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Comparative Evaluation of Fracture Resistance and Mode of Failure of Zirconia and Titanium Abutments with Different Diameters

[1]Reza Shabanpour, [2]Niloufar Mousavi, [3]Safoura Ghodsi, [4]Marzieh Alikhasi

ABSTRACT

Aim: The purpose of the current study was to compare the fracture resistance and mode of failure of zirconia and titanium abutments with different diameters.

Materials and methods: Fourteen groups of abutments including prefabricated zirconia, copy-milled zirconia and titanium abutments of an implant system (XiVE, Dentsply) were prepared in different diameters. An increasing vertical load was applied to each specimen until failure occurred. Fracture resistance was measured in each group using the universal testing machine. Moreover, the failure modes were studied and categorized as abutment screw fracture, connection area fracture, abutment body fracture, abutment body distortion, screw distortion and connection area distortion. Groups were statistically compared using univariate and post-hoc tests. The level of statistical significance was set at 5%.

Results: Fabrication method ($p = 0.03$) and diameter ($p < 0.001$) had significant effect on the fracture resistance of abutments. Fracture resistance of abutments with 5.5 mm diameter was higher than other diameters ($p < 0.001$). The observed modes of failure were dependent on the abutment material as well. All of the prefabricated titanium abutments fractured within the abutment screw. Abutment screw distortion, connection area fracture, and abutment body fracture were the common failure type in other groups.

Conclusion: Diameter had a significant effect on fracture resistance of implant abutments, as abutments with greater diameters were more resistant to static loads. Copy-milled abutments showed lower fracture resistance as compared to other experimental groups.

Clinical significance: Although zirconia abutments have received great popularity among clinicians and even patients selecting them for narrow implants should be with caution.

Keywords: Copy milling, Diameter failure mode, Fracture resistance.

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[1]Department of Prosthodontics, Azad Dental School Tehran, Iran

[2]Department of Prosthodontics, Dental Research Center School of Dentistry, Tehran University of Medical Sciences Tehran, Iran

[3,4]Department of Prosthodontics, Dental Research Center Dentistry Research Institute, Faculty of Dentistry, Tehran University of Medical Sciences, Tehran, Iran

Corresponding Author: Marzieh Alikhasi, Associate Professor Department of Prosthodontics, Dental Research Center, Faculty of Dentistry, Tehran University of Medical Sciences, North Amirabad, Tehran, Iran, Phone: +989122014160 malikhasi@tums.ac.ir, m_alikhasi@yahoo.com

INTRODUCTION

The efficiency of titanium dental implants for replacing teeth in the oral cavity is well documented, as these abutments are biocompatible and have acceptable mechanical properties.[1] However, even when placed subgingivally, a dull gray background may compromise the esthetic results of these abutments.[2,3] Because of high implant survival and success rates in treating single, partial or total edentulism, the esthetic outcome has become the main focus of interest in esthetically sensitive areas.[4,5] Hence, all ceramic abutments were introduced in 1991 to evade discoloration at the cervical margin.[6] Although these abutments show esthetically optimal results, their strength and fatigue resistance compared to metal abutments, remain a concern.[2] Aluminum oxide abutments have the advantage of optical translucency, shade and appropriate fit within the implant. However, they are sometimes not strong enough to endure the masticatory forces.[7] Moreover, zirconia abutments are gaining popularity because of their light transmittance quality and color, as well as the reported high fracture resistance.[8,9] Assumed that the reported peak values for occlusal force in the incisal area is in the range of 90 to 370 N, a durable, esthetic restoration should resist such forces.[10,11] Alumina fracture resistance (239 ± 83 N) is poor as compared to titanium (324 ± 85 N) or zirconia (294 ± 53 N).[3,11,12]

Zirconia abutments that are available in dentistry exist in various forms. They could be either prefabricated or custom-made. Prefabricated zirconia abutments, which could be completely or partially in zirconia, are usually made using computer aided designed/computer assisted manufactured (CAD/CAM) systems.[13] Although, prefabricated abutments are uniform, standardized, easy to use and have an excellent fit, they cannot always provide the optimal morphology and esthetic, such as desired tooth dimensions and soft tissue contours.[11,13,14] The aforementioned criteria can be achieved by customized ceramic abutments fabricated using either CAD/CAM, MAD/CAM (manually aided designed/computer aided manufactured), or MAD/MAM (manually aided designed/manually aided manufactured or copy milled) systems.[15]

On the other hand, there are various implant systems with different implant diameters that are subjected to use zirconia abutments. Stimmelmayr et al compared the fracture resistance of 3.75 and 5.5 mm diameter CAD/CAM one piece zirconia abutments with zirconia abutments containing titanium cores.[16] They reported that the fracture strength of the implant abutment increased with the implant diameter and the fracture strength of zirconia abutments connected to titanium cores was significantly higher than the fracture strength of one-piece zirconia abutments.[16] Although zirconia abutments including abutments fabricated using copy-milled technique are available for clinical use, there have been very few laboratory studies investigating the fracture resistance of these abutment assemblies.[17,18] Moreover, the influence of diameter is discussed in neither of them.

Therefore, this *in vitro* study was performed to compare the fracture resistance and mode of failure of zirconia and titanium abutments with different diameters. The null hypotheses were that abutment diameter, fabrication technique and abutment material would not affect the fracture resistance of the assembly.

