

# In Vitro Failure of Crowns Produced by Two CAD/CAM Systems

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*Abstract - Previous laboratory studies have demonstrated satisfactory fracture resistance of all-ceramic crowns placed using a resin-composite luting material and a dentine bonding system. This study investigated the fracture resistance of teeth restored using CAD/CAM technology, namely, Zirconia Based crowns and Cerec® produced feldspathic porcelain crowns, both luted with a self adhesive resin luting material (RelyX™ Unicem Clicker™ 3M ESPE). Standardized preparations were carried out on two groups of ten sound, unrestored, maxillary premolar teeth. Ceramic crowns were constructed to have a thickness of 2mm at their midline fissure. Compressive fracture resistance was determined for each group using a Universal Testing Machine. The failure modes were also examined visually and interpreted according to a chosen scale. Mean Compressive fracture resistance of 746 (147)N and 1630 (175)N were recorded for the Cerec® and Lava™ groups respectively; differences were statistically significant ( $p < 0.001$ ). The fracture resistance of teeth restored with Lava™ crowns is significantly greater than a similar group of teeth restored with Cerec® crowns.*

KEY WORDS: All-ceramic, Self adhesively luted, CAD/CAM, Compressive failure

## INTRODUCTION

Ceramics have become popular for indirect dentistry because of their good aesthetic and optical qualities and excellent biocompatibility. Earliest systems, such as aluminous-reinforced feldspathic glass (porcelain) utilised platinum foil as a template for the ceramic<sup>1</sup>, but all-ceramic restorations formed by computer-aided design / computer-aided machining (CAD/CAM) methodology have become available in the past quarter of a century. The introduction of the Cerec® 'in surgery' system allowed porcelain blocks to be manufactured in factory conditions and then to be milled in the surgery to exacting tolerances to create same day restorations<sup>2</sup>. However, it may be considered that the potential for this type of system is still to be completely realised. Most recently, CAD/CAM has been used in the milling of a new generation of dental ceramics, among these being high density, polycrystalline materials such as zirconium oxide (zirconia), this being milled generally in its unsintered state. Despite the fact that zirconia was first proposed as a dental material less than a decade ago<sup>3</sup> the number of CAD/CAM systems using this material has risen rapidly. One such system is Lava™ (3M ESPE Dental Products, Seefeld, Germany). The basis of this system is a zirconia core of varying thickness, with the final morphology of the tooth being created with a veneer of feldspathic porcelain.

Catastrophic failure was a problem with the early aluminous porcelain crowns<sup>1</sup>, so it is important to ascertain the forces at which catastrophic failure is initiated. Whilst the so-called "crunch the crown" methodology has been criticized in the past<sup>4</sup>, it does permit comparison of the potential "strength" of different materials, providing all other parameters are stand-

ardised. In this respect, previous laboratory studies have demonstrated satisfactory fracture resistance of all-ceramic crowns placed using a resin-composite luting material and a dentine bonding system<sup>5-8</sup>.

It is therefore the aim of this study to assess the fracture resistance of teeth restored with standardised morphology crowns of Cerec® produced from Vita® Mark II Vitablocs® feldspathic porcelain and Lava™ crowns formed with a zirconia core and a feldspathic porcelain veneering ceramic, both types being luted with a self-adhesive resin-based luting material (RelyX™ Unicem Clicker™:3M ESPE, Seefeld, Germany).

## MATERIALS AND METHODS

### Selection of teeth

Twenty sound extracted maxillary premolar teeth, which had been examined visually and had been found to be sound and free from defects and cracks, were selected. Patient consent for the use of these teeth for research, following extraction, had been obtained. The teeth were chosen so that the mean measurement of the bucco-palatal width (BPW -the distance from the maximum convexity on the buccal and palatal surfaces) of the teeth varied by no more than 2.5% and that this did not vary by more than 2.5% from a group of teeth previously used in a fracture resistance experiment<sup>7</sup>. Any calculus deposits or soft tissue attached to the teeth was removed using a hand scaler. Following post-extraction storage in buffered formal saline for 24h, the teeth were stored in water at room temperature ( $23 \pm 1^\circ\text{C}$ ) except when aspects of the experimental procedure required isolation from moisture. Each tooth was fixed, crown uppermost and long axis vertical, in a cylindrical stainless steel mould which had a central hole of 12 mm diameter, using auto-polymerised resin, with the resin extending to 2 mm of the cement-enamel junction (CEJ).

