the Journal of CONTEMPORARY DENTAL PRACTICE at www.thejcdp.com
Volume 9 Number 7 November 1, 2008

Fracture Resistance and Failure Location of Zirconium and Metallic Implant Abutments

Philippe Aramouni, DCD, CAGS, DEA, MScD;
Elie Zebouni, DCD, DMD, CAGS, MScD;
Esam Tashkandi, BDS, MSc, PhD;
Salam Dib, RDT; Ziad Salameh, DDS, MSc, PhD;
Khalid Almas, BDS, MSc, FRACDS, FDSRCS, DDPHRCS, FICD

Abstract

Aim: The purpose of this study was to evaluate the fracture resistance and failure location of single-tooth, implant-supported, all-ceramic restorations on different implant abutments subjected to a maximum load.

Methods and Materials: Forty Certain 3i implants and 20 ITI Straumann implants were used in this study in combination with 20 UCLA abutments, 20 ZiReal abutments, and 20 synOcta Ceramic Blanks to form three groups according to abutment type. All 60 abutments were prepared with standard measurements: a 1.0 mm deep chamfer, 2.0 mm of incisal reduction, and a total height of 7 mm. Sixty IPS Empress 2 full ceramic crowns were fabricated and cemented on each abutment with a resin cement. Static loading was simulated under maximum loading and fracture locations were noted.

Results: The mean load to failure data and standard deviations for the three groups were as follows: Group 1 (792.7 N ± 122.5) and Group 3 (793.6 ± 162.3) showed no significant difference in fracture resistance while the values for specimens in Group 2 (604 N ± 191.1) had the lowest mean value and were significantly lower. In Group 1, 16 crowns and four abutment fractures were reported, while in Group 3, 17 crowns and three abutments fractured. Group 2 actually showed three types of fractures. Two specimen fractures were located at the implant level, six with fractures occuring within the Empress 2 all-ceramic crown, and the remaining 12 failures were located at the abutment level.

Conclusion: Within the limitations of this laboratory study, the following conclusions were drawn:

1. The mean load-to-failure values for all three groups were well above the reported normal maximal incisal load range.
2. The load to failure for both the zirconium oxide (ZrO_2) abutments (ZiReal on 3i Certain implants and synOcta Ceramic Blanks on SLA ITI Straumann implants) had mean fracture loads of 792.7 N (+122.6) and 604.2 N (+191.2), respectively.
3. The zirconium oxide (ZrO_2) ZiReal and titanium (UCLA) abutments on the 3i Certain implants had statistically significantly higher fracture loads (792.7 N and 703.7 N, respectively) than those recorded for the 3i Ceramic Blank abutments on the SLA ITI Straumann implant (604.2 N).
4. The ITI Straumann Ceramic Blank abutments showed uniform fracture behavior. Fracture mainly emanated from the cervical buccal aspect of the abutment.

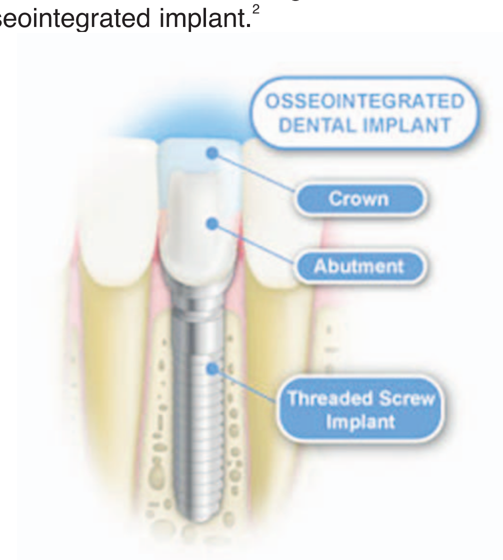
Clinical Significance: The three abutments tested showed they can withstand clinical loads above the normal range of mastication.

