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CAD/CAM to fabricate ceramic implant abutments and crowns: a preliminary *in vitro* study

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ABSTRACT

Background: This study evaluated the feasibility of fabricating implant abutments and crowns from pre-sintered feldspathic porcelain blocks using the chair-side CAD/CAM, CEREC3D® system.
Methods: Thirty-two implant analogues were divided into two groups. In the control group, prefabricated machined anatomical titanium (Ti) abutments were screw-retained to the analogues. In the test group, machined feldspathic porcelain abutments were cemented on prefabricated machined Ti links and screw-retained to the implant analogues. These feldspathic porcelain abutments were fabricated out of pre-sintered feldspathic porcelain blocks as duplicates of the abutments in the control group using the CAD/CAM, CEREC3D® system. Thirty-two feldspathic porcelain crowns, also fabricated out of pre-sintered ceramic blocks, were then cemented with resin cement on all the abutments in both groups. All samples were subsequently subjected to fracture strength testing under static load. An unpaired t-test was used to compare fracture load values between the two groups.
Results: The test group using feldspathic porcelain abutments and crowns showed statistically significant higher mean fracture strength than the control group with the Ti abutments and feldspathic porcelain crowns.
Conclusions: This preliminary study showed that the chair-side CAD/CAM technology can be utilized to fabricate customized ceramic abutments with their associated ceramic crowns using pre-sintered feldspathic porcelain blocks.

Key words: Abutment, CAD/CAM, ceramic, implant, prosthodontics.

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INTRODUCTION

Single tooth replacement with dental implants has become a routine dental treatment. Many studies have shown a success rate of more than 89 per cent over 10 years for implant-supported crowns,[1] with high levels of operator and patient satisfaction.[2]

In the late 1990s, patient demand for rapid treatments to replace missing teeth prompted the development of techniques for immediate implant placement in fresh extraction sockets. Studies on immediate implant placement show success rates of 97 per cent over four years[3] with studies on the immediate loading of implants showing success rates of more than 90 per cent.[4] One drawback of these techniques is that patients still have to wait with or without temporary crowns until permanent crowns are fabricated and inserted.[5]

Restoring natural teeth with ceramic crowns[5] can provide patients with more aesthetically pleasing restorations, with the strongest ceramics having comparable strengths to conventional ceramo-metallic alternatives.[6] Similarly, when ceramic abutments are used to restore single implants, highly aesthetic outcomes can be achieved, particularly when compared to conventional metal abutments.[7,8] Even though the strongest ceramics have lower fracture strengths when compared to their metallic counterparts, especially on oblique loads,[9] they still show acceptable clinical performance.[7]

CAD/CAM technology has proved its ability to fabricate prosthetic restorations with comparable quality to their counterparts fabricated with conventional techniques.[10,11] The expanding possibilities of CAD/CAM allow fabrication of removable partial dentures,[12] complete denture teeth setup with virtual articulation,[13] implant-supported custom ceramic abutments[14] and implant-supported ceramic crowns on prefabricated Ti or ceramic abutments.[15–18]

To date, however, there are no published data on utilizing chair-side CAD/CAM technology to fabricate implant-supported customized ceramic abutments with associated ceramic crowns from pre-sintered feldspathic porcelain blocks. Carrying out this procedure chair-side may offer a single-visit replacement of a missing tooth with an aesthetic permanent all-ceramic implant-supported crown. In addition, this procedure will save time and materials and, when combined with immediate loading of a dental implant, may fulfil the patient's demand of permanently replacing a missing tooth in only one visit.

MATERIALS AND METHODS

Thirty-two implant analogues (Neo system implant replica, Neoss®, UK) were embedded vertically in epoxy resin (Blue Star®, Dentalgeräte GmbH, Germany). They were then randomly assigned to two groups; a test and a control group with 16 samples each. A premolar implant configuration was used (Fig 1).

In the control group, prefabricated anatomical Ti implant abutments (Neo Titanium prepable abutments, Neoss®, UK) were screw-retained to the implant analogues with Ti screws (Neo implant system laboratory screw, Neoss®, UK). In the test group, Neoss® Mono Neolinks® (Neoss® Neo Matrix System, Neoss®, UK) were screw-retained to the implant analogues using the same Ti screws (Fig 1). The Neolink® was dealt with as if it were a prepared tooth. Following the manufacturer's protocol of scanning a natural tooth, a digital impression of the Neoss® Neolink® was taken with the CEREC3D® intra-oral optical camera.

