Eur. J. Prosthodont. Rest. Dent., Vol.16, No. 3, pp 109-115
Printed in Great Britain

Vertical Marginal and Internal Adaptation of All-ceramic Copings made by CAD/CAM Technology.

M.A. AL-Rabab'ah*, T.V. Macfarlane† and J.F. McCord‡

Abstract - *Vertical marginal and internal adaptation scores of all-ceramic copings made by Computer aided manufacturing / computer aided design (CAD/CAM) were investigated. Scores were compared between Procera all-ceram copings, Cerec-in-lab copings and IPS Empress 2 copings. A stereomicroscope was used (at x45) to measure vertical marginal scores and also used to measure internal adaptation after dies were sectioned. Procera copings showed better vertical marginal adaptations on dies and master preparation and internal adaptation on dies than both IPS Empress 2 and Cerec- in-lab copings. All copings appeared to produce vertical marginal and internal adaptation scores well within the maximum clinically acceptable gaps.*

KEY WORDS: Adaptation, All-ceramic, Copings, CAD/CAM, Stereomicroscope

INTRODUCTION

The use of all-ceramic restorations has gained rapid momentum in the last few years, as has the introduction of systems aiding the manufacturing of all-ceramic restorations. The development of tooth-coloured restorative materials was aimed to develop aesthetic replacement of missing tooth structure that will meet the functional, mechanical and biological requirements of the oral cavity.

Driven by the superior aesthetic matching to natural teeth that ceramics have, researchers continued the quest to develop all-ceramic systems that are comparable to metal ceramic restorations in terms of strength and adaptation. Multiple approaches were tried with varying success rates. McLean and Hughes[1] proposed the use of an alumina porcelain jacket crown for anterior teeth. However, this system was far removed from being a real replacement for metal ceramic crowns, even for anterior teeth[2, 3].

During early 1980s, Mormann and Brandestini introduced the Cerec system. This was the first system to implement a CAD/CAM technology in the production of a ceramic dental restoration. Restorations made with the earlier versions of this system, limited to inlays, onlays, veneers and partial crowns, faced major criticism over marginal adaptation[4]. Further extensive development of this system led to much improvement with the introduction of Cerec 3D system for intraoral use and Cerec-in-lab. The former is mainly designed for the production of inlays, onlays, veneers and crowns using a digital "impression" taken directly from the prepared tooth. The latter, introduced in the year 2002, enables the production of a wider variety of restorations including anterior and posterior fixed bridges copings. Those restorations could be machined from blocks made of feldspathic porcelain, glass ceramics, alumina and zirconia ceramics. The intra oral version of Cerec has enjoyed an extensive research; a systematic review by Martin and Jedynakiewicz[5] showed a 97.4% success rate of Cerec inlays over a mean of 4.2 years with failures attributed to fracture of the ceramic inlay, supporting structure, postoperative hypersensitivity and wear of the lute interface.

The Procera all ceram system was first described in 1993 by Anderson and Odén[6] . It enables the production of high purity (99%) densely sintered alumina copings through computerised scanning in dental laboratories and centralised processing in one of two central labs in Sweden and USA. This system has gained popularity ever since its commercial release mainly as a result of its reported higher strength values and superior marginal adaptation[7].

IPS Empress 2 is a lithium disilicate material. It succeeded the original IPS Empress 1 and was commercialised by the manufacturer as a system that combines aesthetic characteristics comparable to tooth structure and enough strength to enable reliable construction and placement of 3 unit fixed prostheses in anterior and premolar areas[8]. This system utilised a lost wax technique similar to that used in cast metal restorations.

Good marginal and internal adaptations are the key success criteria. Wider gaps are associated with marginal caries[9], gingival complications[10] and decreased strength[11].

Studies to compare marginal and internal adaptation of Procera all-ceram copings to Mark II copings made by the Cerec-in-lab method are lacking.

The aim of this study, therefore, was to investigate the vertical marginal and internal adaptation of two all - ceramic copings made by two CAD/CAM techniques; namely Procera all-ceram and Mark II copings made by Cerec-in-lab and to compare them to copings made by a conventional method.

MATERIALS AND METHODS

A Kavo acrylic maxillary central incisor tooth was prepared to act as a master preparation. The preparation had a 1 mm

* BDS, MFD RCS Ire
† BSc PhD
‡ BDS, DDS, FDS, DRD RCS (Ed), FDS RCS (Eng), FDS RCPS, FCDS (HK) C.Biol. MI Biol

rounded shoulder finish line and was 7mm in height with a 10° total taper. A 0.5 mm diameter semicircular notch was prepared at the mid-labial line and immediately below the finish line to help in the reproducibility of seating[12].

The master preparation was duplicated using a silicone model duplicating material from which 45 hard dental stone dies were poured. These dies were examined under magnification x1.75 to ensure that there were no air bubbles or scratches on the prepared part, especially in the region of the finish line. Only those dies which were bubble-free and scratch-free were accepted. The 45 stone dies were then grouped randomly into 3 groups of 15 each to fabricate the following copings: Cerec-in-lab Copings, Procera All-Ceram copings and IPS-Empress 2 copings.