Keywords: Implant abutment, zirconium abutment, titanium abutment, fracture resistance

Citation: Aramouni P, Zebouni E, Tashkandi E, Dib S, Salameh Z, Almas K. Fracture Resistance and Failure Location of Zirconium and Metallic Implant Abutments. J Contemp Dent Pract 2008 November; (9)7:041-048.

Introduction

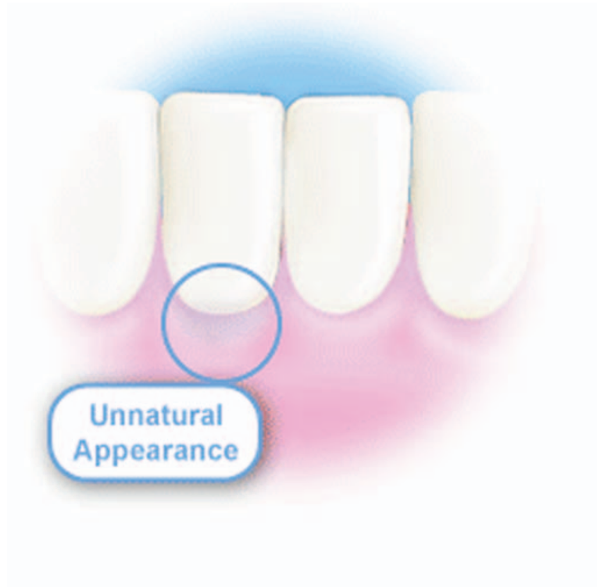
The use of osseointegrated dental implants with a history of confirmed success over time with long-term follow-up of patients has propelled dentistry into a new age of oral rehabilitation which has captured an even more global interest of clinicians and resarchers worldwide.[1] Biomechanical considerations such as bone to implant contact, threaded screw, distribution of vertical or lateral load, and the use of a shock absorbing material (acrylic resin, etc.) are recognized as being among the most important factors for the long-term success of the osseointegrated implant.[2]



Dental implants and abutments are usually fabricated from commercially pure titanium which has a well-documented biocompatibility and favorable mechanical properties.[3] Metal implant abutments are widely considered as the standard treatment option for implant supported restorations but they have inherent esthetic disadvantages. The increase in demand for a better esthetic outcome by clinicians and patients has contributed to the development of a new generation of more esthetic ceramic abutments.

One of the most challenging scenarios for a dentist is the restoration of a single-tooth edentulous space with an implant-supported crown and to achieve a successful outcome in terms of both osseointegration of the implant and the esthetic integration of the crown restoration in the dental arch.[3,4] Implant-supported single-tooth restorations are subject to the most exacting requirements such as optimal implant and superstructure positioning in areas of the dental arch requiring an optimal esthetic result, especially in patients with a high lip line.[5]

Despite the numerous improvements in the fabrication and design of metal abutments[6,7] there remains a risk of the metal components being visible when such abutments are used.



Even when placed subgingivally, a dull gray background may give the soft tissue an unnatural bluish appearance.[4,7] The presence of a gray gingival discoloration may be attributed to a thin gingival tissue thickness in the area around the abutment that is incapable of blocking reflective light from the metal abutment surface.[4,5] As a result, ceramic abutments were developed to achieve optimal mucogingival esthetics.[4,8] Currently, ceramic abutments are fabricated out of Y2O3–partially stabilized zirconia (ZrO_2) ceramic. This material has improved optical and mechanical properties and has demonstrated differences in its microstructure and mechanism due to their transformation toughening properties (tetragonal to monoclinic phase) against flaw propagation and how it fractures under a load.[9-12]

The purpose of this *in vitro* study was to evaluate the fracture resistance of single-tooth implant-supported restorations consisting of titanium and zirconium abutments along with all-ceramic restorations and to identify the location of the failure of these implant-all ceramic crown combinations. The null hypothesis tested was there is no difference in fracture resistance and fracture pattern between different types of abutments used.

