ORIGINAL RESEARCH

A Comparative Evaluation of Marginal Fit of Crowns Fabricated by Three All Ceramic CAD-CAM Systems Using Their Respective Scanners - *An in vitro study*

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Abstract

Aim: To evaluate and compare the marginal fit of crowns fabricated by three All Ceramic CAD-CAM systems using their respective scanners.Objectives:1.To evaluate the marginal fit of All Ceramic crowns fabricated using Contact scanner-Procera system. 2. To evaluate the marginal fit of All Ceramic crowns fabricated using Optical scanner-Lava system. 3.To evaluate the marginal fit of All Ceramic crowns fabricated using Laser scanner-Cercon system . 4.To compare the marginal fit of crowns fabricated by three All Ceramic CAD-CAM systems using their respective scanner-Contact scanner, Optical scanner and Laser scanner. Materials and Methods:5 crowns fabricated with Contact scanner- Procera system (Group I), 5 crowns fabricated with Optical scanner-Lava system (Group II), 5 crowns fabricated with Laser scanner-Cercon system(Group III). The marginal fit would be evaluated at two stages for each group:A- Pre-veneering stage (coping) B-Post-veneering stage (crown). Results: The mean value of marginal gap with Group IA was 27.48 +2.63 and IB was 26.13+ 0.85 and that of Group IIA was 23.27 + 0.99 and IIB 19.22 + 0.88. The mean value of marginal gap of Group IIIA was 32.80 + 2.46 and IIIB was 28.77 + 1.94. Conclusion: The marginal gap was maximum with Group III and minimum with group II amongst the three used systems. The mean marginal gap values of subgroup B were less than subgroup A.

Key Words: All Ceramic CAD-CAM systems, Contact scanner- Procera system, Optical scanner-Lava system, Laser scanner-Cercon system.

Introduction

Prosthodontists have been confronted with functional and esthetic rehabilitation of missing teeth or part of the tooth[1]. Various materials have been used for restoration but the introduction of ceramics have revolutionised this.

In response to increasing patient awareness of esthetic dental rehabilitation, the preference today is for All-Ceramic restorations, which show superior biocompatibility and similar light characteristics to the natural tooth[2]. All ceramic restorations have developed rapidly, their source being the first porcelain jacket crown fabricated by Lund in 1903. The passage of time saw emergence of newer ceramics and development in dental materials and computer science led to the invention of CAD-CAM technology[3].

A major determinant of the quality of fixed prosthodontics is close internal and marginal fit of the crowns. The fit of dental restoration depends on quality throughout the entire manufacturing process[4]. The final result is affected by multiple factors, such as preparation of the tooth, the impression, production of a dental cast, fabrication of the restoration that is the coping and the veneering method, chairside adjustment of the restoration and finally, the material and method used for cementation[5].

There are various methods of making ceramic copings. The traditional way of producing a ceramic restoration was by using the lost-wax technique. Newer techniques which have been introduced are CAD-CAM systems and copy milling units. With the CAD-CAM systems, restorations can be produced more quickly and the automation allows consistent quality[6]. CAD-CAM systems were applied to dentistry in the early 1980s.There are various methods available for digitalizing the geometry of a body into a digital form[7]. A dental surface digitalization device or scanner can be based on non-contact or contact methods where three-dimensional images are captured. Thereafter the images are transformed into a three dimensional construction file and transferred to the milling device[8].

A contact method is based on touch-probe scanning, where a sapphire stylus is in contact with the surface of the die and is moved around while registering points from the topography of the surface. The stylus is further attached to a computer, makes a blue print of the die[9]. A non-contact method uses optical systems which can be based on methods: laser and white light. Non-contact method using white light fringe pattern

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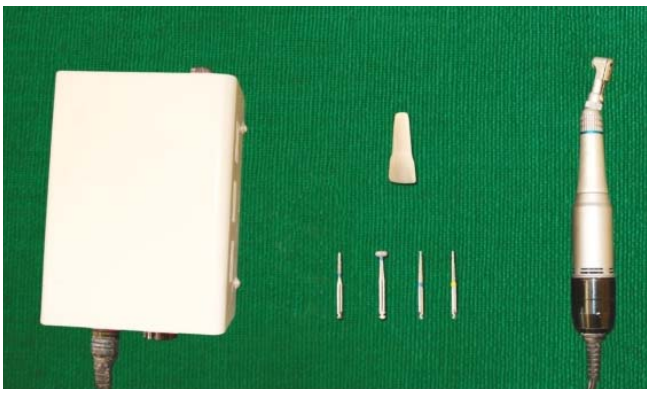


Fig.1 Materials used for master die preparation

Fig.2 Contact scanner – Procera system

Fig.3 Optical scanner - Lava system

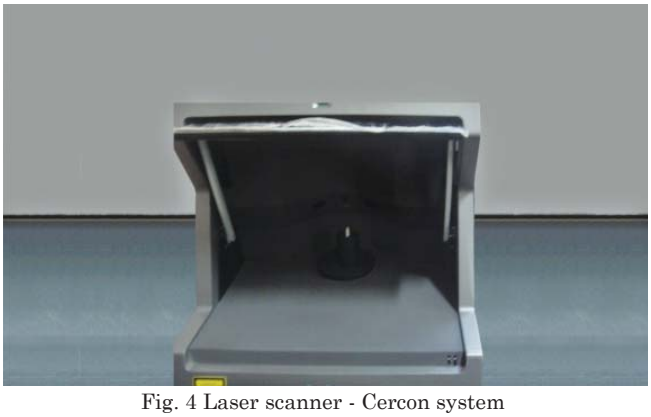


Fig. 4 Laser scanner - Cercon system

reads and measures approximately about 1,20,000 points and digitalizes it to a 3-D soft image[10].

