Fracture Strength and Failure Mode of Maxillary Implant-Supported Provisional Single Crowns: A Comparison of Composite Resin Crowns Fabricated Directly Over PEEK Abutments and Solid Titanium Abutments

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ABSTRACT

Background: Polyetheretherketone (PEEK) temporary abutments have been recently introduced for making implant-supported provisional single crowns. Little information is available in the dental literature on the durability of provisional implant-supported restorations.

Purpose: The objectives of this study were to evaluate the fracture strength of implant-supported composite resin crowns on PEEK and solid titanium temporary abutments, and to analyze the failure types.

Material and Methods: Three types of provisional abutments, RN synOcta Temporary Meso Abutment (PEEK; Straumann), RN synOcta Titanium Post for Temporary Restorations (Straumann), and Temporary Abutment Engaging NobRplRP (Nobel Biocare) were used, and provisional screw-retained crowns using composite resin (Solidex) were fabricated for four different locations in the maxilla. The specimens were tested in a universal testing machine at a crosshead speed of 1 mm/minute until fracture occurred. The failure types were analyzed and further categorized as irreparable (Type 1) or reparable (Type 2).

Results: No significant difference was found between different abutment types. Only for the position of the maxillary central incisor, composite resin crowns on PEEK temporary abutments showed significantly lower ($p < 0.05$) fracture strength (95 ± 21 N) than those on titanium temporary abutments ($1{,}009 \pm 94$ N). The most frequently experienced failure types were cohesive fractures of the composite resin crowns (75 out of 104), followed by screw loosening (18 out of 104). According to reparability, the majority of the specimens were classified as Type 1 (82 out of 104). Type 2 failures were not often observed (22 out of 104).

Conclusions: Provisional crowns on PEEK abutments showed similar fracture strength as titanium temporary abutments except for central incisors. Maxillary right central incisor composite resin crowns on PEEK temporary abutments fractured below the mean anterior masticatory loading forces reported to be approximately 206 N.

KEY WORDS: composite resin, dental, failure type, fracture strength, implant-supported, provisional

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INTRODUCTION

Implant-supported fixed partial dentures (FPD) are viable alternatives to conventional full coverage FPDs, especially for restoring missing or failed maxillary anterior teeth. Although single tooth dental implants have become routine in reconstructive dentistry with well-established results,[1–3] restoring anterior teeth with implant-supported single crowns is still considered to be a technique-sensitive task.[4]

The focus of attention in implant dentistry is shifting from "survival" to "quality of survival." Highly aesthetic restorations are becoming important criteria for the definition of success. This involves the establishment of a soft tissue contour that is harmonious with the gingiva of the adjacent teeth, as well as the restoration being in balance with the adjacent dentition.[3,5–7] When an implant is placed with proper three-dimensional orientation in relation to the adjacent teeth, the gingival tissue from the gingival margin to the implant platform can be altered using a provisional restoration at the time of implant placement or second-stage surgery. The anatomical provisional restoration is used for achieving a harmonious soft tissue contour.[5,6,8]

To date, no premanufactured implant components with an anatomical emergence profile exist that suits each situation. This is mainly due to individual anatomical variations in tooth shape, size, and supporting soft and hard tissues. Different approaches have been suggested for fabrication of implant-supported provisional restorations.[4,9] Such restorations could be fabricated either chair side or at the dental laboratory.[6,10–15] Regardless of the method used to fabricate a provisional restoration, development and maintenance of harmonious soft tissue contours before fabrication of the definitive prosthesis is the key objective in implant dentistry. Furthermore, provisional abutments should be able to resist the masticatory forces during service.[16,17]

Provisional solid titanium abutments are commonly used as provisional abutments. A major disadvantage is the color of the titanium.[18] The use of opaque composite resin is recommended to overcome the grayish color of the provisional restorations. Furthermore, the titanium abutment is difficult to process in the dental office, making it difficult for a chair-side approach. As an alternative to titanium, polyetheretherketone (PEEK) temporary abutments have been introduced. PEEK abutments are easy to process chair side and their whitish color makes it easier to achieve a good provisional aesthetic result.[19]