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## Preparation of teeth

The previously described<sup>7</sup> standardised preparation was carried out as follows:

- (1) A 2 mm groove was cut along the central fissure with a diamond bur marked to a depth of 2 mm.
- (2) A line was marked on the buccal and palatal cusps 2 mm from the cusp tips. This line was joined to the bottom of the groove prepared in (1) using a tapered diamond fissure bur (HiDi 501, Dentsply Ash Instruments).
- (3) Any convexity from the buccal, palatal, mesial and distal surfaces was removed using a tapered diamond fissure bur, with a finish line on enamel, 1 mm from the CEJ.
- (4) An axial taper of 6° was created using specially constructed tapered diamond burs of 6° divergence held in a laboratory handpiece operating at 8000 rpm without water coolant, placed in a Bachmann design parallelometer.
- (5) Any sharp preparation angles were rounded using a tapered diamond fissure bur in a high speed handpiece operating with water coolant.
- (6) The preparation margins were completed to a 0.5 mm shoulder preparation.

Stages 1-3 and 5-6 were carried out using a high speed handpiece operating with water coolant. Figure 1 presents an example of a preparation utilised in the study.

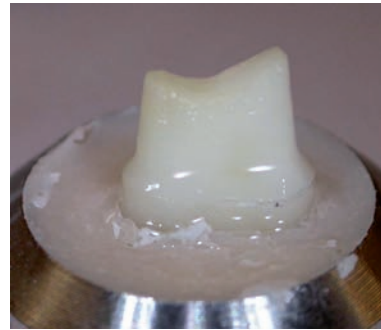


Figure 1. A typical preparation

## Construction of Crowns

### Cerec® 3D

Each prepared tooth was placed in a jig to allow the optical impression to be taken. The tooth surfaces were coated with a minimal layer of light-reflecting powder (Cerec® powder Vita Zahnfabrik, Bad Säckingen, Germany). An optical impression was then taken (Figure 2). The crown margins were detected on the image and a standard database crown was selected (Figure 3). This was adjusted to keep the crown thickness at the fossa to be 2 mm when milled. Following milling, the residual sprue (Figure 4) was removed with an extra-fine diamond bur (ultra fine grit 652UF, Unodont), the external crown surface was smoothed with a polishing bur, a glaze was applied and then the crown was fired in an oven at 960°C for 60 seconds (Figure 5), this being a method employed by one of the authors (TJD) in his surgery to enhance the appearance of Cerec crowns. When cooled, the crown fitting surface was etched with a hydrofluoric acid mixture (Vita® Ceramic Etch <5% Hydrofluoric acid < 10% sulphuric acid) and was then treated with a silane bond enhancer (Sil™ 3M ESPE). The crowns were then placed in protective packaging.

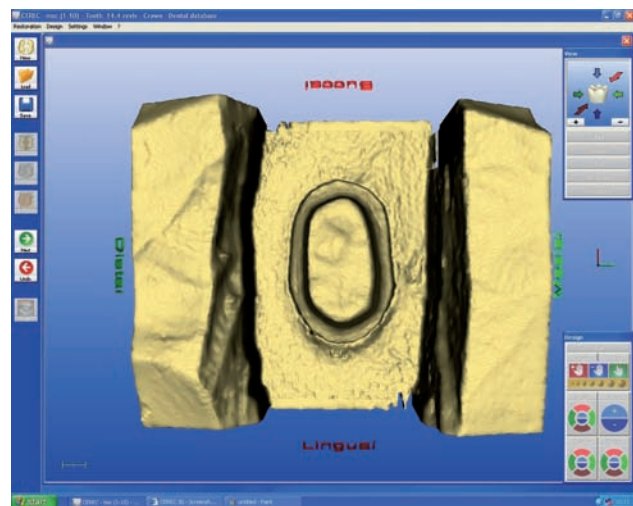


Figure 2. Screen shot of captured image.