Methods and Materials

As shown in Table 1, 40 3i Certain implants with a diameter of 4 mm and 13 mm in length and 20 SLA ITI Straumann implants with a diameter of 4.1 mm and a length of 13 mm were used in this study. The implants were divided into three groups according to the type of abutments used as follows:

- **Group 1:** Consisted of 20 3i Certain implants with 20 ZiReal abutments.
- **Group 2:** Consisted of 20 SLA ITI Straumann

Table 1. Test group configurations.

Group	Number	Implant	Abutments	Manufacturer
1	20	3i Certain	ZiReal	3i, Implant Innovation, Palm Beach, FL, USA
2	20	SLA ITI Straumann	synOcta Ceramic Blanks	3i, Implant Innovation, Palm Beach, FL, USA
3	20	3i Certain	UCLA	3i, Implant Innovation, Palm Beach, FL, USA

Figure 1. Prepared UCLA abutment.

Figure 2. Prepared ZiReal abutment.

Figure 3. Prepared and infiltrated Ceramic Blank abutment.

implants and 20 synOcta Ceramic Blanks abutments.

- **Group 3:** Consisted of 20 3i Certain implants and 20 UCLA abutments.

UCLA abutments were waxed and cast in high-noble alloy (Lodestar, Ivoclar Vivadent AG, Liechtenstein). The composition of the alloy is Au 51.5%, Pd 38.5%, In 8.5%, and Ga 1.5% (Figure 1).

The ZiReal abutments were prepared using diamond rotary cutting instruments (Bur No. 379EF016; Brasseler GmbH & Co KG, Lemgo, Germany) with water-spray application (Figure 2).

SynOcta abutments were placed on their corresponding ITI Straumann implants, hand tightened, and all 20 abutments were prepared using Straumann® CARES, Computer Aided Restoration Service technology (Institute Straumann AG, Straumann® Dental Implant System, Switzerland) (Figure 3).

All 60 abutments were prepared with standard measurements of 1.0 mm of chamfer depth, 2.0 mm of incisal reduction, and total preparation height of 7 mm. After preparation, the Ceramic Blank abutments were infiltrated to achieve maximum hardness following manufacturer's recommendation.

All 40 abutments (UCLA and ZiReal) were placed on their corresponding implants and tightened at 32 N following the manufacturer's instructions. All 20 SynOcta abutments were placed on their corresponding implant and abutment screws tightened at 32 N. Ceramic Blank abutments were then placed on top of each synOcta abutment and the abutment screws tightened at 20 N following the manufacturer's instructions. All 80 abutment screws were tightened using a contra angle torque driver (Contra Angle Torque Driver, 3i, Implant Innovation, Palm Beach, FL, USA).

Sixty lithia-disilicate-based Empress 2 pressed copings were constructed using a silicone index of the waxed coping for consistency between the samples. Frameworks were then layered with A3 shade Empress 2 porcelain then fired using another silicone index of a waxed central incisor with a height of 11 mm and width of 8 mm to assure similarity between specimens. All crowns were lightly sandblasted with 50 micron-size aluminum oxide particles then the fitting surfaces of the crowns were etched with 5% HF, IPS ceramic etching gel for 60 seconds, then rinsed, dried, and silanated with Monobond-S for 60 seconds. The crowns were then cemented on their corrresponding abutment using Multilink self-cure resin cement following the manufacturer's instructions. All materials used for this process were products of Ivoclar Vivadent, Schaan, Liechtenstein. Excess resin was removed using a regular size microbush (Microbrush, Microbrush International, Grafton, WI, USA), and the crowns were held in place using finger pressure until the cement was set. The 60 implant-abutment