To date, little information is available in the dental literature on the survival rate of provisional implant-supported restorations.[3] It can, however, be assumed that PEEK abutments are less likely to resist masticatory forces than titanium provisional abutments, as their physical properties are inferior to that of metals. A commonly used method to determine whether a restoration can withstand masticatory forces is to evaluate fracture strength of the material used in vitro.[20–22]

With the advances in adhesive technologies, small chippings or fractures could be repaired thereby prolonging service life of failed restorations both functionally and aesthetically.[3,23,24] Such failures may not be influencing the overall survival of temporary crowns.

Therefore, the objectives of this study were to evaluate the fracture strength and failure types of laboratory-made, screw-retained provisional composite resin single-unit crowns on PEEK and titanium abutments and at different locations in the maxilla. The null hypothesis was that no difference in fracture strength exists between PEEK abutments and provisional titanium abutments.

MATERIALS AND METHODS

Experimental Groups

This study included 12 groups consisting of three types of provisional implant abutments veneered with composite resin restorations at four different locations in the maxilla. One additional group (control) comprised all-ceramic, implant-supported crowns. Each group consisted of eight specimens ($N = 104$, $n = 8$ per group). The distribution of groups and materials used are listed in Table 1.

Specimen Preparation

Irreversible hydrocolloid impressions (CA 37, Cavex, Haarlem, The Netherlands) were made of a fully dentate phantom model (KaVo Dental GmbH, Biberach, Germany) of the maxilla and a plaster cast was fabricated. The right central incisor was removed and replaced with an implant analogue (RN synOcta analogue; Institut Straumann AG, Basel, Switzerland) using a drill press. The analogue was placed 2 mm below the cemento-enamal junction. After placement and adjustment of an abutment (RN synOcta titanium Post for Temporary Restorations (Institut Straumann AG), a

TABLE 1 Groups, Location, Brands of Abutments, Manufacturers, Composition, Batch No., Brands of Crown Materials, Manufacturer, Composition, and Batch No. of the Crown Materials

Group	Location	Abutment	Manufacturer	Composition	Batch No.	Crown Material	Manufacturer	Composition	Batch No.
1	11	RN synOcta Temporary Meso Abutment	Institut Straumann AG, Basel, Switzerland	Titanium/PEEK	C7716	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1642 070611 A2B
2	11	RN synOcta Post for Temporary Restorations	Institut Straumann AG, Basel, Switzerland	Titanium	A7044	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1650 110625 C1B
3	11	Temporary Abutment Engaging NobRpl RP	Nobel Biocare AB, Göteborg, Sweden	Titanium	390515	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1650 110625 C1B
4	12	NN Temporary coping	Institut Straumann AG, Basel, Switzerland	Titanium/PEEK	C2138/E2772	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1652 070428 C3B
5	12	NN Coping	Institut Straumann AG, Basel, Switzerland	Titanium	F4805	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1650 110625 C1B
6	12	Temporary Abutment Engaging NobRpl NP	Nobel Biocare AB, Göteborg, Sweden	Titanium	389524	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1656 030416 D4B
7	13	RN synOcta Temporary Meso Abutment	Institut Straumann AG, Basel, Switzerland	Titanium/PEEK	C7716	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1642 070611 A2B
8	13	RN synOcta Post for Temporary Restorations	Institut Straumann AG, Basel, Switzerland	Titanium	A7044	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1643 070683 A3B
9	13	Temporary Abutment Engaging NobRpl RP	Nobel Biocare AB, Göteborg, Sweden	Titanium	390515	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1644 080633 A35B
10	14	RN synOcta Temporary Meso Abutment	Institut Straumann AG, Basel, Switzerland	Titanium/PEEK	E3034	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1646 070416 B1B
11	14	RN synOcta Post for Temporary Restorations	Institut Straumann AG, Basel, Switzerland	Titanium	A7044	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1650 110625 C1B
12	14	Temporary Abutment Engaging NobRpl RP	Nobel Biocare AB, Göteborg, Sweden	Titanium	390515	Solidex	Shofu Inc, Kyoto, Japan	Urethandi-methacrylate	PN1645 010544 A4B
13	11	Procera abutment RP	Nobel Biocare AB, Göteborg, Sweden	Zirconia		Cercon ceram-Kiss	Degudent GmbH, Hanau, Germany	Feldspathic porcelain for layering technique	31271

