Influence of fatigue on resistance and deformation of implant abutments used for provisional prosthetic restoration

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Abstract

Objective

One of the most difficult challenges for implant-supported prosthetic restorations is the management and maintenance of periimplant soft-tissue esthetics, especially in the anterior region. In order to do this effectively, there are diverse techniques for tissue management, the most significant being fixed provisionalization, which can be immediate or delayed. The aim of this study was to analyze fracture resistance of provisional implant-prosthetic abutments (titanium, PEEK and methacrylate) and to determine whether previously fatiguing the abutments influenced fracture resistance.

Materials and methods

Forty implant-prosthetic abutments underwent static load testing; 20 of these were subjected to fatiguing before load testing. Forty internal hex connection implants supported the 40 abutments: ten titanium provisional abutments, ten castable methacrylate provisional abutments, ten PEEK resin provisional abutments and ten titanium definitive abutments.

Results

The group that showed the greatest fracture resistance was the nonfatigued definitive titanium abutments, with values over 1,000 N. The abutments that showed the lowest fracture resistance were the fatigued castable methacrylate provisional abutments, with a mean value of 192.8 N.

Conclusion

Fatiguing the abutments did not significantly influence their fracture resistance or elastic behavior. All of the abutments studied fulfilled the mechanical requirements for survival in the mouth.

Keywords

Dental implant, provisional/definitive implant abutment, fatiguing, immediate loading.

Introduction

In the field of dentistry, implant dentistry is one area that has undergone extensive development in recent years, owing to the high demand for this treatment and constant innovation and research into new materials and attachments. Implant placement has become the first treatment choice for replacing missing teeth, particularly single teeth, because of the excellent clinical results confirmed by long-term research.[1] Nowadays, esthetics is an important factor in judging the final outcome of dental treatment. In the case of implant dentistry, various factors influence esthetics. It is not enough to place a natural-looking restoration with correct proportions and adequate color, for a successful outcome will also depend on management of the periimplant soft tissue.[2] This is not always straightforward, as the soft tissue is governed by multiple factors: the periodontal biotype, alveolar bone crest level, angle of implant insertion, depth of implant platform and level of the first point of bone-to-implant contact.[3] Given this scenario, achieving optimal esthetic results is a complicated process. A diverse range of techniques are available for soft-tissue management. From the prosthodontic perspective, provisional prostheses are useful to help model the surrounding tissue and create a harmonious profile before placing the definitive restoration.[4] Furthermore, provisional restorations help improve communication with the patient, as they offer the opportunity to view future outcomes.[2]

For all these reasons, dental professionals need to be aware of the different materials available on the market, as well as their physical and chemical properties, for the correct fabrication of both provisional and definitive prostheses that will achieve optimal esthetics and good peri-implant health.[3–11] Provisional restoration can be useful as a diagnostic tool too, as it allows the dentist to assess the final outcome in advance and provides an opportunity to obtain the patient's feedback and opinion. Its main function is to guide and shape the soft tissue during healing and maturation, allowing the tissue to develop more quickly and suggest the definitive gingival shape.[12–29]

This study was designed with the following objectives:

– to analyze the deformation and fracture resistance of implant-supported provisional abutments made of different materials (titanium, PEEK and methacrylate)
– to determine whether fatiguing prior to static load testing influenced fracture resistance and deformation of the abutments.

Materials and methods

Materials

Forty Kohno internal hex connection implants (Sweden & Martina, Due Carrare, Italy) were used (4.25 mm in diameter and 11.5 mm in length). Forty abutments were screwed on to the implants, 30 of which were provisional and ten definitive (n = 40). The abutments were divided into four groups **(Table 1)**: castable methacrylate provisional (CMP) abutments with a titanium base; PEEK (polyether ether ketone) provisional (PP) abutments with a machined titanium base; Grade III titanium provisional (TP) abutments; and Grade IV titanium definitive (TD) abutments.