Non-contact method using laser scanner projects the laser onto the object and digital camera registers the information. The data is digitalized and converted by the integrated computer unit using complex software algorithms. This digitalization method makes it possible to digitalize negative shapes as well as soft or brittle materials[11].

With the improvement in the ceramic technology, ceramic with better esthetics and strength have been made available. The marginal fit is one of the most important factor towards the success of a restoration[12]. Thus, how the scanning device affects the marginal fit of the restoration needs to be studied. Therefore, this study was planned to evaluate the marginal fit of All-Ceramic crowns fabricated using CAD-CAM technology with their respective scanning methods.

Materials and Instruments used for Master Die Preparation (Fig 1):

i) Typhodont Right Maxillary Central Incisor

ii) Micro-motor with contra-angle hand piece

iii)Diamond Points-

Torpedo, Wheel shaped, Tapered and Finishing points

A. Materials, Instruments and Equipments used for Fabrication of Copings by the three all Ceramic CAD-CAM Systems:

1. ALL CERAMIC COPING FABRICATED USING CONTACT SCANNER OF THE PROCERA SYSTEM

   a) Materials used for coping fabrication:

   Composition:

   Zirconium oxide (99.9%)

   Other oxide

   Colouring oxides

   b) Equipment (Fig 2):

   Contact scanner - Procera system

   Computer-controlled design digital scanning device consisting of a sapphire stylus, a rotating platform that is attached to a computer, which via modem sends the scanned image.

2. ALL CERAMIC COPING FABRICATED USING OPTICAL SCANNER OF THE LAVA SYSTEM

   a) Materials used for coping fabrication:

   Composition:

   Zirconium oxide

   Other oxide

   Colouring agents

   b) Equipment (Fig 3):

   Optical scanner - Lava system

   Optical scanner uses white light fringe pattern, reads and measures approximately about 1,20,000 points and digitalizes it to a 3-D soft image[10]

Fig.5 Ceramic veneering material

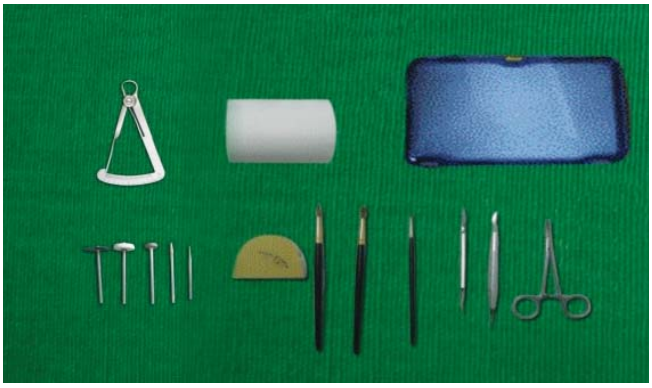


Fig.6 Instruments used for application and finishing of veneering ceramic

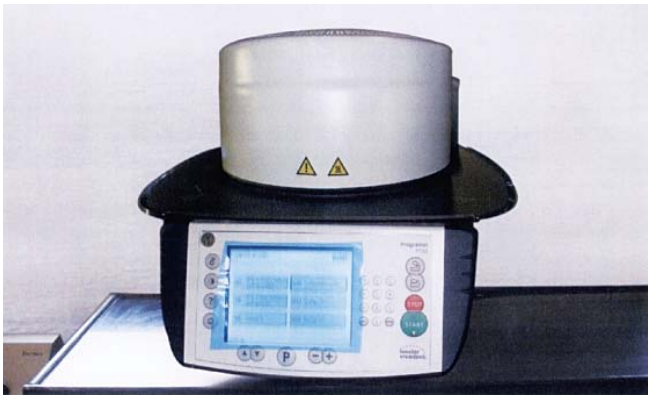


Fig.7 Ceramic furnace

Fig.8 Equipment used for evaluation of marginal fit

3. ALL CERAMIC COPING FABRICATED USING LASER SCANNER OF THE CERCON SYSTEM

a) Materials used for coping fabrication:

Composition : Yttria-stabilized tetragonal zirconia 5%, Hafnium oxide 2%, Other oxides 1%

b) Equipment (Fig 4):

Laser scanner - Cercon system

Laser scanner projects the laser onto the object and digital camera registers the information. The data is digitalized and converted by the integrated computer unit using complex software algorithms. This digitalization method makes it possible to digitalize negative shapes as well as soft or brittle materials[11].

B. MATERIALS, INSTRUMENTS AND EQUIPMENTS USED FOR VENEERING CERAMIC:

i) Ceramic material (Fig 5):
- Nobel Rondo Ceramics
- Lava Ceram Ceramics
- Cercon Ceram Ceramics

ii) Instruments (Fig 6):
- Sable paintbrushes
- Artery forceps
- Mixing pad and spatula
- Tissue paper

iii) Equipment (Fig 7):

Ceramic Furnace

C.EQUIPMENTS USED FOR EVALUATION OF MARGINAL FIT:

i) Optical Microscope (100X magnification) with Image Analyzer (Olympus GX51) (fig 8).

The software analyzes the image of the marginal gap and with the help of an in-built grid, the gap can be measured in micrometers and the results were noted.

Method

The study was divided in the following steps :

A. FABRICATION OF MASTER DIE(Fig 9,10):

Replica of the right maxillary central incisor was selected and prepared to receive a full veneer all-ceramic restoration following the biomechanical principles of tooth preparation, to achieve a master die. A rounded shoulder gingival finishing line was prepared. Care was taken not to leave any sharp line angles and point angles.