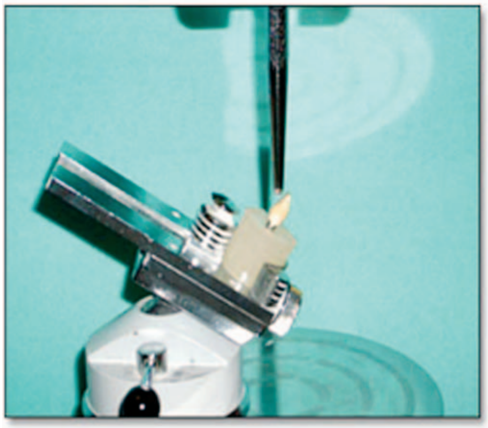


Figure 4. Test setup for maximum loading by means of an Instrom machine. Load was applied at 45 degrees to the long axis of the implant.

complex were embeded in a sample cup with Sampl-kwick resin (Buehler, Lake Bluff, IL, USA) and allowed to polymerize overnight.

An Instron 8500 universal loading machine (Instron, Norwood, MA, USA) was used for fracture testing. Each specimen was inserted into the holding device and a controlled load was applied using a stainless steel rod with a 2 mm tip-diameter at an angulation of 45° to the longitudinal axis of the tooth (Figure 4). Pressure from the rod tip was applied at a crosshead speed of 1 mm/min. All specimens were loaded until fracture, and the maximum breaking loads were recorded in Newtons (N). After mechanical failure, all fractured specimens were inspected using a stereomicroscope (Zeiss OpMi1, Zeiss, Oberkochen, Germany) at 10X magnification to locate the fracture area.

The data recorded was analyzed with one-way analysis of variance (ANOVA) and level of significance was set p=0.05.

Results

One way ANOVA revealed a significant difference between groups (p=0.00035). Group 1 (792.7 N ± 122.5) and group 3 (793.6 ± 162.3) have close mean values for fracture resistance, while Group 2 (604 N ± 191.1) had the lowest mean value (Table 2).

The Tukey Post Hoc test showed no significant difference between Group 1 and Group 3 (p=0.999), while Group 2 has significantly lower fracture resistance than Group 1 (p=0.0014) and Group 3 (p=00132) (Figure 5).

The fracture locations in the three groups is shown in Figure 6. Group 2 showed three types of fractures; two specimens fractured at the implant level, 12 at the abutment level, and six resulted in fracture of the crowns. In Group 1, 16 crown and four abutment fractures were reported. Group 3 had 17 crown and three abutment fractures. Descriptive statistics for fracture resistance and fracture location by groups are presented in Table 1 and in Figures 5 and 6.

Discussion

The mechanical quality of machined ZrO_2 ceramic is well known and is closely related to the cutting abilities of diamond tools.[13] This was confirmed by Yildirim et al.[14] who demonstrated no deterioration of Y2O3-partially-stabilized ZrO_2 ceramic abutments as a result of the milling process. Vigolo et al.[15] reported no changes

Table 2. Mean and standard deviation for all tested groups. Same alphabetical letter indicates no statistical significance between groups (p>0.05).

Group	Abutments	N	Mean	Standard Deviation	Significance (p<0.05)
1	ZiReal	20	792.7	122.5	A
2	synOcta Ceramic Blank	20	604.0	191.1	B
3	UCLA	20	793.6	162.3	AC