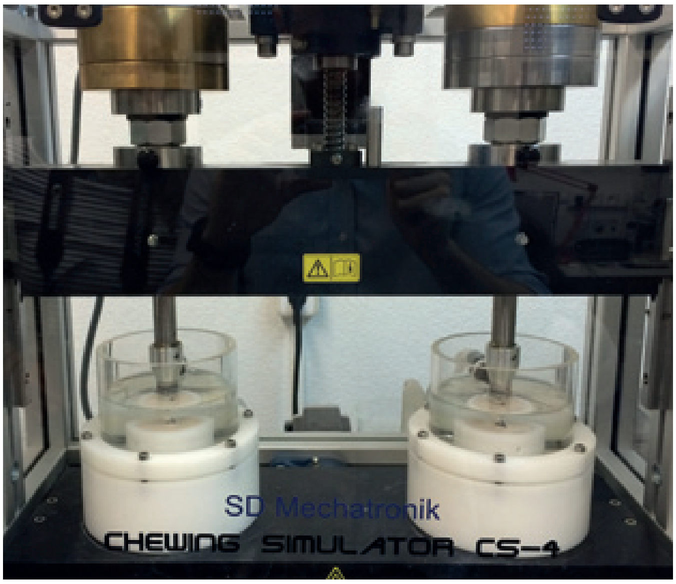
Forty specimens were fabricated, each consisting of an implant set in a 5 cm diameter nylon cylinder with epoxy resin (Exakto-Form, bredent, Senden, Germany). In order to simulate implant

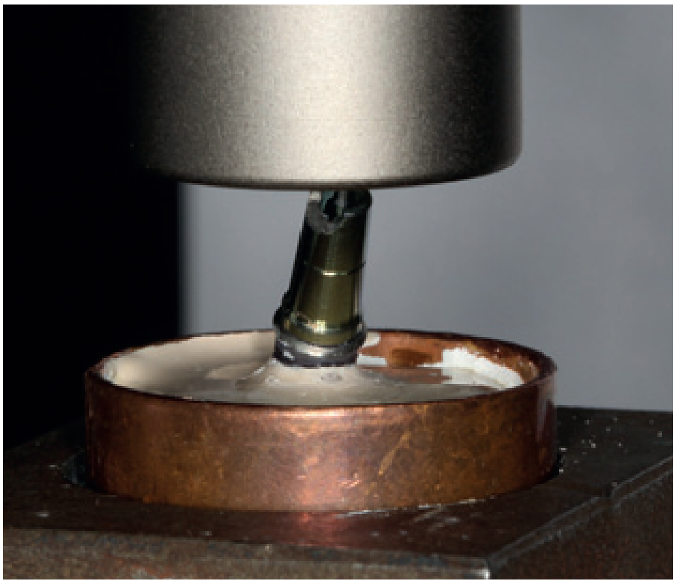
Table 1

Group	Abutment type	Connection
CMP	Castable methacrylate provisional abutments with a machined titanium base	Anti-rotational
PP	PEEK provisional abutments	Anti-rotational
TP	Grade III titanium provisional abutments	Anti-rotational
TD	Grade IV titanium definitive abutments	Anti-rotational

Table 1

Specimen distribution by abutment type





Figs. 1 & 2

Fig. 1

Cyclic loading of implant-supported abutments.

Fig. 2

Static load testing of implant-supported abutments.

position conditions in the alveolar ridge in the premaxilla, specimens were placed in the cylinder at an angle of 30° to the direction of the load. The abutments were screwed on to the implant–cylinder complex using a dynamometric torque wrench, applying a torque of 30 N, as recommended by the manufacturer.

Method

Before specimens underwent static load testing, they were subjected to dynamic loading. This fatiguing process was performed using a chewing simulator (CS-4, SD Mechatronik. Rosenheim, Germany; **Fig. 1**). Loading was applied to the upper part of the abutment (angled at 30°) with an impact force of 80 N and a frequency of 2 Hz. Each specimen was subjected to 60,000 cycles at an application speed of 40 mm/s. They then underwent thermocycling (Thermocycler 2000, Heto-Holten A/S, Allerod, Denmark) for 6000 cycles with temperature changes between 5°C and 55°C every 30 seconds.

Static compression load testing was used to evaluate the abutments' fracture resistance. The testing was performed using a static load testing machine (AG-X plus, Shimadzu, Kyoto, Japan). A load cell of 5,000 N was used at a crosshead speed of 0.5 mm/min **(Fig. 2)**.

Statistical analysis consisted of preliminary descriptive analysis of the force (fracture resistance) and deformation variables (mean, standard deviation, range and median). Comparisons were made adopting a nonparametric approach. Significance was set at 5% ($p = 0.05$).

Results

The results obtained registered the force in Newtons (N) required to produce the fracture of each specimen **(Tables 2 & 3)**. Fracture of the prosthesis was understood as the first mechanical failure that the specimen underwent, whether this was the maximum load that produced a clearly observed fracture or the maximum load before the test machine registered a decrease in load even if the fracture was not visibly obvious. Fracture resistance values for two specimens (not subjected to fatiguing) were discarded owing to failure to fulfill the study procedure. The same also occurred with two specimens subjected to fatiguing.