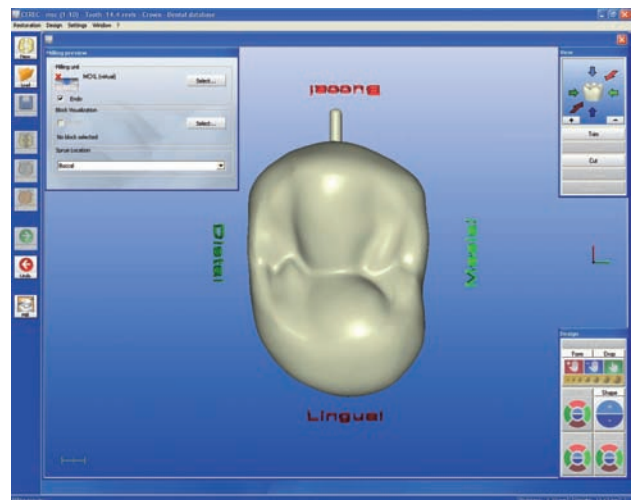


Figure 3. Screen shot of crown to be milled

### Lava™

A one-stage impression of each prepared tooth was taken using a polyether impression material (Impregum™, 3M ESPE Seefeld, Germany) in a stock plastic tray painted with tray adhesive. Original impressions were poured using artificial diestone. Each die was then scanned, the resultant optical impression was manipulated to supply a close fitting coping of 0.6mm minimum thickness but designed

using the Digital Wax Knife (3M ESPE) to produce a contour which would allow a minimum thickness (*circa* 1mm) of the veneering porcelain, Lava Ceram (3M ESPE, Seefeld, Germany). When completed, the fitting surface was treated by air abrasion with CoJet™ (3M ESPE), a silica deposition device which has been found to create an adhesive bond when used with a silane bond enhancer (Sil™ 3M ESPE)<sup>9</sup>.



Figure 4. Crown milled with sprue attached and tried in



Figure 5. Crown glazed and fitted

### Crown Placement

Following examination of the fit of each crown, the protocol dictated that any specimens in which the fit was not considered satisfactory (namely, where there was a defect visible to the operator wearing x3.8 magnifying lenses or in which a defect was felt at the crown margin with an explorer) would be remade. In specimens where the fit was satisfactory each crown was luted using RelyX Unicem Clicker (shade A2) mixed in accordance with the manufacturer's instructions. Excess luting material was removed using sponge pellets. The luting material was light-cured using a light-curing unit (Demi SDS, Kerr Hawe SA) for 20 seconds with an irradiance from 1100 mW/cm<sup>2</sup> to a peak of 1330 mW/cm<sup>2</sup> (Periodic Level Shifting) from mesial, distal, buccal, palatal and occlusal directions

### Compressive fracture resistance determination

Each crowned tooth was immersed in water at room temperature for 24h prior to testing, to allow for any additional polymerisation of the luting material to occur. The restored teeth were subjected to compressive loading at a cross-head speed of 1 mm/min in a Universal Testing Machine (Instron Model 1544: Instron, High Wycombe, England, UK), with the load being applied through a 4 mm cylindrical steel bar placed along the occlusal fissure of the restored tooth. The associated compressive force required (N) to cause fracture was recorded. The results were subjected to statistical analysis by a simple T-test to identify differences in mean compressive fracture resistance. The mode of fracture was also recorded following visual inspection, using a classification designed for the investigation, as follows:

- I minimal fracture/crack in crown/veneering.
- II < ½ of crown/veneering lost.
- III Crown/veneer fracture through midline; ½ of crown/veneer displaced/lost.
- IV > ½ of crown/veneer lost.
- V Coping fracture
- VI Tooth, Crown / Coping Fracture

## RESULTS

All 20 crowns that were constructed were found to be of satisfactory fit and were therefore suitable for inclusion in the study. The mean compressive fracture resistance of the ten Cerec® crowns was 746 (147) N (range 520 to 980 N)

and the mean compressive fracture resistance of the ten Lava™ crowns was 1630 (175) N (range 1420 to 1920 N) (Table 1). The two groups were significantly different ( $p < 0.001$ ), with fracture resistance of the Lava™ group being significantly greater than the Cerec® group.