On the circumference of the root, eight equidistance points were marked from where the marginal gap of the respective sample would be measured.

Fig.9 Preparation of the typhodont Tooth

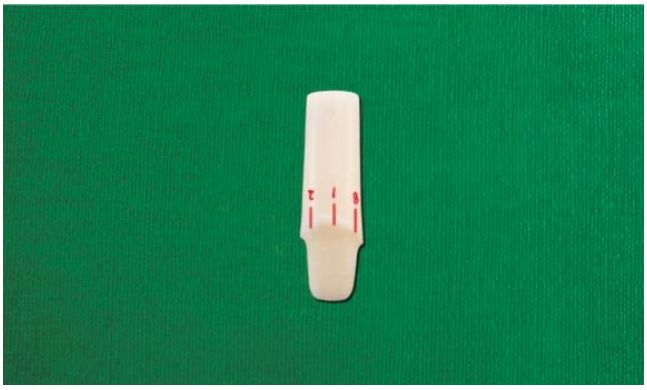


Fig.10 Master die with markings

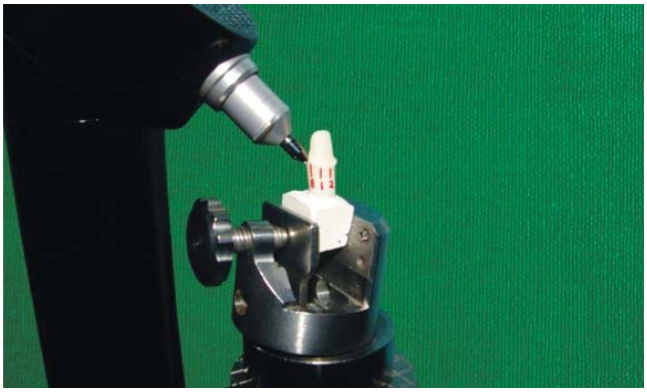


Fig.11 Scanning of master die with Contact scanner- Procera system

Fig.12 Two dimensional scanned image of the master die- Procera system

Fig.13 Computer generation of the All Ceramic CAD-CAM coping - Procera

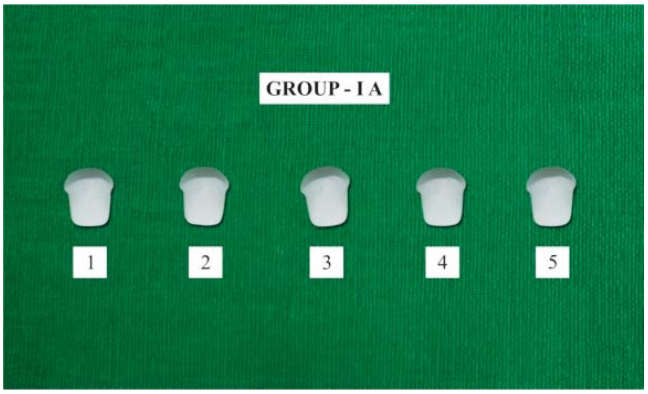


Fig.14 All Ceramic CAD-CAM Copings - Procera system

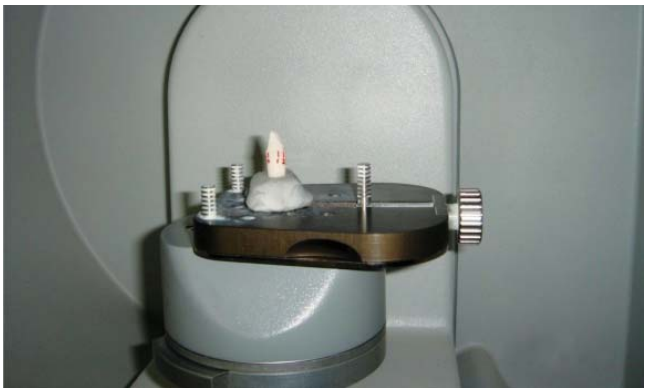


Fig15 Scanning of master die with the master die- Lava system

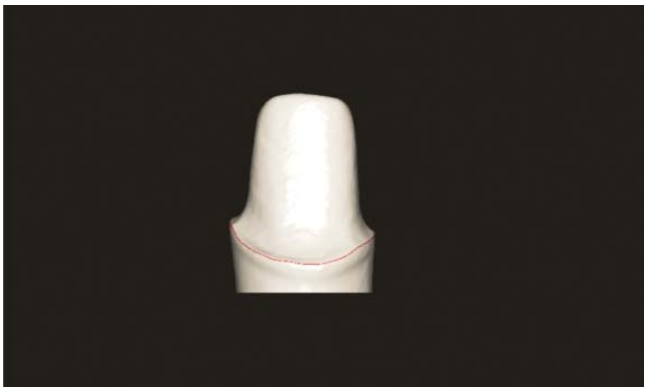


Fig16 Two dimensional scanned image of Optical scanner- Lava system

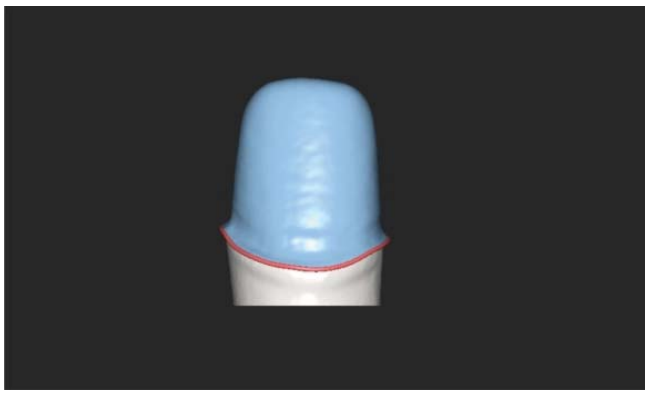


Fig.17 Computer generation of the All Ceramic CAD-CAM coping - Lava system

Fig.18 All Ceramic CAD-CAM Copings - Lava system

Fig.19 Scanning of master die with Laser scanner - Cercon system

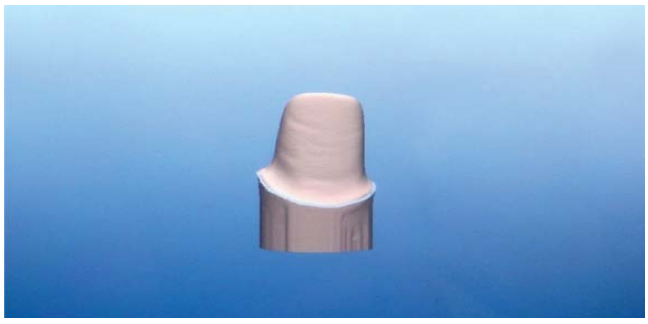


Fig.20 Two dimensional scanned image of the master die - Cercon system

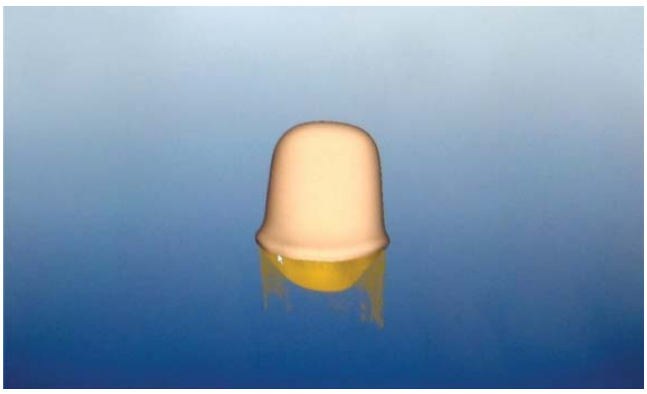


Fig.21 Computer generation of the All Ceramic CAD-CAM coping - Cercon system

Fig.22 All Ceramic CAD-CAM copings - Cercon system

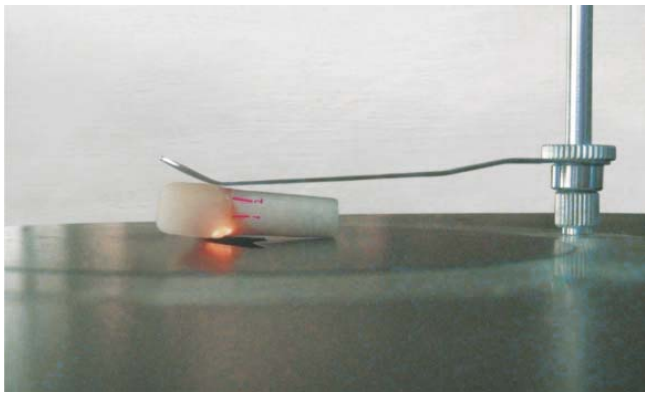


Fig.23 Evaluation of marginal fit of crown pre-veneering (coping)

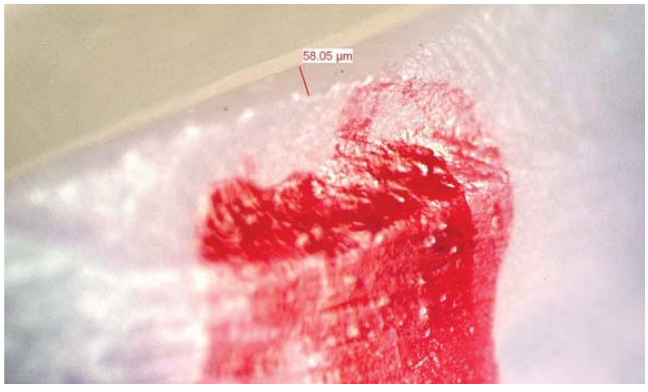


Fig.24 Image of coping captured by the image analyzer along with the measurement

B. FABRICATION OF SAMPLES:

Crowns were fabricated by each of the All Ceramic CAD-CAM system using their respective scanner and they were grouped as follows:

Group I 5 crowns fabricated with Contact scanner-Procera system

Group II 5 crowns fabricated with Optical scanner-Lava system

Group III 5 crowns fabricated with Laser scanner-Cercon System

To evaluate the marginal fit, the Groups were further divided into

Groups A: Pre-veneering stage (coping)

Groups B.: Post-veneering stage (crown)

GROUP I: All Ceramic CAD-CAM system using Contact scanner-Procera system (Fig 11, 12, 13, 14)

The Contact scanner of the Procera system was used to scan the master die.

The master die was mounted on a rotating platform in a digital scanning device that was attached to a computer. The sapphire stylus was held against the die placed on a rotating platform, with a light pressure of 20 gm to ensure close contact during the scanning process. The die was rotated, and the scanning probe, with the sapphire stylus, approached the die at a 45^0 angle[12]. At each angle of rotation, the position of the stylus was recorded and 360 readings were registered along the whole circumference of the master die. Following each complete rotation, the stylus got elevated by 200 μm, and another cycle of recording was taken until the entire preparation was digitalized.

After scanning of the master die, two-dimensional image got displayed on the computer screen. The finish line was marked by enlarging the image of the margin; with help of computer stroke commands and the software interpolated the segment between the marks.