PEEK, polyetheretherketone.

screw-retained composite resin, single crown was fabricated (Solidex, Shofu, Higashiyama-Ku, Kyoto, Japan). The composite resin was photo-polymerized for 180 seconds using a laboratory polymerization unit (Tecnomedica, Bareggio, Italy). Excess composite resin around the margins was removed and the restorations were finished using finishing burs (FG 863 4,405 L, Intensiv SA, Grancia, Switzerland). After finishing, a vacuum-formed plastic mold (1.8 mm thick) was made (Erkoform 3D, Erkodent Erich Kopp GmbH, Pfalzgrafenweiler, Germany). This mold was used to produce identical composite resin crowns on the abutments (Figure 1). Thereafter, the crowns were polished in sequence (Sof-Lex discs, 3 M ESPE, St. Paul, MN, USA). The process was repeated for each group, with use of the corresponding abutments and implant analogues. The dimensions of the crowns per location are listed in Table 2.

In order to form the control group (screw-retained), a Procera custom abutment (Procera, Nobel Biocare AB, Göteborg, Sweden) was designed using the Nobel Biocare three-dimensional CAD/CAM software, and eight Procera custom abutments were fabricated by the manufacturer. One experienced dental technician veneered the abutments with feldspatic porcelain (Cercon ceram Kiss, Degudent GmbH, Hanau, Germany).

The crowns were mounted on the corresponding implant analogues using a manual torque wrench (Manual Torque Wrench Prosthetic #29165 for Nobel Biocare and the Torque control device #046049 for Straumann) and the screws (titanium) were torqued to 35 Ncm. The analogues were then embedded perpendicular in polymethylmethacrylate (Autoplast, Condular, Wager, Switzerland) up to the analogue neck in the middle of polyvinyl chloride rings (diameter: 2 cm, height: 1.5 cm).

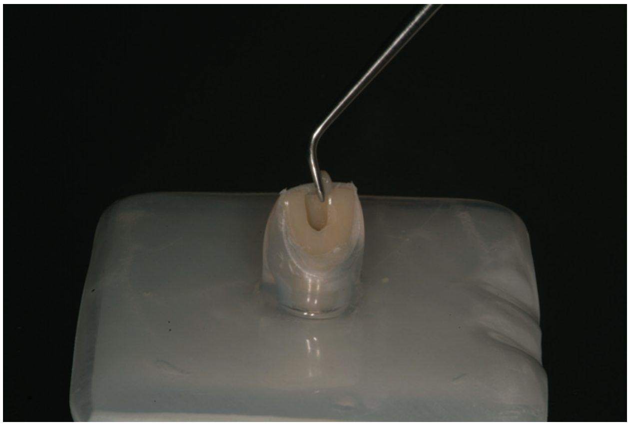

Figure 1 Vacuum-formed plastic mold to produce identical composite resin crowns on the abutments.