There were differences in fracture mode between the groups (Table 1), with one (severe) mode VI fracture occurring in the Cerec® group, with 40% of crowns exhibiting a mode I fracture, 30% a mode II fracture (Figure 6) and 20% mode III fractures. Forty per cent of crowns in the Lava™ group exhibited a mode II fracture (Figure 7), 10% a mode III fracture, 30% a mode IV fracture, 10% a mode V fracture, and 10% a mode VI fracture. In all cases of failure the results would have necessitated clinical replacement of the crown, with the exception of the (severe) mode VI fractures, in which the failed tooth structure which would have resulted in extraction of the remaining tooth tissues.

## DISCUSSION

The purpose of this study was to examine the *in vitro* performance of two types of crowns under compressive load, both being constructed using CAD/CAM techniques. However, beyond the CAD/CAM input in their manufacture, the similarities end, given the differences in the materials from which the crowns are manufactured. The Cerec® crowns are essentially a feldspathic porcelain which consists of ceramic grains in a glass matrix, albeit one in which the production of flaws in the construction process should be reduced in comparison with those formed using the traditional methods for production of crowns formed in feldspathic porcelain. Until recently, there were only two types of feldspathic porcelain block available for milling with a Cerec3 milling machine, namely, Vita® Mark II Vitablocs® (Vita Zahnfabrik) and ProCAD (Ivoclar Vivadent Schaan, Lichtenstein), with the use of these blocks for restorations from single surface inlays to full crowns being commonplace amongst Cerec® users. For the present study, the Vita® Mark II Vitabloc® (Vita Zahnfabrik) was chosen, having had extensive clinical trials<sup>10</sup>. The technology is now simple to use and may produce excellent aesthetics, but has a limited range of materials from which to choose<sup>10</sup>. The advantage of chairside production is obvious as it may reduce the number of return appointments for patient and dentist. The patient experience is enhanced by the removal of the impression and temporisation stage from construction of the restorations. Good clinical longevity of Cerec® restorations in all forms has been demonstrated<sup>11-14</sup>.

**Table 1.** Compressive fracture resistance and failure mode for extracted, standardised teeth restored with Cerec® crowns and Lava™ Crowns.

Crown	Cerec® Crowns		Lava™ Crowns	
	Fracture Resistance (N)	Failure Mode	Fracture Resistance (N)	Failure Mode
1	680	III	1540	IV
2	980	II	1720	III
3	620	II	1820	II
4	700	II	1720	II
5	510	III	1920	VI
6	960	I	1560	IV
7	680	I	1420	V
8	700	I	1460	II
9	760	I	1420	II
10	860	VI	1720	II
Mean ± SD	746 ±147		1630 ±175	

**Figure 6.** Mode II and mode III Cerec® crown fractures**Figure 7.** Mode II Lava™ crown fracture

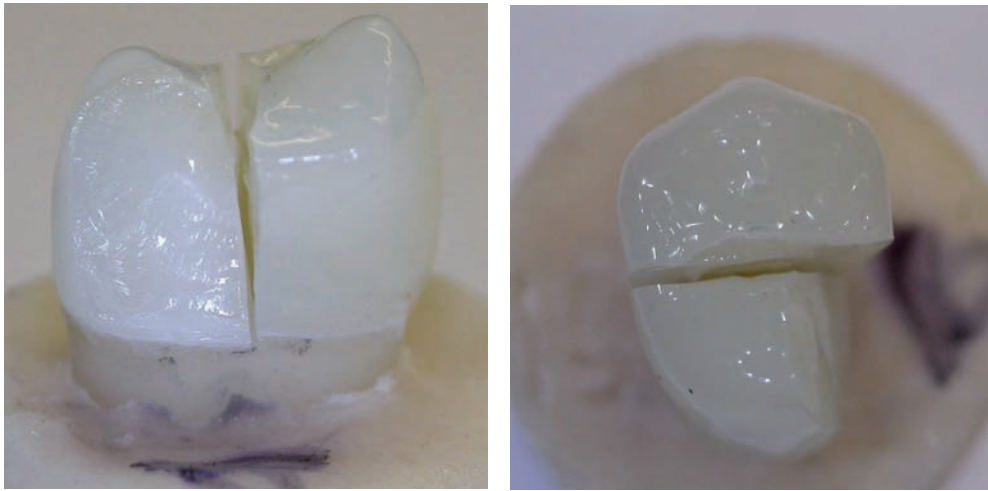
By contrast, the Lava™ crowns are formed from a zirconia core veneered with a feldspathic ceramic<sup>15</sup> (Lava Ceram, 3MESPE). Indirect CAD/CAM<sup>16</sup> using zirconia is a rapidly expanding area. The technical difficulties in manufacturing appear to have been overcome, with a wide variety of systems now delivering tooth coloured restorations with good clinical performance.