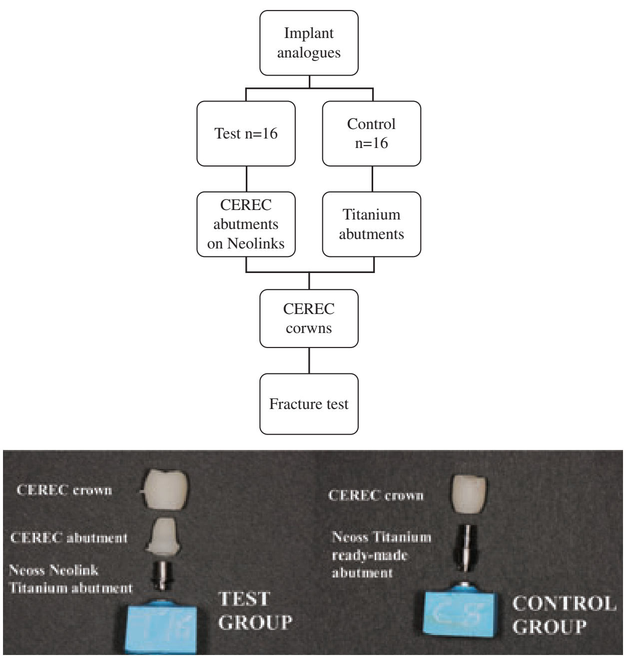

Fig 1. The study protocol and the two groups' configurations.

Subsequently, using the CEREC3D® software (version 260 R2005), an abutment was designed to fit the Neolink® (Fig 2). The abutment was designed by a process called replication in order to copy the shape of the Ti abutments in the control group. The ceramic abutments were milled using pre-sintered feldspathic porcelain blocks (CEREC® VITABLOCS® Mark II, VITA® Zahnfabrik, Germany). Then they were etched (VITA® CERAMICS ETCH), treated with a single-component silane-based coupling agent (VITASIL®, VITA® Zahnfabrik) and cemented to the Neoss® Neolink® with resin cement (PanaviaF® 2.0, Kuraray Medical Inc., Japan). To fabricate the ceramic crown, a second digital impression was taken of the previously milled and cemented ceramic abutment, as if it were a prepared tooth. The crown was CAD/CAM fabricated using the same ceramic block. To finish off the procedure, the crown was cemented to the abutment with the same resin cement following the same cementing protocol.

All specimens were loaded until fracture in a computer-controlled 4505 Instron machine (Instron® Corporation, Canton, MA, USA). Two layers of 0.3 mm thick tin foil were placed over the occlusal surfaces of the crowns to achieve an even stress distribution.[19] A perpendicular load was applied to the occlusal surface of the samples, with a crosshead speed of 1 mm/min. The Instron computer software recorded the load required for fracturing the specimens (Table 1).

Statistics

For statistical analysis, an unpaired Student's t-test was used, with confidence intervals at 95 per cent considered statistically significant ($p \leq 0.05$).

RESULTS

The test group using feldspathic porcelain abutments and crowns showed a higher mean fracture strength of 2.02 kN (± 0.95, S.D.). The control group with the Ti abutments and feldspathic porcelain crowns showed a mean fracture strength of 1.33 kN (± 0.52) (Fig 3). The difference between the two groups was statistically significant ($p = 0.017$) (Table 2). In both groups, only the ceramic components fractured with none of the Ti abutments fracturing (Fig 4).

DISCUSSION

This preliminary study utilized the chair-side CEREC3D® system to fabricate custom feldspathic porcelain implant abutments and crowns. Although the laboratory version, CEREC® InLab®, is capable of fabricating such abutments,[14] the chair-side version is