Table 4 shows the descriptive data by group for fracture resistance in specimens not subjected to fatiguing. The group that presented the highest resistance to fracture was the TD group and the group that showed the least resistance was the PP group, with mean values of 1,106.7 N and 329.4 N, respectively. The groups that presented the lowest resistance to fracture were CMP and PP, obtaining values of between 300 N and 400 N. Fracture resistance levels were heterogeneous, as the Kruskal–Wallis test confirmed that there was no homogeneity in the distribution of resistance across the four groups ($p = 0.006$).

When the Mann–Whitney test was applied to identify differences between pairs of groups, CMP showed lower resistance than TP ($p = 0.032$) and TD ($p = 0.016$), with the differences being statistically significant. PP restorations obtained lower resistance than the TP ($p = 0.016$) and TD

Table 2

Specimen	CMP	PP	TP	TD
1	370.0	355.0	878.7	937.2
2	359.3	198.0	1089.0	No data
3	192.0	382.0	1403.0	1022.0
4	579.5	254.0	571.0	854.5
5	352.9	485.0	No data	1613.0

Table 2

Fracture resistance (N) for implant-prosthetic abutments not subjected to fatiguing.

Table 3

Specimen	CMP	PP	TP	TD
1	No data	304.8	675.3	1289.0
2	173.6	340.9	904.9	1578.0
3	194.5	282.6	810.3	1521.7
4	No data	432.8	566.5	1397.7
5	210.3	340.8	485.9	1086.3

Table 3

Fracture resistance (N) for implant-prosthetic abutments subjected to fatiguing.

Table 4

	CMP	PP	TP	TD
N	5	5	4	4
Mean	370.7	329.4	985.4	1106.7
Standard deviation	137.8	103.6	350.3	344.4
Minimum	192.0	198.0	571.0	845.5
Maximum	579.5	458.0	1403.0	1613.0
Median	359.3	355.0	983.9	979.6

Table 4

Descriptive data by group for abutments not subjected to fatiguing (N).

Table 5

	CMP	PP	TP	TD
N	3	5	5	5
Mean	192.8	340.4	688.6	1373.5
Standard deviation	18.4	57.3	171.7	196.2
Minimum	173.6	282.6	485.9	1086.3
Maximum	210.3	432.8	904.9	1578.0
Median	194.5	340.8	675.3	1397.7

Table 5

Descriptive data by group for abutments subjected to fatiguing (N).

Table 6

Specimen	CMP	PP	TP	TD
1	1.509	0.977	3.937	1.599
2	2.362	1.463	1.899	No data
3	3.991	2.349	3.530	1.379
4	1.811	2.313	1.349	0.733
5	2.645	2.694	No data	1.316

Table 6

Deformation data (mm).

Table 7

Deformation data (mm).

Specimen	CMP	PP	TP	TD
1	No data	2.330	0.867	0.825
2	0.794	2.222	3.796	0.845
3	1.449	2.006	2.258	0.978
4	No data	2.345	3.978	0.921
5	1.897	1.476	1.967	0.978

Table 7

Table 8

Descriptive deformation data by group for abutments not subjected to fatiguing (mm).

	CMP	PP	TP	TD
N	5	5	4	4
Mean	1.3	1.6	1.9	1.3
Standard deviation	0.3	0.7	1.1	0.4
Minimum	0.9	0.6	1.2	0.7
Maximum	1.6	2.3	3.5	1.6
Median	1.4	1.4	1.6	1.3

Table 8

Table 9

Descriptive deformation data by group for abutments subjected to fatiguing (mm).

	CMP	PP	TP	TD
N	3	5	5	5
Mean	1.4	2.1	2.6	0.9
Standard deviation	0.6	0.4	1.3	0.1
Minimum	0.8	1.5	0.9	0.8
Maximum	1.9	2.3	4.0	1.0
Median	1.4	2.2	2.3	0.9

Table 9

groups (p = 0.016), with the differences being statistically significant. The performance of the TP group was similar to that of the TD group (p = 0.886). CMP and PP were also homogenous, but with a significantly lower resistance than the other two groups (p = 1.000).