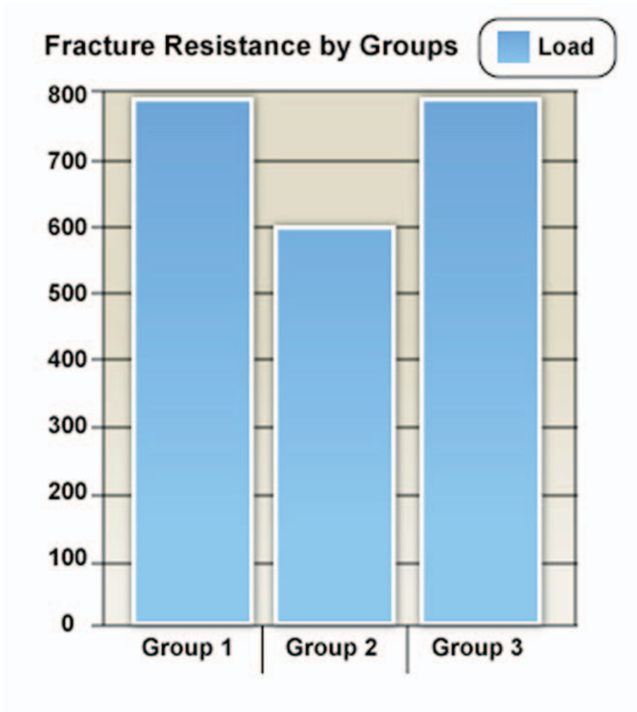


Figure 5. Fracture resistance of Groups 1, 2, and 3.

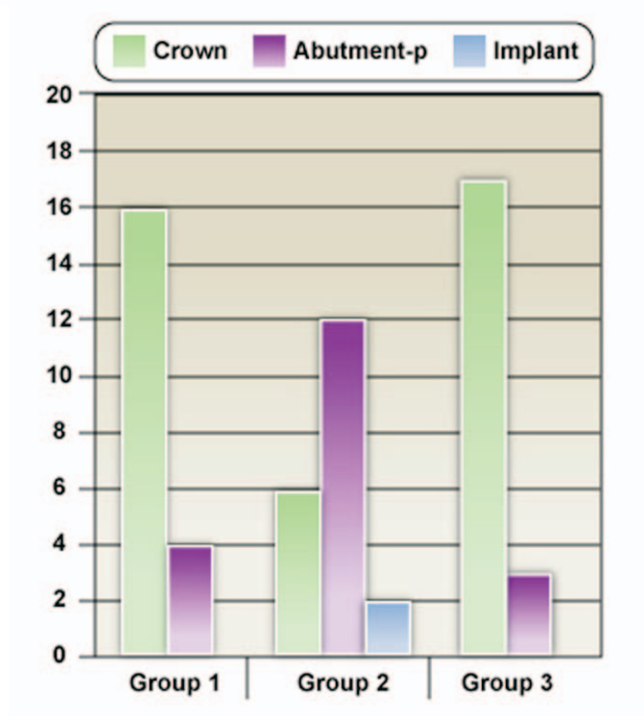


Figure 6. Fracture location of Groups 1, 2, and 3.

in the rotational freedom were noted following preparation of ZiReal abutments.

There are very few data reports available in the literature on Ceramic Blank abutments. Aramouni et al.[16] showed a statistically significant increase in rotational freedom of the Ceramic Blank over the synOcta counterpart after preparation and infiltration of the Ceramic Blank abutments with values being slightly higher than recommended by Binon and McHugh.[17]

The Empress 2 core ceramic is composed of crystalline and glass phases. The crystalline Empress 2 core consists of elongated lithia-disilicate crystals ($Li_2Si_2O_5$).[16] It has a flexural strength of 215 (±40) Mpa and a fracture toughness of 3.4 MPa.[17] It is considered the material of choice for the restorations in anterior teeth due to the favorable esthetic outcome made possible by replicating the translucency of natural teeth when used in combination with high-strength cores.[18] In a severe contact event surface cracks can propagate to cause fracture.[19] Different studies showed that crack propagation continued through the Empress 2 veneer-core interface.[16]

Occlusal forces were reported in the range of 90 to 370 N and 150 to 235 N in the anterior region.[20,21] Loads of this magnitude were safely tolerated by ZrO_2-ceramic abutments in the present study which had a mean load-bearing capability of 792.7 N and a mean load-bearing of 604.1 N by Ceramic Blank abutments. While the ZiReal abutment load fracture resistance was comparable to the UCLA abutment, the values of the ITI Straumann Ceramic Blank were lower than the fracture resistance values measured for the UCLA abutment. It is therefore plausible to expect the combination of implant superstructures (ZiReal) to have a load resistance similar to those supported by a titanium abutment.