The copings were sent to a dental laboratory certified in making the three types of coping. The IPS Empress2 copings were fabricated in compliance with the manufacturer's instructions. A wax-up pattern was made for each die to obtain a uniform 0.8 mm coping thickness. Lithium di silicate ingots were then pressed in an EP500 furnace. The copings were then retrieved by divesting, and cleaned by Invex liquid.

The dies allocated for Procera copings were mounted in the holder of the Procera scanner. Scanning of each die using the contact probe transferred the shape into the computer screen. The dental technician then designed the coping. The first step was to confirm the finish line on the screen. The coping design was then finished and copings ordered from Procera. The internal cement thickness is predetermined at 50 µ for Procera. The resultant copings of 0.4 mm thickness were then transferred back to the local dental laboratory. No veneering steps were performed.

The Cerec copings were made from Mark II blanks using the Cerec-in-Lab machine. The dies were first coated with a scan film liquid. The dies were scanned using a laser scanner installed in the Cerec-in-lab unit. The dental technician designed the coping using the Cerec software installed within the Cerec-in-lab machine. The film thickness was set to 70 µ. The copings were then milled using the attached milling machine. The milling time was around 15 minutes per coping. Also as in the case of Procera and IPS-Empress2 copings no veneering was carried out for these copings.

The copings were received and examined visually and under a magnifying lens x1.75 for marginal adaptation both on the respective dies and on the master preparations. Some copings did not demonstrate an optimum clinical fit when first inspected on the master preparation. Optimum clinical fit was defined according to the criteria set by Ryge and Snyder[13] to determine the clinical fit of cemented restorations. These criteria stated that a sharp probe should not penetrate into the space between the tooth and the restoration and there should be no visible evidence of a crevice along the margin. Fit Checker was used to aid in identifying spots that interfered with complete seating. These spots were relieved using a high speed small diamond bur under water coolant. Maximum care was practised to limit the cut to the interferences; cutting did not involve any marginal points.

The vertical marginal adaptation readings were measured under a stereomicroscope provided with a camera EMZ-TR and x45 magnification. Each coping was first fitted on the corresponding die and then onto the master preparation without cementation and held in place by means of slight tightening by a hinged Hoffman bottom bar which was used to prevent rebounding of the copings (Figure 1). This in turn was attached to a straight headpiece and clamped by a stand. The apparatus was set so that the die-coping interface is parallel to the specimen stage of the microscope. With the light of the microscope perpendicular to the interface, any shadow areas were easily identified and the angulation was corrected if needed. Five images of the coping-die interface and another five images of coping-master preparation interface were made by rotating the headpiece in a clockwise direction five times. The mid-labial notch was not used to register any measurement. Figure 2 shows an example of the images.

Using the Sigma scan pro 5 software, 10 measurements were made from each image to yield a total of 50 measurements for each coping on their respective dies and another 50 measurements on the master preparation. The copings were then seated under digital pressure on their respective die with a small amount of RelyX™ cement to prevent uplifting movement of the crown during setting of resin material. The copings and dies were then embedded in resin. A period of 24 hours was allowed to ensure setting of the resin material. The resin replicas were then sectioned using a low speed diamond wheel saw in a labio-lingual direction. The section line was first drawn to divide the resin block into 2 halves mesio-distally by running through the med labial notch described earlier and the sectioning stage modified accordingly. The 2 sections were then mounted into the EMZ-TR stereomicroscope. 5 images were taken and a total of 20 readings for each specimen were retrieved. The shoulder area of the finish line was not used for measurements. Figure 3 shows a sample image of internal adaptation.

All statistical analysis was performed using SPSS (SPSS 14.0 for Windows, SPSS Inc., 2005). Descriptive statistics and ANOVA were used for statistical data analysis. The Kolmogorov-Sminrov test was used to test for normality.

RESULTS

The repeatability of the measurements was determined by randomly selecting a specimen, and the resultant images of it and performing 50 measurements repeatedly for 30 times following a similar procedure to that described by Suliman et al.[14]. The standard deviation was 1.49 µ and the 95% confidence limit of the measurements repeatability was (0.94, 2.04µ).

Optimal fit on the master preparation which was checked visually and with the aid of a magnifying lens revealed that 3 copings (20%) of Cerec-in-lab, 4 (27%) of the IPS-Empress 2 and one (7%) of Procera did not show an optimal fit and required the use of fit checker and slight internal grinding with a high speed hand piece and water coolant. However, there was no statistically significant difference between 3 groups (Chi-square test Exact P=0.488).

