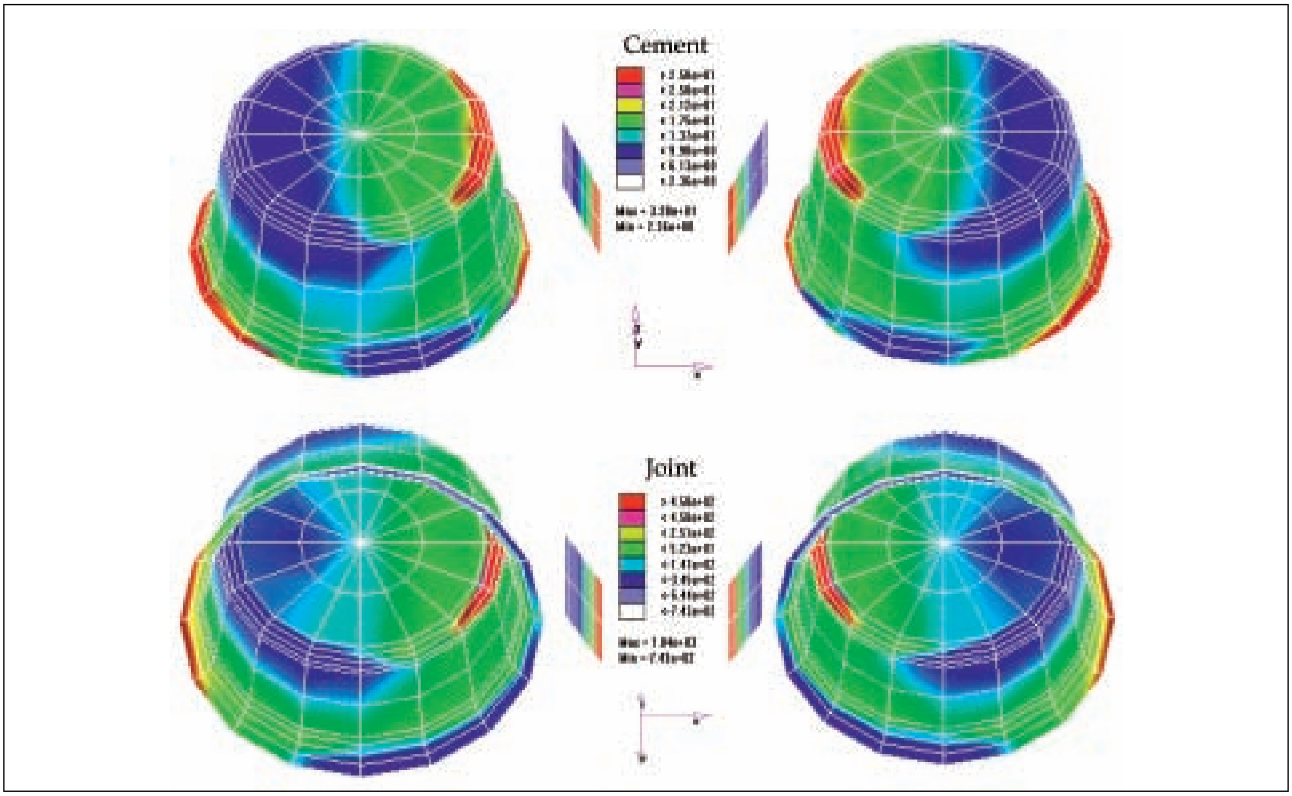

Fig. 11. The primary stress-XX distributions for the cement and joint.

Cement	Load to Fracture(N)	Load to Fracture(N)	Material	Load to Fracture(N)
Zinc Phosphate	382.20	872.95	Aluminum Oxide	3345.08
Fuji Plus	2844.22	820.56	Aluminum Oxide	2993.62
Panavia 21	3807.82	869.83	Aluminum Oxide	3323.07

Table 2. The load to fracture data (FEA) by model, cement, joint, and coping.

the major contributor to the stress patterns as compared to the other normal stress components YY and ZZ (Fig. 9).

Figure 10 illustrates the von Mises stress distribution and Figure 11 demonstrates the primary stress-XX distribution at the cement and the joint spaces of the Procera AllCeram test bridge models. Comparing the von Mises stress values of each element with the ultimate tensile strengths of the materials in Table 1 established the load to failure data. Table 2 demonstrates the load to fracture data (FEA) by model, cement, joint, and coping.

DISCUSSION

Under each of the cement conditions (Zinc Phosphate, Fuji Plus and Panavia 21) the FEA was conducted to determine the influence that a 3000 N load applied in the center of the pontic had on the overall structural response of the model. The distribution of stresses in the various areas of the finite element model can be determined by matching the colors in each element to the scale in the upper left hand corner of the FEA report. The standard eight color system was used in each report. The red color always represented the higher von Mises value and the blue the lowest value. In the bridge models, high von Mises stress values were concentrated in the loading region and the area directly beneath the lowest part of the coping/pontic junction extending into the copings, cement, and teeth.