TABLE 2 Dimensions (mm) of the Crowns on the Abutments

Tooth	Mesiodistal	Buccolingual	Height
Central incisor	8.7	6.6	11.5
Lateral incisor	7.2	6.3	10.4
Canine	7.5	7.9	11.8
First premolar	6.8	8.1	9.8

Fracture Strength Test

The fracture test was performed in a universal testing machine (Zwick ROELL Z2.5MA, 18-1-3/7, Zwick, Ulm, Germany). In order to simulate the clinical situation as closely as possible, the specimens were mounted in a metal base and load was applied at 137 degrees at a crosshead speed of 1 mm/minute.[25] The spherical loading cell was centrally positioned in the median plane of each crown between the upper end of the cingulum and the incisal edge. Commercially available aluminium foil was folded to achieve a thickness of approximately 1 mm and was placed between the loading cell and the crown to avoid slipping of the load cell. In case of the premolars, load was applied occluso-gingivally perpendicular to the occlusal surface. The maximum load at the universal testing machine was set at 2,000 N. The applied force was graphically recorded on an x-t recorder (Zwick testXpert, Zwick, Ulm).

Failure Analysis

Digital photos (Nikon D100, Nikon GmbH, Düsseldorf, Germany) were taken from each specimen to determine the failure type, location, and size. After analyzing all specimens after the fracture test, four types of failures were recorded: cohesive fracture of the composite resin restoration (CF), adhesive failure between the composite resin and the abutment (AF) (Figure 2), screw loosening (SL), and deformation of implant analogue (DIA) (Figure 3). Failure types were further classified as irreparable (Type 1 ≥ 1/2 fracture of the crown or deformation of the analogue) or reparable (Type 2 ≤ 1/2 fracture of the crown or screw loosening). Some specimens were examined using scanning electron microscopy (JSM 5500, Jeol, Tokyo, Japan).

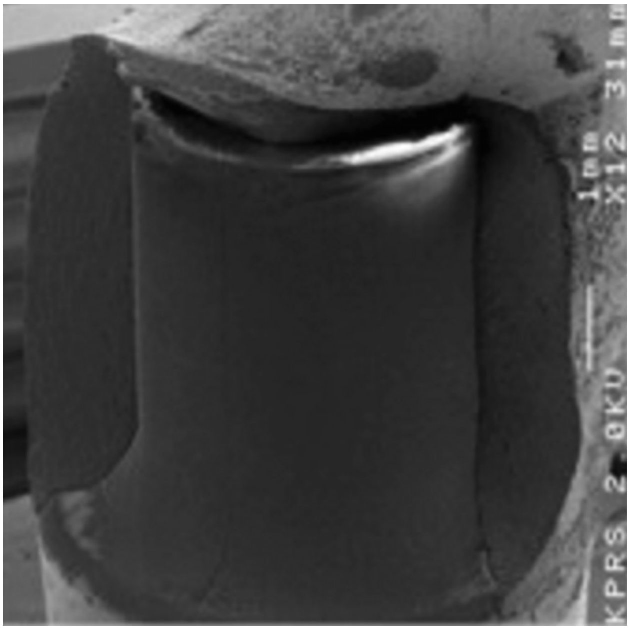

Figure 2 Representative scanning electron microscopy image of adhesive failure on polyetheretherketone.

Statistical Analysis

The statistical analysis was performed with the SPSS software package (version 14.0, SPSS Inc., Chicago, IL, USA). The data were analyzed for differences using one-way analysis of variance (ANOVA). Because of the significant difference ($p < 0.001$) between groups according to ANOVA, multiple comparisons were made using Tukey's *B*-test. *p* Values less than 0.05 were considered to be statistically significant in all tests.

RESULTS

No significant effect of tooth type was found between different abutments types ($p = 0.164$) except for central incisors for which composite resin crowns on PEEK temporary abutments showed significantly lower fracture loads (95 ± 21 N) than those on titanium temporary abutments (1,009 ± 94 N, $p < 0.05$) (Table 3). Overall, mean fracture strength ranged from 95 ± 21 to 486 ± 34 N for composite resin crowns on PEEK abutments and from 387 ± 23 to 1,009 ± 94 N for composite resin crowns on titanium abutments. The ceramic implant supported crowns showed a mean fracture load of 214 ± 60 N.

The most frequently experienced failure types were CF (75 out of 104) followed by SL (18 out of 104). According to reparability, the majority of the specimens were classified as Type 1 (82 out of 104). Type 2 failures were not often observed (22 out of 104; Table 4).