In a comparison of the statistical data for fracture resistance of restorations subjected to fatiguing **(Table 5)**, the group that showed the highest resistance was the TD group (1,373.5 N). The groups with the lowest resistance were PP and CMP; both groups obtained values of between 200 N and 350 N. Fracture resistance levels were heterogeneous, and the Kruskal–Wallis test confirmed that there was no heterogeneity in the distribution of resistance across the four groups (p < 0.001).

When resistance distribution was compared between pairs of groups of fatigued specimens, statistically significant differences were identified for all comparisons. Unlike the groups not subjected to fatiguing, no group of fatigued specimens presented a homogenous distribution of resistance when paired comparisons were made.

CMP restorations showed lower fracture resistance than the rest of the groups, with the differences being statistically significant (PP: p = 0.036; TP: p = 0.036; TD: p = 0.036). The PP group also showed lower resistance than TP (p = 0.008) and TD specimens (p = 0.008), with the differences being statistically significant.

In making a comparative analysis between the specimens subjected to fatiguing and those that were not fatigued, a slight decrease in fracture resistance was observed among all of the provisional restorations subjected to fatiguing (CMP, PP and TP). However, the TD group showed stable performance despite cyclic loading, such that its performance was not affected by fatiguing. The Mann–Whitney test was applied to evaluate differences between fatigued and nonfatigued specimens and a p-value of 0.401 was obtained, indicating that resistance to fracture was similar between the two groups (fatigued/nonfatigued). Likewise, within the individual groups, no significant differences were found between fatigued or nonfatigued subgroups (CMP: p = 0.143; PP: p 1.000; TP: p = 0.190; TD: p 0.286), although the CMP and TP groups did show a certain tendency toward difference, but this did not reach statistical significance.

In data analysis of the deformation that the restorations suffered up to the point of fracture or mechanical failure (in mm; **Tables 6 & 7**), deformation values for specimen 2 in the TD group and specimen 5 in the TP group (not fatigued) were discarded from analysis owing to various technical failures in the study procedure. The same occurred with two specimens (1 and 4) in the CMP group (subjected to fatiguing).

In deformation data analysis of groups not subjected to fatiguing **(Table 8)**, it was found that the group that presented the highest deformation values was the TP group. The group with the least deformation was the TD group. The PP and CMP groups showed similar median values, but a dispersed range of values. The Kruskal–Wallis test showed that there were no overall significant differences (p = 0.187). The Mann–Whitney test found that the only significant difference occurred between the CMP and TD groups, the TD group showing the lowest deformation values (CMP–PP: p = 0.421; CMP–TP: p = 1.000; PP–TP: p = 0.556; CMP–TD: p = 0.032; PP–TD: p = 0.190; TP–TD: p = 0.114).

As for deformation data analysis of specimens subjected to fatiguing **(Table 9)**, the TD and CMP groups underwent the least deformation. The PP and TP groups showed similar median values, but the range of values was more widely dispersed in the TP group. The group that underwent the greatest deformation was the TP group. When homogeneity was analyzed between groups, the Kruskal–Wallis test found a p-value of 0.022, indicating homogeneity between the groups. The Mann–Whitney test for paired groups only identified statistically significant differences between the TD and PP groups, with the TD group obtaining lower deformation values (CMP–PP: p = 0.071; CMP–TP: p = 0.143; PP–TP: p = 0.841; CMP–TD: p = 0.571; PP–TD: p = 0.008; TP–TD: p = 0.056). In order to determine whether fatigue influenced deformation, specimens subjected to fatiguing were compared with those not subjected to fatiguing, but no significant differences were found (CMP: p = 0.143; PP: p = 1.000; TP: p = 0.905; TD: p = 0.286).

Discussion

Nowadays, many patients regard dental esthetics as one of the principal requirements of dental treatment. In the case of implant dentistry, a range of factors influence esthetic outcomes, including color, contour, the natural appearance of the definitive prosthesis, and most importantly, the topography and appearance of the peri-implant soft tissue.[2] Soft-tissue management is not straightforward, as multiple factors affect the final outcome, in which the provisional prosthesis plays a key role.[2, 4] Given the importance of provisionalization as a part of dental implant treatment, the present study set out to evaluate the resistance to fracture of implant-supported provisional prostheses of different materials (titanium, PEEK resin and methacrylate) subjected to fatiguing. While definitive prostheses have been extensively studied, little research has investigated fracture resistance and the influence of fatigue on provisional abutments *in vitro*.