This typical stress pattern was observed in all bridge models. The high von Mises stress concentrations in all models were extended from the pontic through the junction to the sides of the copings. In the bridge models, the loading was uniaxial in direction and the normal stress component in the XX-axis was the major contributor to the stress patterns as compared to the other normal stress components YY and ZZ.

Comparing the von Mises stress values of each element with the ultimate tensile strengths of the materials in Table 1 establishes if and when the load to failure occurred. Table 2 presents the loading amounts that generated ultimate tensile strength for each component and region of the three test models. Failure of any component or area in the bridge results in total failure of the bridge.

The three-dimensional nature of an all-ceramic bridge makes an accurate representation of the Stress State and the failure potential of a bridge very critical, which are strengths of FEA and the von Mises theory of analysis. Von Mises stress levels are a combination of normal stress components in the XX. YY, ZZ-axes, and Shear stress components XY, YZ, XZ-axes (Fig. 10). It becomes important to be sure that the major normal stress component contributing to the von Mises stress value is tensile stress and not compressive stress when evaluating a ceramic bridge. A positive normal stress component is recognized as a tensile stress while a negative value represents compressive stress.

In the FEA, the elastic behavior of each element was analyzed for its Von Mises stress value, as was its primary stress-XX value. In Fig. 11, the stress-XX distribution in the upper region of the pontic is compressive stress (a negative stress in the XX-axis), and the ceramic would not fail in this region because it was compressive in nature and not tensile stress in which case the ultimate tensile strength of the material would have been exceeded and failure would have occurred.

The stresses in the lower region of the pontic are positive and the areas are experiencing tensile stress. If the von Mises value of an element in Fig. 10 exceeded the ultimate tensile strength of the bridge materials, and that element in Fig. 11 was in an area of tensile stress, then failure would occur in these areas. The primary areas of interest with respect to potential failure of an all-ceramic bridge is the lower joint space between the coping and pontic. This was also demonstrated as a major failure site during the mechanical testing. Figures 10 and 11 illustrate the von Mises stress distribution and the primary stress-XX distribution in the cement and the joint spaces of the Procera test bridge model.

When the bridge was cemented with zinc phosphate, the load on the pontic produced a von Mises stress value in the cement in the area where the coping joints the pontic that exceeded the ultimate tensile strength of the zinc phosphate cement (4.5 MPa). It was determined that this failure could potentially occur at 382 N. However, failure of the bridge as a result of fracture of this small and thin layer of cement in this isolated area may not cause failure of the bridge itself. Failure of the bridge when cemented with zinc phosphate cement did not occur until the load reached 873 N.

When the bridge was cemented with Fuji Plus or Panavia 21, the first area to demonstrate a Von Mises stress value that exceeded the ultimate tensile strengths of any of the materials in the bridge was in the connection/fusing material at the lower border of the coping/pontic junction. For these cements, the load to failure that produced the von Mises stress values were 820 N for Fuji Plus and 869 N for Panavia 21.

In reporting the strength of an all-ceramic bridge, it is important to know the biting force of the human dentition in order to determine the strength requirements needed in a ceramic bridge in the oral environment. It has been reported by Craig & Powers (2002) that the average biting force on adult teeth in the first and second molars is 665 N, the premolars 450 N, and the incisors 220 N. However, they report that biting forces on a fixed partial denture (bridge) are generally much lower than forces with natural teeth.

Chewing forces are lower than biting forces. Chewing forces with a fixed bridge are about 40% of the biting force exerted by the patient on the natural tooth side. On the basis of the information reported by Craig & Powers (2002), it would seem appropriate to use the average biting force (665 N) in the molar area as the target strength for an all-ceramic bridge.

The mean load to fracture data for the Procera AllCeram test bridges from the mechanical tests results (697 ± 102 N) and FEA exceeded the target strength of 675 N. In the FEA, the load to fracture for the bridge cemented with zinc phosphate was 873 N, for Fuji Plus 820 N, and 870 N for Panavia 21. Therefore the Procera AllCeram bridge can be used in not only the anterior part of the mouth, but the posterior regions as well. It would appear that any of the three cements used in this study are acceptable agents for the Procera AllCeram bridge. However, in light of the potential for failure of the zinc phosphate cement with the all-ceramic test bridge one might not want to use this cementing agent with the Procera AllCeram bridge.

SUMMARY AND CONCLUSIONS

The patient therapy presented by the investigators clearly demonstrated successful treatment that satisfies the esthetic and functional needs of the three patients presented. Within the limitations of this study, the results of the mechanical test and the finite element analysis demonstrated that the Procera AllCeram bridge has the strength to withstand loads greater than 800 N when the bridge is cemented with Fuji Plus, or Panavia 21 which exceeds the target strength of 665 N suggested for all-ceramic fixed partial dentures.

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