Regarding the methodology used in the present study, the standardised tooth selection and preparation protocols have been derived from other studies<sup>5-7</sup>. Having chosen the design database, the actual design used for the construction of the Cerec® Crowns, duplicated for the Lava™ crowns,

was left undisturbed by the operator except to ensure that the thickness of the crowns was 2mm at the midline fissure.

In the present study, a self-adhesive luting material (RelyX™ Unicem Clicker™) was used, given that resin cements have been considered optimal for use with ceramic restorations<sup>17</sup> and the recently-introduced self-adhesive types have been demonstrated to obviate the clinical difficulties associated with early resin luting materials<sup>18</sup>.

A feldspathic porcelain (Lava Ceram) is used to veneer the Lava™ coping. One report has considered that the bond to the Lava™ coping may be a weakness of the system<sup>19</sup>. However, of the Lava™ crowns tested in the present study, 80% of the failures were within the porcelain veneer, rather than at the zirconia/veneering ceramic interface. It may be considered interesting to note that, although the veneering porcelains are relatively 'old' technology, the zirconia coping appeared to enhance their performance, since the mean fracture resistance of the Lava crowns was significantly higher than that of the group in which feldspathic porcelain was employed (the Cerec® group). That this was happening at twice the average load applied to the Cerec® crowns may be considered to demonstrate a potential for good clinical performance, although the forces that generated failure here may not be those that normally result in clinical failure.



**Figure 8.** Mode VI catastrophic failure of the Lava™ crown



**Figure 9.** Mode VI catastrophic fracture of Cerec® crown

The Cerec® crowns demonstrated fracture resistance which was similar to teeth restored with dentine-bonded feldspathic porcelain crowns in a previous study<sup>6</sup>. That study<sup>6</sup> concluded that the clinical performance of dentine-bonded crowns had demonstrated satisfactory clinical performance. In addition, Burke<sup>6</sup> was able to compare data with the fracture resistance of sound teeth, using a standardised protocol, followed in this study, demonstrating that there was no statistical difference from a group of dentine bonded crowns. It may be therefore be postulated that the fracture resistance of the Lava™ crowns was greater than sound tooth tissue. A concern that tooth tissue may be rendered unrestorable<sup>6</sup> when high-strength ceramics are used would appear to be unfounded, though this requires further clinical evaluation. The tooth fracture related to the Lava™ crown (Figure 8), occurred at 1920N, a higher value for fracture resistance than that of the Cerec® crown (Figure 9), at 860N, although the direct comparison of these two different materials may be considered to be meaningless.

The methodology utilized in the present study has previously been criticized, principally because the methods do not simulate how all-ceramic crowns fracture in clinical service. In that regard, it could be considered to be a

compressive strength test using a tooth-shaped specimen supported by a tooth. The methodology has also been criticized because the loads used are higher than those seen during mastication and swallowing<sup>4</sup>. The latter has been calculated at between 5 to 364N, whereas the maximum force recorded during clenching has been reported to be between 216 and 890N<sup>4</sup>. When the data obtained from the present work are examined, it may be seen that the forces used to fracture crowns do fall within values seen in the clinical situation, although the load applied in the present work increases with time, which may differ from the clinical situation. However, it is the contention of the authors that the methodology allows the comparison of forces required to fracture crowns constructed in different materials.