DISCUSSION

Although provisional implant-supported resin crowns are expected to function in the oral environment only for a short period of time ranging from 2 weeks to 3 months, they must be able to resist occlusal forces during function.[5,15] Depending on the duration or complexity of the surgical or reconstructive implant therapy, temporary restorations may function for even a longer period of time. This study was undertaken in order to evaluate the fracture strength of such provisional crowns on different implant abutments.

The average masticatory forces in the anterior region may be as high as 290 N depending on the facial morphology and age.[16] However, mean loading forces for this region are reported to be approximately 206 N.[17] In this in-vitro study, all groups except group 1, fracture strength exceeded the mean maximum masticatory forces. Therefore, the hypothesis could only be partially accepted. Hence it can be assumed that all of the tested provisional restorations except group 1 could withstand intraoral masticatory forces. This assumption is supported by the fact that no test group performed significantly worse than the control group. Furthermore, the fracture strengths found in this study are comparable to those found in other in vitro studies.[21,22]

In this study, abutments were prepared according to the manufacturer's recommendations for the materials

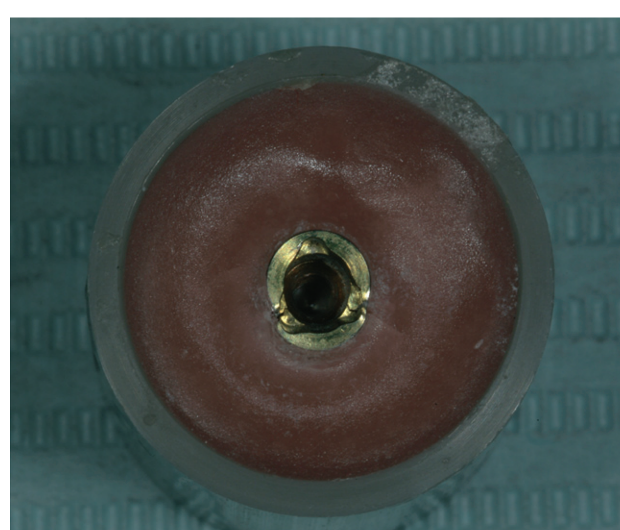

Figure 3 Deformation of the neck of a Replace analogue embedded in polymethylmethacrylate.

TABLE 3 Means (± SD) of Fracture Strength (N) per Experimental Group

Group	*n*	Location	Abutment	Mean (±SD)
1	8	11	RN synOcta Temporary Meso Abutment	95 (±21)^{A}
2	8	11	RN synOcta Post for Temporary Restorations	787 (±74)^{F}
3	8	11	Temporary Abutment Engaging NobRpl RP	1009 (±94)^{G}
4	8	12	NN Temporary coping	277 (±40)^{B}
5	8	12	NN Coping	553 (±36)^{E}
6	8	12	Temporary Abutment Engaging NobRpl NP	387 (±23)^{C}
7	8	13	RN synOcta Temporary Meso Abutment	486 (±34)^{D,E}
8	8	13	RN synOcta Post for Temporary Restorations	650 (±74)^{F}
9	8	13	Temporary Abutment Engaging NobRpl RP	495 (±61)^{D,E}
10	8	14	RN synOcta Temporary Meso Abutment	371 (±22)^{C}
11	8	14	RN synOcta Post for Temporary Restorations	441 (±51)^{C,D}
12	8	14	Temporary Abutment Engaging NobRpl RP	474 (±42)^{D,E}
13	8	11	Procera abutment RP	214 (±60)^{B}

The same capital letters indicate no significant differences (Tukey's *B* test, $\alpha = 0.05$).

investigated. However, especially in group 1, the Straumann RN synOcta Temporary Meso Abutment had to be aggressively reduced in size in order to fit the mold used to fabricate the composite resin crown. Although it cannot be stated whether the results are solely due to the adjustment problem caused by reduction of the abutment, a more conservative preparation would possibly yield higher fracture strengths of the crowns. Furthermore, the flat palatal surface morphology of the central incisors was more in surface contact with the ball shaped loading cell than the other teeth where more point contact was observed. Therefore the central incisors were less able to tolerate the rotational forces.