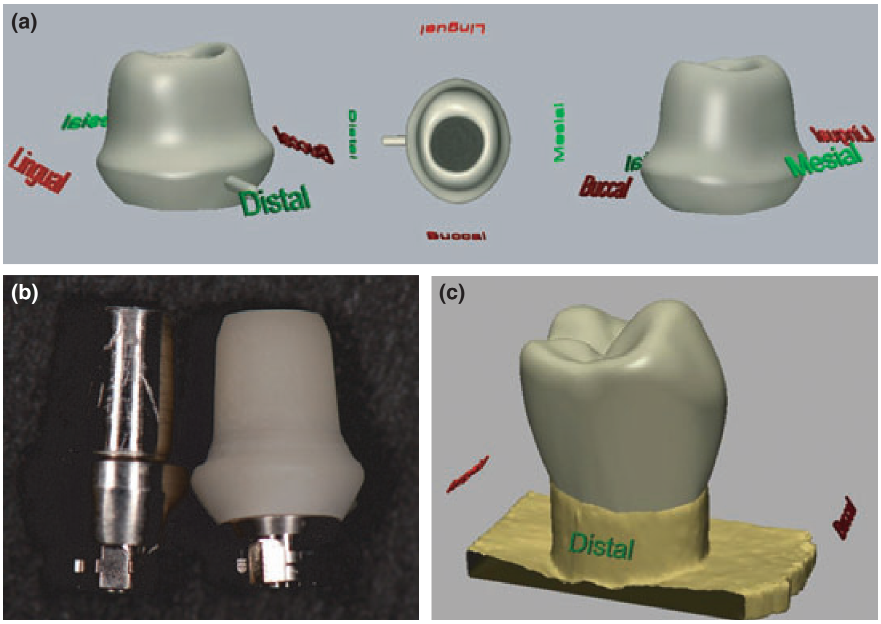

Fig 2. (a) Screen captures of the ceramic abutment CAD designing procedure, (b) ceramic abutment design as a replica of the Ti abutment, and (c) the crown that was designed and milled the same way for both groups.

Table 1. The recorded fracture loads

Control kN	Test kN
0.52	0.24
0.73	0.26
0.92	1.14
0.94	1.22
0.99	1.76
1.00	1.82
1.01	1.88
1.15	2.10
1.27	2.22
1.41	2.35
1.62	2.36
1.71	2.62
1.81	2.76
2.00	2.81
2.00	3.00
2.27	3.77

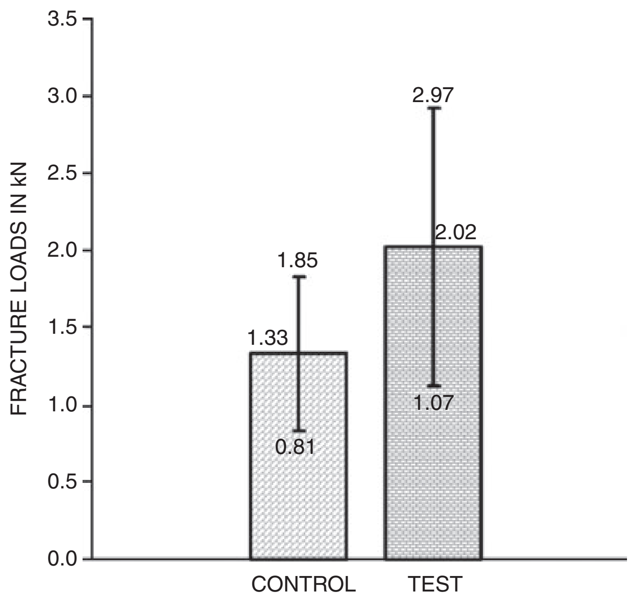

Fig 3. The mean and standard deviations of the two groups. The test group showed statistically significant higher fracture loads.

not configured to do so. Since there are enough studies to support the use of the chair-side CEREC3D® system to fabricate high quality ceramic crowns,[10,18] the challenge was to adapt the chair-side CEREC3D® system to fabricate ceramic abutments. As there is no available abutments database for the chair-side CEREC3D® system, we had to manipulate the computer software to design an abutment. A process called replication was followed to design the abutments. The Ti abutments in the control group were copied in that process.

There are several published case reports[16–19] on the use of the chair-side CAD/CAM technology to fabricate ceramic implant-supported crowns, utilizing prefabricated Ti or ceramic abutments, in a single visit. Ti abutments are strong and predictable with aesthetically compromised outcome.[7,8] Ceramic abutments on the other hand, are more aesthetic with less, yet acceptable strength.[20,21] Both, however, may require manual grinding of the abutment to customize it which can be exhausting and time consuming.