The present study protocol was designed to fulfill the test geometry specified in ISO 14801:2007 for testing single-post endosseous dental implants, in that the implant made a 30° angle with the test machine's load cell.[30–39] This geometry has been used in most other studies of similar characteristics to the present one.[34–37] The material used to set the implant in the cylinder—epoxy resin—was chosen for its elastic modulus > 3 GPa, also required by ISO 14801:2007, and because this material has been used in similar studies too.[30–37] All of the abutments were tested without placing restorations on them, as was the case in Truninger et al., in which the abutments were subjected to load testing without bearing restorations.[35] Likewise, Rack et al. tested abutments without placing restorations on them, but soldered a steel sphere of 10 mm in diameter to the coronal part of the abutment so that the force applied would be evenly distributed throughout the abutment structure.[33]

The choice of test design was based on Agustín-Panadero et al., who studied provisional abutments subjected to static loading.[5] Various authors have proposed similar variables to the present test design in terms of specimen design and distribution, as well as crosshead speed and movement.[30–35] The crosshead speed in compression testing in this study was 0.5 mm/min, a speed established from the literature review conducted in preparation for the study to ensure use of the same speed used in the majority of other similar studies (standardization being important when it comes to comparison of studies).[30–36] However, pure compression studies do appear to be adequate for researching the fracture resistance of implant-prosthetic structures. The ideal procedure in a study of these characteristics is to subject specimens to dynamic loading–artificial aging of the specimens–before performing the static load testing. For this reason, the present study divided the specimens ($n = 40$) into two subgroups and subjected half to a prior fatiguing process to simulate the aging of the abutments. Like compression testing, the fatiguing process must meet criteria established in ISO 14801:2007.[39]

The literature contains several studies that have subjected specimens to aging prior to testing.[27, 28, 30, 34–39] Stimmelmayr et al. used the same test machine (Mechatronic), the same specimen distribution and frequency parameters (1.2 Hz), as well as impact speed (10 mm/s), as the present work[36] to determine the fracture resistance of fatigued zirconia abutments. Artificial aging or dynamic loading reproduces conditions in the mouth to which the implant-prosthetic abutments are exposed, reducing their fracture resistance evaluated by static load compression testing.[27, 28, 30, 34–39] Several studies have observed that the use of substances that simulate saliva, creating a moist environment, generates environmental conditions that negatively affect the fatigued implant abutment.[27, 28] Steinebrunner et al. carried out fatigue testing of implant-prosthetic abutments submerged in artificial saliva, imitating intra-oral conditions in order to evaluate the influence of the fluid medium.[28] A control group was made up of specimens subjected to fatiguing in ambient air. The results showed that the artificial saliva acted as an aggressive environment, affecting the implants' fracture resistance.[28] The oral environment is clearly an important factor to consider when evaluating dental implants' mechanical properties and that the present study did not simulate oral conditions by exposing specimens to artificial saliva can be considered a significant limitation.

To date, few studies have provided scientific evidence in relation to provisional abutments, while definitive abutments have been extensively studied. The range of fracture resistance values obtained in similar studies is 714–906 N.[28, 34, 35] The data obtained in the present study for the definitive abutments (TD), whether subjected to fatiguing or not, and the TP abutments not subjected to fatiguing fall within this range and even exceed them. Sannino and Barlattani obtained values of 906 N in static load testing of definitive titanium abutments.[34] Truninger et al. evaluated the fracture resistance of zirconia abutments, using titanium abutments as a control group, and obtained a mean value of 714 N.[35] It is important to consider the fracture resistance levels cited in the literature that implant-prosthetic abutments must support in the oral environment under normal conditions. Ferrario et al. affirmed that the occlusal load that a single tooth must support in the anterior region is 150 N; this study included 52 patients who used a bite force transducer to register occlusal force.[38] In this scenario, the present results confirm that all of the abutments analyzed, whether subjected to fatiguing or not, fulfilled the requirements for survival in the anterior region.

Conclusion

The Grade IV titanium definitive abutments obtained the highest fracture resistance and deformation values. The nonfatigued PEEK resin provisional abutments and fatigued castable methacrylate provisional abutments obtained the lowest fracture resistance values. The Grade III titanium provisional abutments showed the highest deformation values. Fatiguing did not influence fracture resistance significantly or the abutments' elastic performance. All of the abutments tested fulfilled the mechanical requirements for survival in the oral environment.

Competing interests

The authors declare that they have no competing interests related to this study. No financial support was received for this study.

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