For each of 5 images, a mean out of 10 measurements was calculated for each coping. Following that, the mean measurement out of five images was calculated and used for the analysis. The data obtained in this way for marginal adaptation on both the dies and the master preparation was then tested for normality using normal probability plot and the one-sample Kolmogorov-Sminrov test. There was

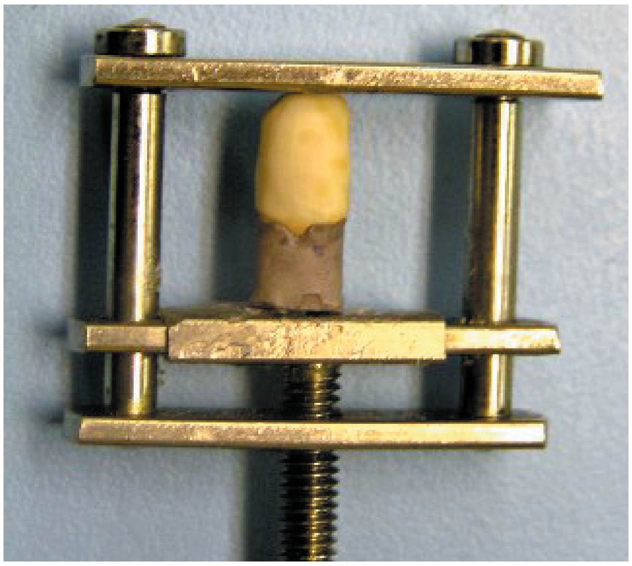

Figure 1. *A coping over a die attached to a hinged Hoffman bottom bar to prevent rebounding of coping.*

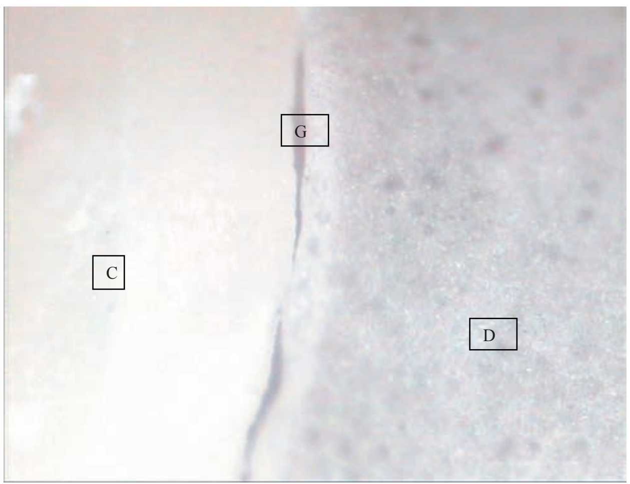

Figure 2. *A sample image that was used in the determination of marginal gap width, C: Coping, D: Die and G: gap.*

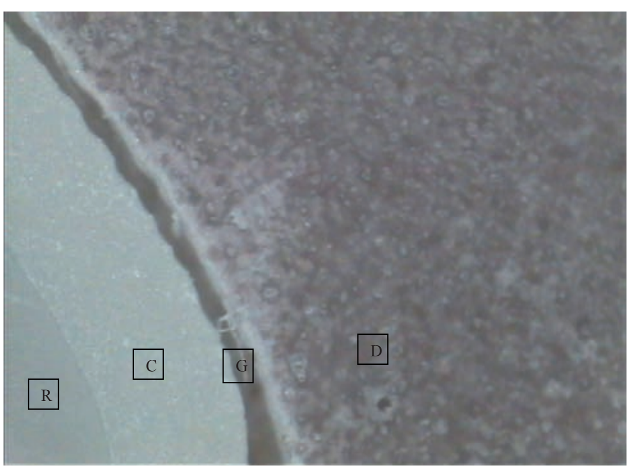

Figure 3. *A sample image that was used to measure the internal adaptation on the dies, C: coping, D: Die, G: Gap and R: Resin replica.*

no reason to reject the null hypothesis of normality and it was assumed that the data were normally distributed.

A one way ANOVA test with the Bonferroni post hoc test showed that Procera copings had smaller marginal gaps (mean 26.1µ, SD 11.1) compared to both Cerec copings (mean 44.6µ, SD 12.9) (P=0.002) and IPS –Empress copings (56.5µ, SD 16.2) (P<0.001). The difference between Cerec copings and IPS-Empress copings was not statistically significant (P=0.063) (Table 1, Figure 4).

The marginal adaptation scores were then measured for the copings on the master preparation without cementation. Procera scored also the least and significantly different mean marginal opening readings (43.0 µ, SD 14.5) from Cerec copings (64.6µ, SD 21.4) (P=0.006) and IPS-Empress2 (85.3µ, SD 17.6) (P<0.001). There was a statistically significant difference between Cerec and IPS-Empress2 (P=0.009) (Table 1, Figure 5).

For internal adaptation, Cerec-in-lab scored a mean of (166.1µ, SD 30.8); IPS-Empress 2 scored a mean of (117.9µ, SD 22.5); while Procera scored the lowest with mean (65.5µ, SD 10.0). One-way ANOVA showed statistically significant difference between the three systems (P<0.001) for all combinations. Figure 6 depicts the major findings of the internal adaptation of the three systems:

Liner regression (R^2=0.56) showed that the marginal adaptation (MA) on the master preparation could be predicted by using this equation:

MA-master preparation (µ) = 43.054µ+ 0.482×MA-die (µ) +15.004×Type2-12.649×Type3

For example, for coping type 3 and a die measurement of 40.04µ, the predicted master preparation is 49.71µ, while for coping type 1 and a die measurement of 73.90µ, the predicted master preparation is 78.7µ. Figure 7 shows the scatter plot to illustrate the linear relationship between marginal adaptation on the master preparation and marginal adaptation on the die of each coping.