The next step was to decide the thickness of the coping, which was kept at 400 μm as advised by the company for anterior restorations. After designing of the coping, a file was saved in the computer and was sent via e-mail to the production station in Sweden. Five copings of CAD-CAM zirconia (Procera) all ceramic system were ordered from Sweden.The copings were examined for quality control and received for the evaluation.

GROUP II: All Ceramic CAD-CAM system using Optical scanner-Lava system (Fig 15, 16, 17, 18)

The Optical scanner of the Lava system used to scan the master die.

The master die was mounted on a rotating platform in an optical scanning device Lava Scan that was attached to a computer. The rotating platform of the scanner rotates at different angles and approximately 1,20,000 data points are measured and digitalized.

After scanning the die, the three dimensional image got displayed on the computer screen. The finish line was marked by enlarging the image of the margin, with help of computer stroke commands and software Lava CAD.

The next step was to decide the thickness of the coping, which was kept at 0.4mm as advised by the company for anterior restorations. After designing of the coping, the 3D shape was milled from a pre-sintered zirconia oxide blank using hard metal tools. The milling time for the crown was 35 minutes. After the milling process got completed the manual finishing was carried out before sintering takes place. The colouring of the framework was also done before sintering process. The framework was coloured using shade guide which corresponds to Vita classic shade guide. Then fully automated, monitored sintering process was done with no manual handling in a special furnace, the Lava Therm for 11hr including heating and cooling phase at 1500oC . Five copings of CAD-CAM zirconia oxide (Lava) all ceramic CAD-CAM system were prepared and were ready for evaluation[11].

GROUP III: All Ceramic CAD-CAM system using Laser scanner-Cercon system (Fig 19, 20, 21, 22)

The Laser scanner by Cercon system was used to scan the master die.

The master die was mounted on a rotating platform and scanned using Cercon eye laser scanner. The Cercon eye scanner scans the die using a three camera system as well as a laser, for extremely precise measurements. The digital output of the Cercon eye was visualized on computer monitor and was customized using the Cercon Art CAD Module which designed the core framework in virtual 3-D. The system utilizes a unique instrument, Cercon Move, which is a 3-D navigation tool providing an easy way to visualize all the dimensions of the design on screen

Once the design phase was completed, the file was sent to Cercon Brain for milling. The milling machine milled the Cercon zirconia block which comes in two color- white and natural shade, the zirconia block used for this study was natural shade zirconia block. The sample was milled from presintered zirconia block in an enlarged size. The enlargement factor was compensated for the sintering shrinkage (18% linear). The milled sample was sintered in the Cercon Heat furnace at 1350^0C for six hours[15]. The sample was then finished and polished. Five samples were prepared, finished and polished and were ready for evaluation.

Fig.25 Application of veneering ceramic

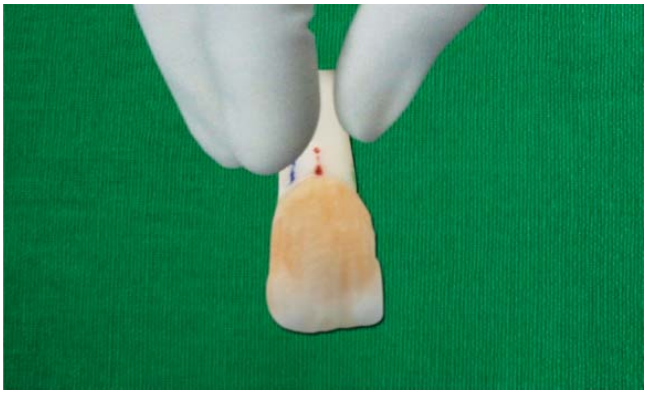


Fig.26 Ceramic build-up

Fig.27 Firing of the veneering ceramic

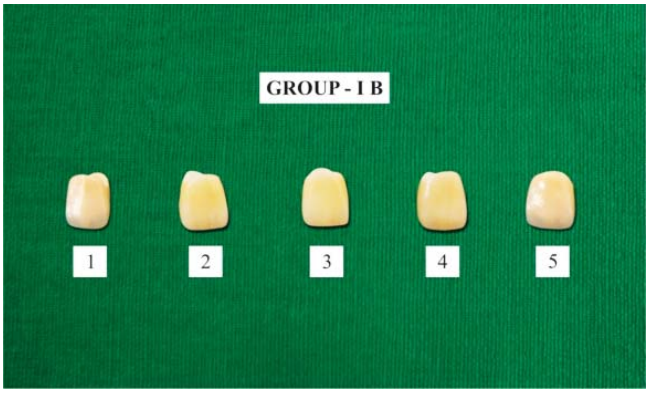


Fig.28 All Ceramic CAD-CAM crowns - Procera system

C. EVALUATION OF MARGINAL FIT OF CROWNS AT PRE-VENEERING STAGE (COPINGS) (Fig 23, 24):

Crowns of groups I, II, III at the preveneering stage (copings) were placed on the master die and secured in position with adhesive plaster tape to prevent displacement. The marginal fit was evaluated, by placing it on the Optical Microscope table. Measurements were made at eight predetermined points marked on the circumference of the root. The image of the marginal gap between the coping and master die was focused under the microscope of 100X magnification. The image was then captured on the computer screen. Image analyzer with the inbuilt grid facilitated the measurement of gap between the coping and the master die. The readings were noted and analyzed statistically.

D. APPLICATION AND FIRING OF VENEERING CERAMIC OVER COPINGS(Fig 25, 26, 27, 28, 29,30):

All the copings were cleaned by a steam jet cleanser just prior to the ceramic build up. The ceramic build up was done for each group using the respective ceramic material as per the manufacturers' instructions.