A recent study by Senyilmaz and co-workers<sup>20</sup> is of relevance, given that the results are broadly in agreement with those from the present work. The study examined the influence of thermomechanical fatigue on the fracture resistance of all-ceramic posterior crowns, comparing three zirconia-based materials with porcelain-fused-to-metal (PFM) and IPS-Empress 2 (Ivoclar, Schaan, Liechtenstein). These crowns, formed in accordance with the manufacturers' instructions, were cemented, using a resin-based luting material (PanaviaF: Kuraray, Osaka, Japan) to standardised preparations made on extracted teeth, with half of the specimens being exposed to 1.2 million cycles of thermomechanical fatigue in a computer-controlled chewing simulator, prior to static loading in a universal testing machine until fracture of the veneering material, copings or tooth occurred. The results indicated that, with and without artificial aging, the failure resistance of IPS Empress 2 crowns were significantly lower than those of the zirconia-based crowns (Cercon [Degudent, Hanau, Germany], Procera AllZircon [Nobel Biocare, Goteborg, Sweden] and In-Ceram Zirconia [Vita, Bad Sackingen, Germany]). Furthermore, there was no difference between the fracture resistances of the zirconia-based ceramic crowns and the PFM crowns<sup>20</sup>.

Finally, given the performance demonstrated by the Lava zirconia crowns in the present study and the performance of the zirconia-based crowns in the study by Senyilmaz and co-workers<sup>20</sup>, it is not surprising that consideration has been given, by the manufacturers of the chairside CAD/

CAM (Cerec®) process, to the development of zirconia blocks for use in their milling machine. This would, of course, mean the development of new burs for the milling machine, given the greater difficulties in cutting zirconia when compared with the porcelains currently used in the Cerec® machine. However, it may be considered unlikely that the same strengths would be obtained if zirconia is milled at the chairside because the greenware zirconia block has to be sintered for six hours or more to achieve the strengths which have been achieved with the crowns utilized in the present study and it is unlikely that many surgeries would have the necessary furnace. The six hours' delay would also negate one of the advantages of Cerec® restorations, namely the same visit production of the restorations. Furthermore, if the manufacturers were to produce a block which could be milled without the need for sintering, it would be unlikely to be fully crystalline zirconia because of the difficulties in milling this.

## CONCLUSION

It is concluded that the laboratory fracture resistance of extracted teeth, prepared to a standardised protocol, and restored with Lava™ crowns whose cores were manufactured using CAD/CAM, is significantly greater than teeth restored with Vita® mark II Vitablocs® produced in a Cerec® CAD/CAM machine, both being luted with a self adhesive luting material ( $p < 0.001$ ). However, it could also be considered that the only common factor between the two types under test is the use of CAD/CAM in their manufacture, given the differences in the two materials under test.

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## MANUFACTURER'S DETAILS

- Lava™, 3M ESPE, Seefeld, Germany
- Vita® Mark II Vitablocs®, Vita Zahnfabrik, Bad Säckingen, Germany
- RelyX™ Unicem Clicker™, 3M ESPE, Seefeld, Germany
- Cerec®3D Sirona, Bensheim, Germany
- Vita® Ceramic etch Vita Zahnfabrik, Bad Säckingen, Germany
- ESPE Sil™ 3M ESPE, Seefeld, Germany
- CoJet™ 3M ESPE, Seefeld, Germany
- Cerec® powder Vita Zahnfabrik, Bad Säckingen, Germany
- Impregum™, 3M ESPE Seefeld, Germany
- Demi SDS, Kerr Hawe SA, Orange, California, USA
- Instron Model 1544: Instron, High Wycombe, England, UK
- ProCAD Ivoclar Vivadent Schaan, Lichtenstein

- Lava Ceram, 3M ESPE Seefeld, Germany
- IPS-Empress 2 Ivoclar, Schaan, Liechtenstein
- PanaviaF: Kuraray, Osaka, Japan
- Cercon Degudent, Hanau, Germany
- Procera AllZircon Nobel Biocare, Goteborg, Sweden
- In-Ceram Zirconia Vita, Bad Säckingen, Germany

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