DISCUSSION

In this study, marginal and internal adaptations were measured by a stereomicroscope for Cerec-in-lab, IPS Empress 2 and Procera copings. The IPS Empress 2 served as the conventional control group. Three previous studies reported the marginal adaptation of zirconia ceramics produced by the Cerec in lab system. One was with a chamfer preparation of a molar tooth[15], the second was for 3 unit bridges[16] and the third was for anterior four unit frameworks[17]. It would appear that no study has been carried out for feldspathic porcelain in this lab version of Cerec. The laboratory production of feldspathic porcelain might be necessary in cases of uncommon shades of the prepared or adjacent teeth where the multi-chromatic Trilux blanks are not good enough either to mask the underlying structure or match adjacent teeth and, finally, where customised characterisation and staining are needed.

The master preparation followed the basic principles of all ceramic crown preparation. The rounded shoulder preparation was used to standardise the construction procedures for all three systems. Although the manufacturer of Procera recommends use of chamfer burs to produce a chamfer finish line, a study published in 2004[12] showed no signifi-

Table 1. *Mean and standard deviation in μ of the marginal adaptation of Cerec-in-lab, IPS-Empress2 and Procera copings on their respective dies, master preparation and internal adaptation*

Type	*N*	*Die*		*Master preparation*		*Internal adaptation*	
		Mean	SD	Mean	SD	Mean	SD
Cerec	15	44.63	12.89	64.57	21.37	166.06	30.75
IPS-Empress 2	15	56.50	16.19	85.29	17.58	117.92	22.51
Procera	15	26.12	11.06	42.99	14.54	65.49	9.99

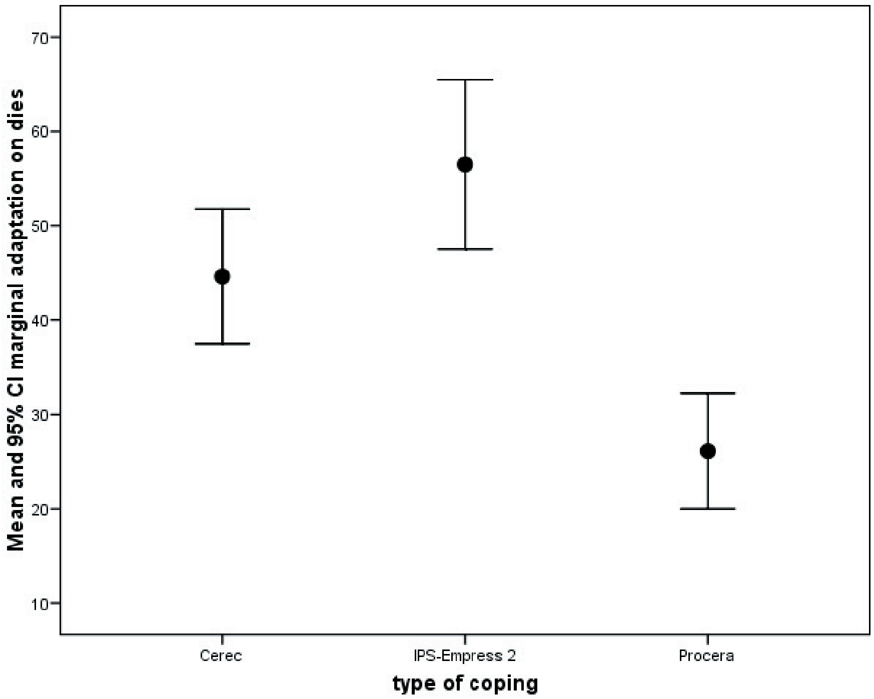

Figure 4. *Vertical marginal gaps of Cerec-in-lab, IPS Empress2 and Procera copings on dies.*