The crowns of each group were then subjected to firing cycles in the ceramic furnace programmed at temperature specific to each of the system.

Group I- B : - Ceramic Build up was done with Nobel Rondo Ceramic material.

Group II-B : - Ceramic Build up was done with Lava Ceram Ceramic material

Group III-B: - Ceramic Build up will be done with Cercon Ceram Ceramic material

E. EVALUATION OF MARGINAL FIT OF CROWNS AFTER APPLICATION AND FIRING OF VENEERING CERAMIC(Fig 31, 32):

The crowns were placed on the master die and secured in position with adhesive plaster tape. The marginal fit was evaluated in the similar manner as for copings. The measurements were made at the same predetermined points for each crown. The readings were noted and analyzed statistically.

RESULTS

The observations were statistically analyzed to comparatively evaluate the values obtained. The student ' t' test was applied to the data to test separate differences by permutation and combinations. Student's unpaired 't' test was also used to analyze and compare each group with the other groups individually and decide whether their comparisons were statistically significant.statistical analysis. The

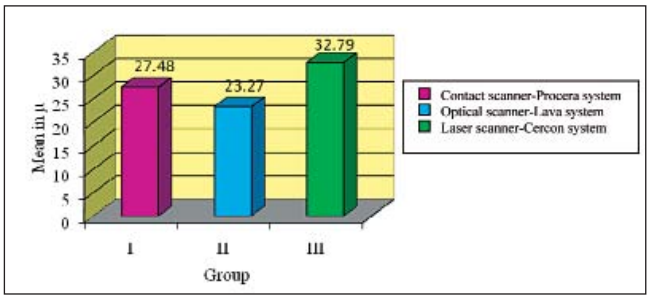
mean value of marginal gap with Group IA was 27.48 +2.63 and IB was 26.13+ 0.85 and that of Group IIA was 23.27 + 0.99 and IIB 19.22 + 0.88. The mean value of marginal gap of Group IIIA was 32.80 + 2.46 and IIIB was 28.77 + 1.94. The marginal gap was maximum with Group II. The mean marginal gap values of subgroup B were less than subgroup A.

Tables

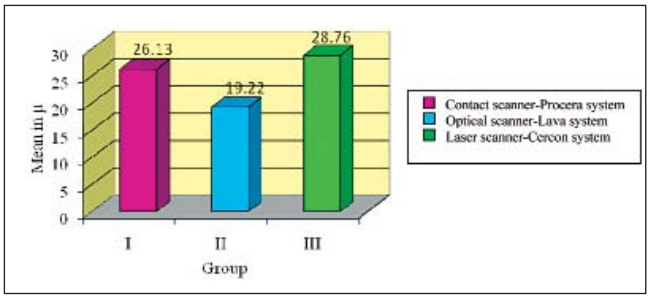
MEAN AND STANDARD DEVIATION VALUES

GROUPS	A		B	
	Mean Value µm	Standard Deviation	Mean Value µm	Standard Deviation
I	27.48	2.63	26.13	.85
II	23.27	.99	19.22	.88
III	32.80	2.46	28.77	1.94

Graph: THE MEAN VALUES OF MARGINAL DISCREPANCY FOR GROUP I, II AND III, PRE-VENEERING



Graph 1



Graph 2

Discussion :

The marginal fit of restorations is of particular interest and is an important quality criterion for the evaluation of dental restoration. The presence of marginal discrepancies in the restoration exposes the luting agent to oral fluids, leading to more rapid rate of cement dissolution[21]. The resultant micro leakage permits the percolation of liquids, food, oral debris and other substances that are potential irritants for vital pulp[22], thus leading to poor prognosis of the restoration[22-26].

This study was planned to evaluate and compare the marginal fit of All Ceramic crowns fabricated by the three scanning systems, namely Contact scanner (Procera CAD-CAM system), Optical scanner (Lava CAD-CAM system), Laser scanner (Cercon CAD-CAM system) as per the manufacturer's instructions. The marginal fit was evaluated at eight predetermined points marked on circumference of the root of the master die, under an optical microscope at 100x magnification.

The error incurred at each step of the fabrication of the crowns would either compound or offset the previous errors. Although the number of steps involved in the fabrication of the samples were not a direct indication of the quality of the marginal integrity. One may suggest that the more steps involved and the more sensitive techniques, the more likely it is that the technical errors would occur.

The results of this study showed that significant differences were found among the systems suggesting that the different fabrication procedure accounted for the marginal discrepancy of the ceramic systems. Fabrication of the Contact scanner (Procera CAD-CAM system) all ceramic samples were done by digitalization of the master die. The data input was determined by the sensitivity of the probe, which has a mean shape related error of 27.48 µm in a complete revolution. The stylus of the scanner approaches the die at a 45º angle. At each angle of rotation the position of the stylus is recorded and 360 readings are registered.

Evaluation of All Ceramic crowns fabricated by Optical scanner (Lava CAD-CAM system) reported a marginal discrepancy of a mean of 23.27 µm, which included the inaccuracies caused by the CAD-CAM system. The rotating platform of the scanner rotates at different angles and approximately 1,20,000 data points are measured and digitalized.

Evaluation of All Ceramic crowns fabricated by Laser scanner (Cercon CAD-CAM system) reported a marginal discrepancy of a mean of 32.80 µm. The Cercon Eye Laser scanner scans the die using three camera system and a laser. An instrument-Cercon Move then navigates around the die to get 3D visualization of all the dimensions.