Fracture analysis revealed the UCLA and ZiReal abutments had similar fracture locations. Crown fracture with an intact abutment under loads greater than what was observed in the mouth occurred in 80% and 85% of the specimens in Groups 1 and 3, respectively. In Group 2 only 30% had crown fracture with an intact abutment but two implant fractures were noted. The majority of the fracture locations in this group were observed within the abutment (60%), and the fatal crack emanated primarily from the cervical part of the Ceramic Blank abutments in the buccal area. This part of the all-ceramic implant restoration presumably represents the area of the highest torque and stress concentrations caused by levering effects. Further investigations are needed to improve the strength of the cervical portion of ITI Straumann Ceramic Blank abutments.

The results of this *in vitro* evaluation of all-ceramic prosthetic implant superstructures are promising. Long-term *in vivo* evaluation, however, is mandatory to provide a definitive prognosis of the clinical performance.

Conclusion

Within the limitations of this *in vitro* study, the following conclusions were drawn:

1. The mean load-to-failure values for all three groups were well above the reported normal maximal incisal load range.
2. The load to failure for both the zirconium oxide (ZrO_2) abutments (ZiReal on 3i Certain implants and synOcta Ceramic Blanks on SLA ITI Straumann implants) had mean fracture loads of 792.7 N (+122.6) and 604.2 N (+191.2), respectively.
3. The zirconium oxide (ZrO_2) ZiReal and titanium (UCLA) abutments on the 3i Certain implants had statistically significantly higher fracture loads (792.7 N and 703.7 N, respectively) than those recorded for the 3i Ceramic Blank abutments on the SLA ITI Straumann implant (604.2 N).
4. The ITI Straumann Ceramic Blank abutments showed uniform fracture behavior. Fracture mainly emanated from the cervical buccal aspect of the abutment.

Clinical Significance

The three abutments tested showed they can withstand clinical loads above the normal range of mastication.

References

1. Adell R, Lekholm U, Rockler B, Branemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981; 10:387-416.
2. Shakak R. Biomechanical considerations in osseointegrated prostheses. J Prosthet Dent 1983; 1983;843-848
3. Att W, Kurun S, Gerds T, Strub JR. Fracture resistance of single-tooth implant all-ceramic restorations: An *in vitro* study. J Prosthet Dent 2006; 95:111-6.
4. Glauser R, Sailer L, Wohlwend A, Studer S, Schibli M, Scharer P. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004; 17(3):285-90.
5. Yildirim M, Edelhoff D, Hanisch O, Spiekermann H. Ceramic abutments–a new era in achieving optimal esthetics in implant dentistry. Int J Periodontics Restorative Dent. 2000; 20(1):81-91.
6. Jemt T. Modified single and short span restorations supported by osseointegrated fixtures in the partially edentulous jaw. J Prosthet Dent 1986; 55:243-257.
7. Tripodakis AP, Strub JR, Kappert HF, Witkowski S. Strength and mode of failure of single implant all-ceramic abutment restorations under static load. Int J Prosthodont. 1995; 8(3):265-72.
8. Binon PP. Implants and components: entering the new millennium. Int J Oral Maxillofac Implants 2000;15(1):76-94.
9. Christel P, Meunier A, Heller M, Torre JP, Peille CN. Mechanical properties and short term *in vivo* evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989; 23:45-61.
10. Andersson M, Oden A. A new all-ceramic crown. A dense-sintered, high-purity alumina coping with porcelain. Acta Odontol Scand, 1993; 51(1):59-64.
11. Mante FK, Brantley WA, Dhuru VB, Ziebert GJ. Fracture toughness of high alumina core dental ceramics: the effect of water and artificial saliva. Int J Prosthodont, 1993; 6:546-52.
12. Seghi RR, Sorensen JA. Relative flexural strength of six new ceramic materials. Int J Prosthodont 1995; 8:239-46.
13. Luthardt RG, Holzhüter M, Sandkuhl O, Herold V, Schnapp JD, Kuhlisch E, Walter M. Reliability and properties of ground Y-TZP-zirconia ceramics. J Dent Res, 2002; 8:487-91.
14. Yildirim M, Fischer H, Marx R, Edelhoff D. *In vivo* fracture resistance of implant-supported all-ceramic restorations. J Prosthet Dent 2003; 4:325-31.