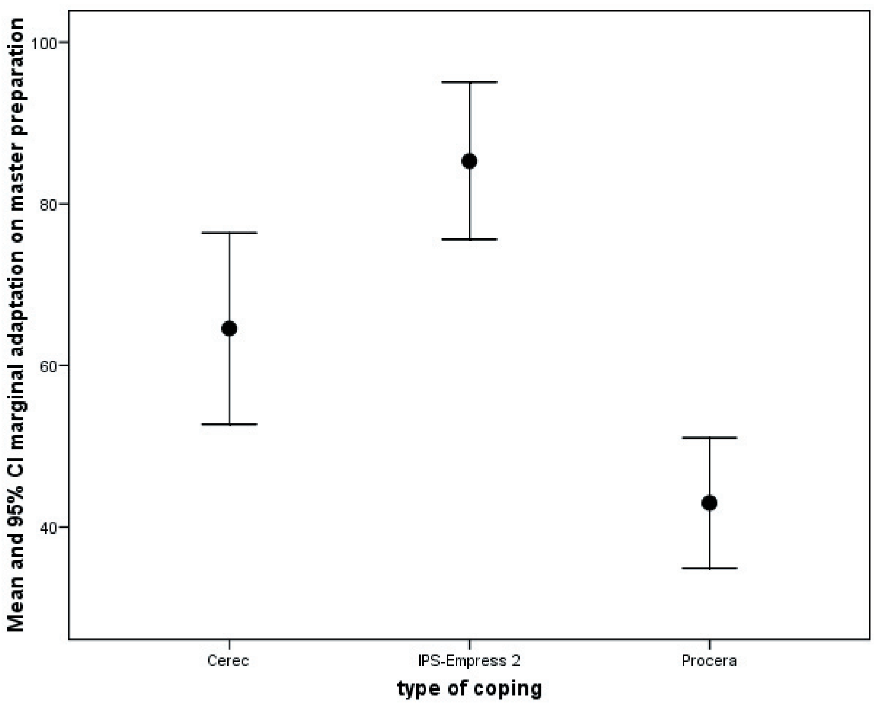

Figure 5. *Vertical marginal gaps of Cerec-in-lab, IPS Empress2 and Procera copings on master preparation.*

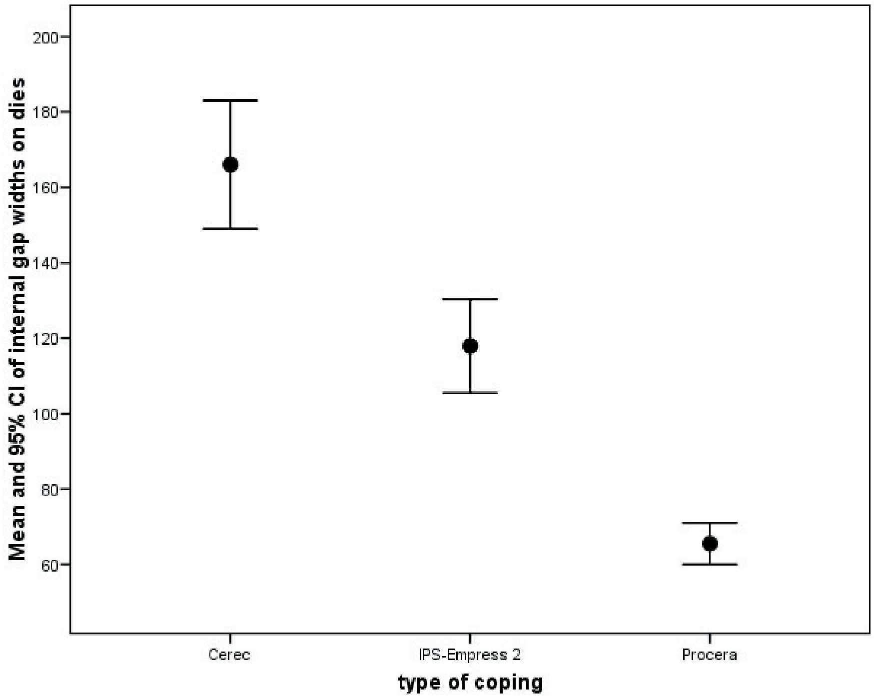

Figure 6. *Internal gaps of Cerec-in-lab, IPS Empress2 and Procera copings on dies.*

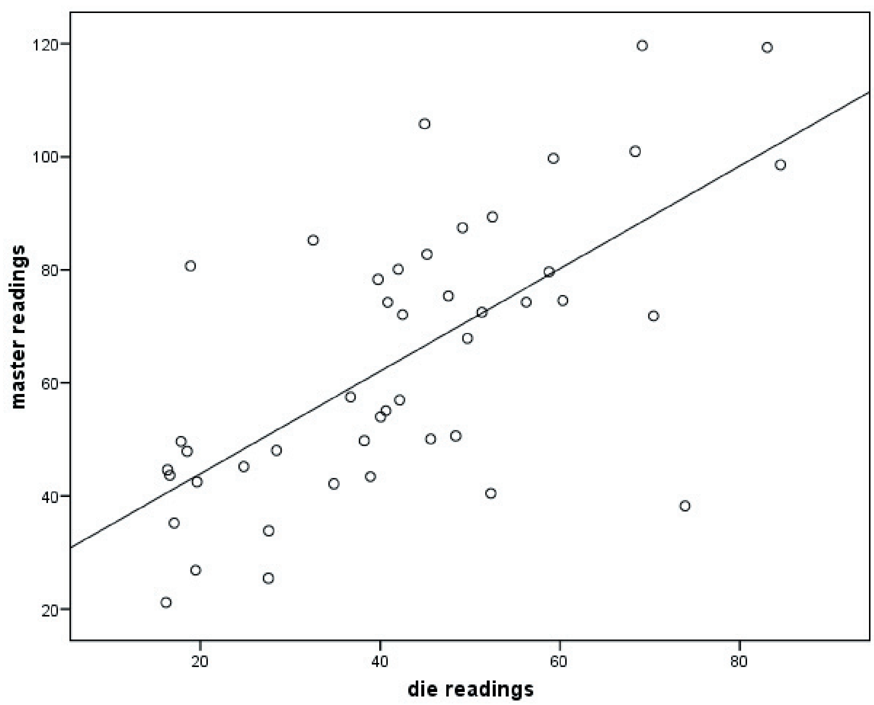

Figure 7. *Scatterplot of linear relationship between marginal adaptation on dies and master preparation of each coping.*