Out of these three systems the Contact scanner[11] works on a touch probe technique at 45º angle, where 360 readings are taken, the Optical scanner rotates at different angles and takes 1,20,000 readings[13] whereas, the Laser scanner works on three camera and a laser, and an instrument Cercon Eye navigates to get the readings[13]. Thus the variations in the

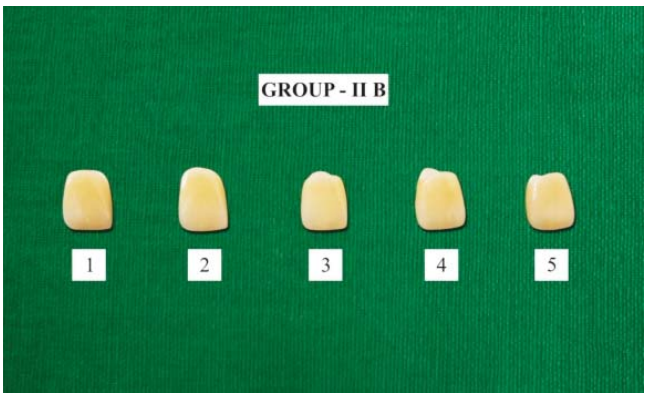


Fig.29 All Ceramic CAD-CAM crowns - LAVA system

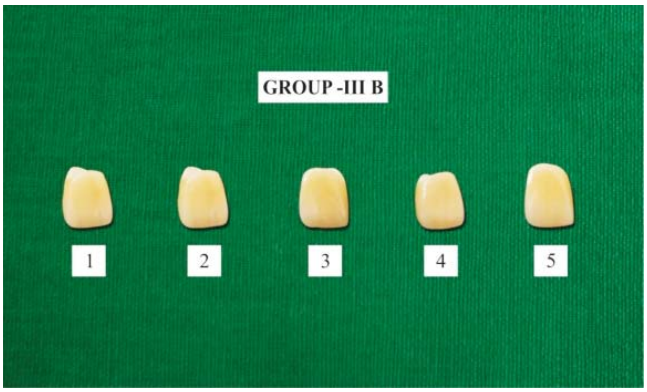


Fig.30 All Ceramic CAD-CAM crowns - Cercon system

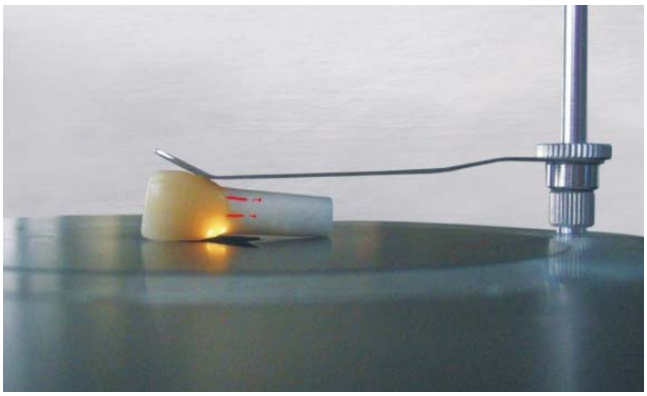


Fig.31 Evaluation of marginal fit of crowns post-veneering

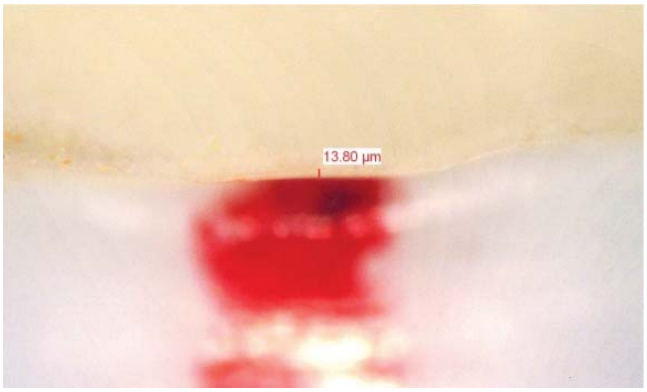


Fig.32 Image of crown captured by the image analyzer along with the measurement

marginal discrepancies of the All Ceramic crowns could be attributed to the above mentioned factors.

The results of this study suggested that the mean marginal discrepancy of the systems follows in descending order: Optical scanner (Lava CAD-CAM system), Contact scanner (Procera CAD-CAM system), Laser scanner (Cercon CAD-CAM system). However according to a consensus between various authors that marginal openings below 120 µm are clinically acceptable[26], the mean of marginal discrepancy recorded in all the three systems were in accepted clinical range.

It was also observed that the marginal discrepancy of all the three systems was reduced after application and firing of veneering ceramic. Though this difference was statistically insignificant, an explanation for the same is based on the physical properties of the materials[22]. There is an inward compressive contraction of the veneered ceramic layer. This could have lead to the resultant decrease in the marginal discrepancy of the All Ceramic crowns. Similar observation was obtained by Buchanan in his study on the two metal ceramic systems. There was a decrease in the marginal gap of the samples after ceramic firing due the contraction of opaque ceramic layer[23, 24].

The mean marginal discrepancy of 30.12 µm of the CAD-CAM zirconia (Procera) samples in this study was not in agreement with the findings of Sulaiman and Chai[24] who found a mean marginal discrepancy of 83µm, Suafrez and Pablo[11] who found mean marginal gap of 71µm with a rounded shoulder finish line design. Albert and Mowafi[25] also reported the mean marginal discrepancy of 54µm. Conversely, Quantas and Oliveria[17] who found the mean marginal discrepancy before cementation as 25µm, which supports the results of this study.

Similar study was done by Florian Beuer, Michael Naumann, Wolfgang Gernet, John A. Sorensen in the year 2008 to compare the precision of crowns fabricated with Procera zirconia CAD-CAM system and Lava CAD-CAM system. Mean gap dimensions at the marginal opening for Lava and Procera were 15(+/- 7) µm and 9(+/- 5) µm respectively. However, within the limitation of the study, the results suggest that the accuracy of both investigated systems is satisfactory for clinical use[26].