15. Vigolo P, Fonzi F, Majzoub Z, Cordioli G. An *in vitro* evaluation of ZiReal abutments with hexagonal connection: in original state and following abutment preparation. Int J Oral Maxillofac Implants 2005; 20:108-14.
16. Taskonak B, Sertgoz A. Two-year clinical evaluation of lithia-disilicate-based all-ceramic crowns and fixed partial dentures. Dent Mater 2006; 22:1008-1013.
17. Della Bona A, Mecholsky JJ, Anusavice KJ. Fracture behavior of lithia-disilicate- and leucite-based ceramics. Dent Mater 2004; 20:956-62.
18. Wohlwend A, Scharer P. The Empress rechnique: a new technique for the fabrication of full ceramic crowns, inlays, and veneers. Quintessenz Zahntech 1990; 16:966-78.
19. Zhang Y, Lawn B. Competing damage modes in all-ceramic crowns: fatigue and lifetime. Key Eng Mater 2005; 17:697-700.
20. Haraldson T, Carlsson GE, Ingervall B. Functional state, bite force and postural muscle activity in patients with osseointegrated oral implant bridges. Acta Odontol Scand, 1979; 34:195-206.
21. Paphangkorakit J, Osborn JW. The effect of pressure on a maximum incisal bite force in man. Arch Oral Biol 1997; 42:11-7.

About the Authors

Philippe Aramouni, DCD, CAGS, DEA, MscD

Dr. Aramouni is an Assistant Professor in the Department of Fixed Prosthodontics and Occlusion at Saint-Joseph University in Beirut, Lebanon.

e-mail: philippearamouni@gmail.com

Elie Zebouni, DCD, DMD, CAGS, MScD

Dr. Zebouni is a Professor in the Department of Fixed Prosthodontics and Occlusion at Saint-Joseph University in Beirut, Lebanon.

e-mail: elie.zebouni@usj.edu.lb

Esam Tashkandi, BDS, MSc, PhD

Dr. Tashkandi is an Assistant Professor in the Department of Prosthetic Dental Sciences of the College of Dentistry at King Saud University in Riyadh, Saudi Arabia.

e-mail: esamtash@ksu.edu.sa

Salam Dib, RDT

Mr. Dib is the Director of the Dental Laboratory at King Faysal Specialist Hospital and Research Center in Riyadh, Saudi Arabia.

e-mail: salamd@hotmail.com

Ziad Salameh, DDS, MSc, PhD

Dr. Salameh is a Specialist in Prosthodontics in the Department of Prosthetic Dental Sciences of the College of Dentistry at King Saud University in Riyadh, Saudi Arabia. He is also an Assistant Professor in the Research Department of the School of Dentistry at the Lebanese University in Beirut, Lebanon.

e-mail: ziadplanet@yahoo.com

Khalid Almas, BDS, MSc, FRACDS, FDSRCS, DDPHRCS, FICD

Dr. Almas is an Associate Professor and the Clinic Director in the Division of Periodontology of the School of Dental Medicine at the University of Connecticut in Farmington, CT, USA. Dr. Almas is also the Director of the International Fellowship program in Advanced Periodontics in the Division of Periodontology.

e-mail: khalidalmas@yahoo.com or almas@uchc.edu