cant difference in the marginal adaptation between the two finish line modalities. The use of a 0.5 mm midlabial notch was aimed to facilitate reproducible seating and was not used for marginal adaptation measurements.

Fit checker is a well established aid to determine areas of interferences of full seating. Although this system was originally used for metal and metal ceramic restorations, where it is easier to discern the metal from the white fit checker, this material has also been advocated for all ceramic restorations mixed with a colour modifier[18]. A black coloured variant is also being commercialised by the same company now for all- ceramic restorations.

For the lack of optimal fit part of the study there was not enough power to detect statistically significant difference between the 3 groups. When the results of the correct study for lack of fit were used to calculate the sample size which would have 80% power to detect statistically significant (0.05 level of significance) difference between the three groups, it was found that the sample size required was 67 in each group. Clearly it would be difficult to pursuit the study on this large scale owing to the high laboratory costs.

The use of a stereomicroscope in measuring marginal adaptation is widely practised and has been used in many studies[19, 20]. It enables the production of an image perpendicular to the tooth-coping interface. The measurements of the marginal adaptation of the copings on the respective dies were felt essential for two reasons; first, in the clinical situation, intraoral quantification of marginal opening on the prepared tooth is difficult and the adaptation on the die can give a good indication about the adaptation on the prepared tooth. Secondly, and for statistical / scientific reasons, it was performed to try to plot the relationship between the marginal adaptation on the dies and on the master preparation. A positive linear relationship between the marginal adaptations on dies and on master preparation was found, thus it is recommended that crown or coping showing poor fit on the die should not be tried intra-orally.

The decision to measure the vertical marginal adaptation on the copings rather than on the completed crowns was taken for the following reasons:

i. First, in most ceramic systems, the core material (the coping or substructure frame work) has higher strength than the veneering material; it is important then that the coping material is properly adapted to the margins where higher and unfavourable stresses are concentrated.

ii. Second, veneering procedures depend mainly on the individual expertise of the technician. Although in the same study this could be managed by veneering all coping systems by the same technician direct comparison with other studies would be difficult given the difference in methodologies.

iii. Additionally, some studies showed no significant alteration to the marginal adaptation with veneering or porcelain build-up procedures[14, 21, 22].

The use of 50 marginal readings followed the recommendations by Groten et al[23]. It was concluded in that study that there was no relevant impact on the quality of the results when the marginal adaptation measurements were reduced from 230 to 50 per specimen, however the chance of getting results of clinical relevance with less than 50 measurements per crown is doubtful[23]. To have the 50 readings done in order or randomly was not a crucial factor according to Groten et al[23].

In the present study, Procera alumina copings showed better marginal and internal adaptation than Cerec-in-lab copings. This result is consistent with the results showed by Denisen et al[24] who compared the marginal fit of CICERO,Cerec and Procera copings. The Cerec copings were produced by the intra oral cerec-2 unit. Procera showed also better marginal adaptation in comparison with IPS-Empress 2 copings. This is in agreement with results found by Quintas et al[12] who found that Procera copings presented the lowest mean value of vertical marginal opening before and after cementation regardless any combination among all finish lines and luting cements used . In a study published in 1997, Suleiman et al. reported better marginal adaptation with the original IPS-Empress (Leucite reinforced) in comparison with Procera[14] . Bindl and Mörmann[15] reported better marginal adaptation of Procera copings in molar crowns in comparison to IPS Empress 2 and Zirconia Cerec- in-lab crowns but found wider internal gap with Procera than with the other two systems in a study of marginal and internal adaptation of 6 ceramic systems. The increased cement relief of the Cerec copings (70 µm) compared to Procera copings (50 µm) and IPS Empress 2 might partially explain the increase in internal gaps noted with the Cerec copings. Nakamura et al showed that increasing the cement relief of the Cerec crowns from 10 µ to 50 provided better marginal adaptation25. In a different study Nakamura et al showed that actual internal cement thickness for Decsy CAD/CAM system increased from 85-88 µ when the computer cement relief was set to 15 µ to 126-138 µ when the computer cement relief was set to 50 µ26. Wu and Wilson27 proposed 40 µm and 30 µm as the optimal cement space for the cementation of brass crowns with phosphate and resin cements respectively.

Comparing both Cerec-in-lab and IPS Empress 2 copings in this study showed that Cerec scored better marginal adaptation on the master preparation. There was, however, no significant difference between the two systems when copings were examined for marginal adaptation on the respective dies, although it should be mentioned that the P value was very near to the 0.05 significant level(actual P=0.062) in preference of Cerec copings. When examined for internal adaptation, IPS Empress showed better internal adaptation than Cerec-in-lab copings.