Limitations of the Study

An explanation for disagreement with similar studies[14,11,17,26] could be the variation in the method used for fabrication and measuring the discrepancies as well as variation in the number of readings taken for each sample. This study was limited by the fact that it was an evaluation with a limited sample size. Further studies regarding the influence of different

luting cements on the marginal fit of all ceramic crowns are required. The scanning system are specific to the company. Thus inherent drawback of the system may not be in the hand of the operator.

Conclusion

The study was conducted to evaluate and compare the marginal fit of crowns fabricated using three All Ceramic CAD-CAM systems using their respective scanners.

Within the limitation of the in-vitro study, the following conclusions were drawn:

1. The marginal fit of All Ceramic CAD-CAM crowns fabricated by Contact scanner was better than the Laser scanner but less than the Optical scanner.
2. The marginal fit of All Ceramic CAD-CAM crowns fabricated by Optical scanner was better than the Laser scanner and Contact scanner.
3. The marginal fit of All Ceramic CAD-CAM crowns fabricated by a Laser scanner had less accurate marginal fit when compared with both Contact scanner and Laser scanner.
4. The minimum marginal discrepancy was achieved with Optical scanner (Lava) All Ceramic CAD-CAM system and the maximum marginal discrepancy was recorded with Laser scanner (Cercon) All Ceramic CAD-CAM system, however they were in the accepted clinical range.

References :

1. Touato B., Miara, Nathanson D. Esthetic dentistry and ceramic restoration London; Martiz Dunitz: 1999.
2. John W. McLean. Evaluation of dental ceramics in the twentieth century. J Prosthet Dent 2001; 85:61-6.
3. Matt Andresson,Michel R., Agneta. Procera a new way to achieve an all-ceramic crown. Quintessence International 1998; 29:285-95.
4. Gordan Christensen. Porcelain-fused-to-metal vs. non-metal crowns. JADA 1999; 30:409-11.
5. Perng-Ru Liu. A panorama of dental CAD-CAM restorative systems. Compendium July 2006;26 :507-25.
6. Dr. Thomas Völkel. A new technology revolution in all ceramic systems. Famdent Dec 2006: 55-59
7. Stephen Rosensteil, M F Land, Junhei Fujimoto. Contemporary Fixed Prosthodontics. 2nd Edition 1995; St. Louis: Mosby Publication; p.437.
8. Silness J. Peridontal conditions in patients treated with dental bridges:III The relationship between location of the crown margin and the periodontal condition. J Periodont Res1970;5:225-229.
9. Jelenko C, Smales RI. Anterior crowns and gingival health. Aus Dent J. 1979; 24:225-30.
10. P.Lacroix, G.Albuffy, L.du Port de Poncharra, G.Laborde. Clincial evaluation of marginal fit of LAVA all ceramic system. European Cells and materials; 10: 21-25.
11. Goldin EB,Boyd ,Goldstein GR,Hittelman ,Thompson. Marginal fit of lucite glass pressable ceramic restoration and ceramic pressed to metal restoration. J Prosthet Dent 2005 ; 93:143-47.
12. Mehmet Cudi B., Aynur Cinar and Selim Pamuk. Effect of porcelain and glaze firing cycles on the fit of 3 types of all ceramic crowns. J Prosthet Dent 2005; 45:456-59.
13. Shiratsuchi H,Komine F,Kakehashi Y,Matsumura H. Influence of three different finish line designs on the marginal adaptation of electroformed crowns. J Prosthet Dent 2006; 95:237-42.
14. McLaren EA. All-Ceramic Alternatives to Conventional Metal Ceramic Restorations. Compend Contin Educ Dent. 1998; 3: 307-325.
15. McLean JW. The Nature of Dental Ceramics and their Clinical Use. Quintessence Publishing Co., Inc.Chicago 1979: USA.
16. Florian Beuer, Michael Naumann, Wolfgang Gernet, John A. Sorensen. All Ceramic Systems. BDJ 1999; 106:409.
17. Jacobs MS Windler. A investigations of dental luting cement solubility as a function of the marginal gap.
18. Goldmen M., Laosonthorn, White. Microleakage – Full crowns and the dental pulp. J. Endo 1982; 18: 473-75.
19. Felton, Kenoy, Bayne. Effect of in vivo crown margin discrepancies on periodontal health. J Prosthet Dent 1991; 65: 357-54.
20. Florian Beuer, Michael Naumann, Wolfgang Gernet, John A. Sorensen. Precision of fit: zirconia three-unit fixed dental prostheses. Clin Oral Invest 2008.
21. Craig. Restorative dental materials ed. 9 1993;336-61.
22. Hobo S. Distortion of occlusal porcelain during glazing. J Prosthet Dent 1982;47:154-56.
23. Ivoclar North America. IPS Empres All Ceramic crowns Laboratory manual Anberst New York: Ivoclar North America 1992: 1-10.
24. Giuseppe Isgro, Cornelis K., Hang W., Albert F. The influence of multiple firing on thermal contraction of ceramic materials used for the fabrication of layered all-ceramic dental restorations. Dental Materials 2005;21:557-564.
25. Buchanan W. T., Svare C.W., Turner. The effect of repeated firing and strength on marginal distortion in two metal ceramic systems. J Prosthet Dent 1981; 45: 505-507.
26. Campbell S. D., Pelleter. The thermal cycling distortion of metal ceramics Part III etiology. J. Prosthet Dent 1992;68:284-289.