This study proposed a new technique to fabricate ceramic abutments using the chair-side CAD/CAM technology. This procedure virtually eliminates the need for manual grinding of the abutment as all customization is performed during the design step on

Table 2. The statistical analysis. Student's t-test was used to compare the two groups

	Control	Test
Mean	1.33	2.02
95% confidence interval for mean	0.94 thru 1.72	1.63 thru 2.41
Standard deviation	0.52	0.95
Max	2.27	3.77
Median	1.21	2.16
Min	0.52	0.24
Average absolute deviation from median	0.43	0.72
Probability (p)	0.017	

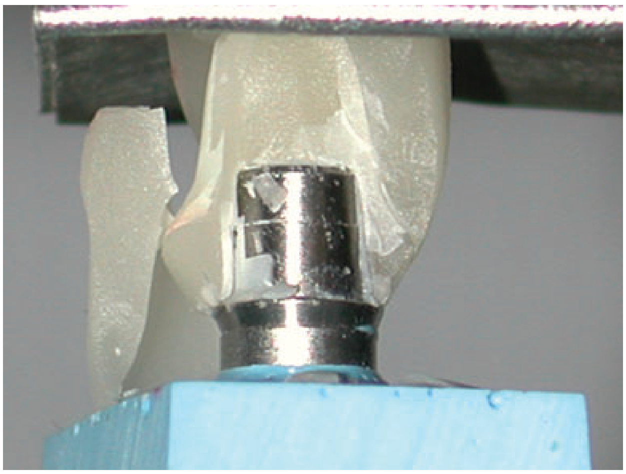

Fig 4. The static fracture test. The Instron machine with 5 kg cell is loading one of the control group specimens. None of the Ti abutments fractured.

the computer screen. Thus, it is less exhausting to both the patient and the clinician. Since we had to manipulate the computer software to accept the abutment design, as mentioned earlier, the time required for designing and customizing the abutment, CAD portion, could not be calculated accurately. The time required to mill the abutment, CAM portion, was around 20 minutes. The CAD/CAM of a crown consumed approximately 30 minutes as we used a premolar crown design from the available database. As an estimate, assuming we have an abutments database, the total procedure from imaging through to cementation can be carried out within one hour. The clinician's skill and training in the use of the CAD/CAM machine has a huge impact on the time taken and the quality of the outcomes. Presence of a database for crowns was very helpful in reducing the amount of time needed for the CAD part.

Screw-retaining a ceramic abutment to an implant is of concern. The retaining screw exerts a clamping force on the abutment to retain it, which may subject the ceramic to static stress leading to crack formation and eventual failure.[20] Ceramic abutment manufacturers have attempted to solve this problem and prevent such failures. Among those is Neoss® Company, with their Neolink® system. The Neolink® is a Ti connector with the purpose of forming an interface between the implant and the abutment. It is screw-retained to the implant. The screw is seated inside the Ti connector. As the ceramic abutment is cemented to the outer walls of the Neolink®, it is thus passively connected to the implant.[21] Also the Neolink® provided what the CEREC3D® recognized as a prepared tooth. This helped us in using the available software that only deals with natural teeth.

Currently, the most successful ceramic implant abutments are zirconia (ZrO_2) ceramic abutments.[22] However, using a pre-made ZrO_2 block requires a six-hour sintering period at high temperature after milling as the ZrO_2 blocks are only partially sintered to enable easy and fast milling.[23] This prevents the single session fabrication of an abutment. To enable single session fabrication of the prosthesis, pre-sintered machineable feldspathic porcelain blocks were used to fabricate both the abutment and the crown. These blocks showed satisfying outcomes when used to fabricate crowns.[24,25]

The static fracture strength test was used in this preliminary study to assess the validity of this new technique and the worthiness of developing it in more comprehensive studies using more clinically relevant criteria.[26]

The aim was to investigate the fracture strength of the complete prosthesis fabricated with the proposed technique. Thus, the samples tested were complete prostheses, i.e. a feldspathic porcelain crown cemented to a feldspathic porcelain abutment cemented to a Ti link which was screwed to an implant. Since studies reporting the fracture strength of implant abutments investigate samples without crowns, i.e. abutments only,[27] direct comparison to this study was not possible.

The statistically significant higher fracture strength values we encountered for the test group (2.02 kN) over the control group (1.33 kN) were not expected. In our belief, two factors may have enhanced the fracture resistance of the test group. The two layers of resin cements[28] and the larger bulk of the high quality porcelain.[24] More comprehensive studies are needed to clarify this.

CONCLUSIONS

This preliminary study showed that the chair-side CAD/CAM technology can be utilized to fabricate customized ceramic abutments with their associated ceramic crowns using pre-sintered feldspathic porcelain blocks. This technique opens up the possibility of a new area for the application of the chair-side CAD/CAM in implant dentistry. In addition, it promises for the single visit permanent replacement of a missing tooth. We recommend the need for future studies to further explore fatigue strength, marginal accuracy and adaptation.

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