The better marginal adaptation of Procera copings found in this study could be explained by the fact that Procera manufacturing technique involves fewer steps to be carried out by the technician; most steps are computer controlled, and thus reproducible procedures can be assured. No die spacer is used in the manufacturing process of the Procera and a 50µm cement width is predetermined in the computerised production of the copings.

Cerec-in-lab showed also better marginal adaptation than IPS-Empress 2 copings. Cerec-in-lab utilises the computerised production procedure as in Procera but the dies are sprayed with a spray scan to enhance the photo digitisation using the laser scanner installed in the Cerec-in-lab unit. This might explain why Cerec-in-lab copings showed higher internal gaps than both Procera and IPS Empress 2.

The laboratory procedures of IPS-Empress 2 involved the use of 2 layers die spacer. Said to be 9-11 µ by the manufacturer, the reproducibility of the die spacer thickness has been long questioned[28]. The procedure also involved the fabrication of a wax pattern. The use of a cleaning liquid containing 1% Hydrofluoric acid and air abrasion of 100µ alumina oxides particles may also have eroded some of the porcelain internal structure in a microscopic level. Furthermore these laboratory procedures require human intervention.

The smaller internal gaps that IPS Empress showed over Cerec could be explained by the fact that the spray used in the Cerec-in-lab procedure might not have set immediately after application and pooled under gravity forces to the areas around the cingulum area and on the same height on the labial surface where larger gaps where noticed.

All three systems showed marginal adaptations that are well within the clinically acceptable limits. There is, however, some controversy about the maximum limit. McLean and Fraunhofer[29] proposed the value of 120 µm depending on *in vivo* observations. Tuntiprawon and Wilson[11] found that the strength of all ceramic (Inceram) crowns deteriorated rapidly if the cement thickness was more than 70 µ. In the latter study, the width was determined by the number of applications of die spacer and the width of the platinum foil used as spacer. The problem of deducing the cement thickness and marginal adaptation from the number of applications of die spacer has previously been discussed[28].

CONCLUSIONS

It can be concluded that CAD/CAM technology can produce ceramic restorations that have a comparable vertical marginal and internal adaptation scores to that produced by the conventional methods.

MANUFACTURERS' DETAILS:

- Kavo teeth, Kavo Dental Ltd, Buckinghamshire, UK
- Gemini model duplicating material, Bracon Dental Laboratories, Sussex UK
- Moon Stone, John White, Halifax, UK
- Luxo magnifying bench light, Luxo UK ltd, London, UK
- IPS Empress 2 ingots , Ivoclar vivadent, Schann, Liechtenstein
- EP500 furnace, Ivoclar vivadent, Schann, Liechtenstein
- Invex liquid, Ivoclar vivadent, Schann, Liechtenstein
- Procera all-ceram, Nobel Biocare, Stockholm Sweden
- Scan film liquid, Dentatec Scan Spray ,Sirona Dental Company, Bensheim, Germany
- Mark II banks, Vitazahn Fabrik, Bad sackingen, Germany
- Cerec-in-lab, Sirona Dental Company, Bensheim, Germany
- Fit Checker, GC Company, Tokyo, Japan
- EMZ-TR Stereomicroscope, Meiji Techno, Tokyo Japan
- Sigma scan pro 5, Aspire software Int, Ashburn, VA USA
- Hoffman bottom bar, Scientific Laboratory Supplies ltd, Manchester UK
- RelyX™, cement 3M™/ESPE™, Peterbrough,UK
- Araldite and Araldite hardener, Ciba specialty chemicals, Duxford-Cambridge ,UK
- Diamond wheel saw, Southern Bay Tech.inc S.B.T, San Clemente, California, USA
- SPSS, Version 13.0, SPSS Inc., Chicago, IL, USA.