Fracture resistance of all-ceramic single crowns on implants was evaluated in a study by Yildirim and colleagues where Al_2O_3 and ZrO_2 abutments on Brånemark implants were restored with glass-ceramic crowns.[22] The statistical analysis showed significant differences between both groups, with mean fracture load values of 280 N and 737 N for Al_2O_3 and ZrO_2 abutments, respectively. Similar to the current study, no artificial aging was applied. Our results with composite resin are comparable to the results obtained for Al_2O_3 and ZrO_2 abutments. Because the goal was to test the materials for temporary purposes, no adhesive procedure was conducted. In another in vitro study, fracture resistance of single tooth implant-supported all-ceramic restorations (Replace) was tested for Ti, Al_2O_3, and ZrO_2 abutments on implants restored with alumina crowns (Procera).[21] The crowns were adhesively luted using resin cement (Panavia 21), artificially aged through dynamic loading and thermal cycling and thereafter subjected to static

TABLE 4 Distribution and Frequency of Failure Types per Group

Groups	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
CF	6	1	2	7	6	7	6	8	8	8	8	8		75
AF	2			1			2							5
SL		5	2		2	1							8	18
DIA		2	4											6
Type 1	8	5	4	7	6	7	6	8	8	7	8	8		82
Type 2		3	4	1	2	1	2			1			8	22

CF, cohesive fracture of the composite resin restoration; AF, adhesive failure between the composite resin and the abutment; SL, screw loosening; DIA, deformation of implant analogue; Irreparable, Type 1 ≥ 1/2 fracture of the crown or deformation of the analogue; Reparable, Type 2 ≤ 1/2 fracture of the crown or screw loosening.

loading. The median fracture strengths were found to be 1,454 N, 422 N, and 443 N for Ti, Al_2O_3, and ZrO_2, respectively. Because a short-term durability was the focus of this study, a direct comparison could not be made because the lack of adhesive cementation and aging conditions. The obtained results of this study need to be verified under fatigue conditions in future studies. However, the duration of fatigue loading for temporary restorations has not been defined in the dental literature.

The fracture strength results should be considered in combination with the failure types. Screw loosening and deformation of implant analogues appeared to be a major failure type in the temporary titanium abutments groups (10/64). Failure analysis of the fractured crowns showed mainly cohesive fractures of the composite resin for the test groups. Fracture of the abutment was observed neither in Ti nor in PEEK abutments, indicating that both temporary abutments could be indicated.

In this study, a static mechanical test in dry conditions was used. The application of the load cell should have a direct contact without any lubricant such as saliva or water in the environment. The presence of such aqueous media may result in slipping/sliding of the loading jig in an uncontrolled manner. The existence of such liquid media as found in the oral environment may accelerate crack propagation in the aqueous media.[20]

The majority of the failures covered more than half the size of the entire restoration and were therefore considered to be irreparable. Only in the PEEK groups were some incidences of adhesive splitting between the abutment and the composite resin observed. When such failures have to be repaired, adhesion between the PEEK material and the composite resin could be of future topic.

In this study, only the teeth in the aesthetic zone, namely the incisors, canines, and the first premolars were considered. The results of this study may vary depending on the morphology of the posterior teeth and the elastic modulus of the chosen composite resin material for the crowns.

CONCLUSIONS

From this in vitro study, the following could be concluded:

1 Composite resin crowns on PEEK abutments showed significantly lower mean fracture strength compared with those on titanium temporary abutments for central incisors. For other locations in the aesthetic zone of the maxilla, no significant differences were found between fracture strengths on PEEK and titanium abutments.
2 In general, irreparable failure types were more common than reparable ones in all groups.

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