ADDRESS FOR CORRESPONDENCE

5 Dunworth Street, Manchester, M14 7WH. UK.
E-mail: Mohammad.Al-rabab'ah@postgrad.manchester.ac.uk

REFERENCES

1. McLean, J.W., Hughes, T.H. The reinforcement of dental porcelain with ceramic oxides.*Br Dent J*.1965;**119**:251-267.
2. Marquis, P. Optimising the Strength of all ceramic jacket crown. In Dental ceramics: Proceedings of the 4th international sypiosum in ceramics; Preston J, editor. 1985; Chicago: Quintesence; 1985.
3. O'Brien, W.J.Magnesia ceramic jacket crowns. *Dent Clin North Am*.1985;**29**:719-723.
4. Hickel, R., Dasch, W., Mehl, A., Kremers, L.CAD/CAM--fillings of the future? *Int. Dent J*.1997;**47**:247-258.
5. Martin, N., Jedynakiewicz, N.M.Clinical performance of CEREC ceramic inlays: a systematic review. *Dent Mater*.1999;**15**:54-61.
6. Andersson, M., Oden, A.A new all-ceramic crown. A dense-sintered, high-purity alumina coping with porcelain. *Acta Odontol Scand*.1993;**51**:59-64.
7. Brunton, P.A., Smith, P., McCord, J.F., Wilson, N.H.Procera all-ceramic crowns: a new approach to an old problem? *Br Dent J*.1999;**186**:430-434.
8. Holand, W., Schweiger, M., Frank, M., Rheinberger, V.A comparison of the microstructure and properties of the IPS Empress 2 and the IPS Empress glass-ceramics. *J Biomed Mater Res*.2000;**53**:297-303.
9. Felton, D.A., Kanoy, B.E., Bayne, S.C., Wirthman, G.P.Effect of in vivo crown margin discrepancies on periodontal health. *J Prosthet Dent*.1991;**65**:357-364.
10. Lang, N.P., Kiel, R.A., Anderhalden, K.Clinical and microbiological effects of subgingival restorations with overhanging or clinically perfect margins. *J Clin Periodontol*.1983;**10**:563-578.
11. Tuntiprawon, M., Wilson, P.R. The effect of cement thickness on the fracture strength of all-ceramic crowns. *Aust Dent J*.1995;**40**:17-21.
12. Quintas, A.F., Oliveira, F., Bottino, M.A.Vertical marginal discrepancy of ceramic copings with different ceramic materials, finish lines, and luting agents: an in vitro evaluation. *J Prosthet Dent*.2004;**92**:250-257.
13. Ryge, G., Snyder, M. Evaluating the clinical quality of restorations. *J Am Dent* Assoc.1973;**87**:369-377.
14. Sulaiman, F., Chai, J., Jameson, L.M., Wozniak, W.T.A comparison of the marginal fit of In-Ceram, IPS Empress, and Procera crowns. *Int J Prosthodont*.1997;**10**:478-484.
15. Bindl, A., Mormann, W. Marginal and internal fit of all-ceramic CAD/CAM crown- copings on chamfer preparations.*J Oral Rehabil*.2005;**32**:441-447.
16. Reich, S., Wichmann, M., Nkenke, E., Proeschel, P.Clinical fit of all-ceramic three-unit fixed partial dentures, generated with three different CAD/CAM systems. *Eur J Oral Sci*.2005;**113**:174-179.
17. Komine, F., Gerds, T., Witkowski, S., Strub, J.R. Influence of framework configuration on the marginal adaptation of zirconium dioxide ceramic anterior four-unit frameworks. *Acta Odontol Scand*.2005;**63**:361-366.
18. Keys, L.G. An alternate method of verifying the seating of all-ceramic restorations. *J Prosthet Dent*.2002;**87**:411.
19. Goldin, E.B., Boyd, N.W., 3rd, Goldstein, G.R., Hittelman, E.L., Thompson, V.P.Marginal fit of leucite-glass pressable ceramic restorations and ceramic-pressed-to-metal restorations.J *Prosthet Dent*.2005;**93**:143-147.
20. Cho, L., Song, H., Koak, J., Heo, S.Marginal accuracy and fracture strength of ceromer/fiber-reinforced composite crowns: effect of variations in preparation design.*J Prosthet Dent*.2002;**88**:388-395.
21. Groten, M., Girthofer, S., Probster, L.Marginal fit consistency of copy-milled all-ceramic crowns during fabrication by light and scanning electron microscopic analysis in vitro.*J Oral Rehabil*.1997;**24**:871-881.
22. Shearer, B., Gough, M.B., Setchell, D.J.Influence of marginal configuration and porcelain addition on the fit of In-Ceram crowns.*Biomaterials*.1996;**17**:1891-1895.
23. Groten, M., Axmann, D., Probster, L., Weber, H.Determination of the minimum number of marginal gap measurements required for practical in-vitro testing.*J Prosthet Dent*.2000;**83**:40-49.
24. Denissen, H., Dozic, A., van der Zel, J., van Waas, M.Marginal fit and short-term clinical performance of porcelain-veneered CICERO, CEREC, and Procera onlays.*J Prosthet Dent*.2000;**84**:506-513.
25. Nakamura, T., Dei, N., Kojima, T., Wakabayashi, K. Marginal and internal fit of Cerec 3 CAD/CAM all-ceramic crowns. *Int J Prosthodont*.2003;**16**:244-248.
26. Nakamura, T., Tanaka, H., Kinuta, S., et al. In vitro study on marginal and internal fit of CAD/CAM all-ceramic crowns. *Dent Mater J*.2005;**24**:456-459.
27. Wu, J.C., Wilson, P.R. Optimal cement space for resin luting cements. *Int J Prosthodont*.1994;**7**:209-215.
28. Campagni, W.V., Preston, J.D., Reisbick, M.H. Measurement of paint-on die spacers used for casting relief. *J Prosthet Dent*.1982;**47**:606-611.
29. McLean, J.W., von Fraunhofer, J.A. The estimation of cement film thickness by an in vivo technique. *Br Dent J*.1971;**131**:107-111.