MATERIALS AND METHODS

Prefabricated zirconia, copy-milled zirconia and titanium abutments of an implant system (XiVE, Dentsply-Friadent, Mannheim, Germany) were prepared in different diameters. Description of all 14 groups is presented in Table 1. Ten specimens were constructed for each group. Copy-milled zirconia abutments were fabricated with respect to prefabricated titanium and zirconia-metal abutments using Zirkonzahn (Zirkonzahn GmbH, Gais, Italy) device. The technician fixed the model in the copy-milling unit (Zirkonzahn) and milled it by means of milling burs in partially yttrium-stabilized zirconia (Y_2O_3) green stage blocks, according to the manufacturer's directions. Afterwards, the abutments were sunk in the color covering liquid, and then dried under red lamp. The zirconia abutments were then subjected to a sintering process at 1,500°C in the sintering oven for 8 hours.

All abutments were connected to their corresponding implants using 24 N/cm torque (Electronic torque wrench, Implant innovations, Palm beach, FL, USA), following the manufacturer's instructions. The implant, abutment screw and the abutment combination were hereafter referred to as 'abutment assembly'. A stainless steel jig was fabricated to hold the specimens in a position so that the long axis of the implant fixture was tilted in a 30° angulation.[11,18-21] To prevent inadvertent surface damage by the loading stylus on the zirconia abutment and to further control loading, a thin layer (0.1 mm) of mylar film was inserted between the stylus and the abutment. A vertical load was applied to the incisal edge (crosshead speed = 0.1 mm/min). The load increased with this speed until failure occurred. Fracture resistance was measured for all specimens in each group using the universal testing machine (Germany 2050, Zuick/Roell) and statistically analyzed. After fracture resistance tests, the failure modes were studied and categorized as abutment screw fracture, connection area fracture, abutment body fracture, abutment body distortion, abutment screw distortion and connection distortion.

Table 1: Descriptive data regarding abutment groups

Fabrication method	*Material*	*Diameter (mm)*	*Group name*
Prefabricated	Titanium	3.4	PT3.4
		3.8	PT3.8
		4.5	PT4.5
		5.5	PT5.5
	Zirconia metal	3.4	PZM3.4
		3.8	PZM3.8
		4.5	PZM4.5
		5.5	PZM5.5
	Zirconia	3.8	PZ3.8
		4.5	PZ4.5
Custom made	Zirconia	3.4	CZ3.4
		3.8	CZ3.8
		4.5	CZ4.5
		5.5	CZ5.5

STATISTICAL ANALYSIS

Normal distribution of the data was tested using Kolmogorov-Smirnov test. Univariate and post-hoc tests were used to assess the influence of abutment diameter, material and fabrication method on fracture resistance of the specimens. The level of statistical significance was set at 5%.

RESULTS

Fracture Resistance

Mean fracture resistance of all groups have been categorized by their material and fabrication method (Table 2). Univariate analysis showed that fabrication method ($p = 0.03$) and diameter ($p < 0.001$) had significant effect on the fracture resistance of abutments. Results of post-hoc Tukey HSD test showed that fracture resistance of abutments with 5.5 mm diameter was higher than other diameters ($p < 0.001$). Also, fracture resistance of abutments of 3.4 and 3.8 mm diameter were statistically lower than 4.5 mm diameter abutment ($p = 0.003$ and 0.001, respectively). Moreover, it was observed that in the 5.5 and 3.4 mm groups, copy-milled abutments showed the lowest fracture resistance in comparison with prefabricated groups of the respective diameter ($p = 0.03$).

Modes of Failure

All of the prefabricated titanium abutments fractured within the abutment screw. Zirconia-metal abutments showed two modes of failure: abutment screw distortion (50% of specimens) and body fracture (50% of specimens). Prefabricated zirconia abutments with 3.8 mm diameter fractured within the abutment body while the same abutments with 4.5 mm diameter underwent connection area fracture. Fracture mode in all groups of custom made abutments was the same and happened at the connection area, except two of these abutments with 3.8 mm diameter which failed in form of abutment screw distortion (Figs 1 to 4).

Table 2: Various abutment groups and their mean fracture resistance

Fabrication method	*Material*	*Diameter (mm)*	*Group name*	*Mean (SD)*
Prefabricated	Titanium	3.4	PT3.4	597.96 (54.35)
		3.8	PT3.8	500.59 (43.21)
		4.5	PT4.5	740.08 (32.12)
		5.5	PT5.5	1120.02 (52.01)
	Zirconia metal	3.4	PZM3.4	605.08 (63.64)
		3.8	PZM3.8	426.79 (86.29)
		4.5	PZM4.5	822.79 (231.09)
		5.5	PZM5.5	1286.02 (135.58)
	Zirconia	3.8	PZ3.8	688.48 (109.47)
		4.5	PZ4.5	838.99 (99.62)
Custom made	Zirconia	3.4	CZ3.4	286.81 (257.05)
		3.8	CZ3.8	451.21 (124.61)
		4.5	CZ4.5	725.04 (200.78)
		5.5	CZ5.5	989.54 (98.22)

DISCUSSION

Fracture of dental implants, abutments and screws is a potential mechanical complication that poses an important and difficult challenge. A systematic review on survival and complications of rehabilitation of dental implants showed that fracture of abutments and screws occurred in 1.5% of abutments after a follow-up time of 5 years and in 2.5% after 10 years.[22] The present study investigated several groups of abutments made from different materials and with various diameters to assess the effect of abutment material and dimension on the fracture resistance of the abutment assembly. This investigation did not include a full veneer crown in the model system, which is in accordance with previous studies.[11,16,23] Yildirim used crowns on zirconia abutments

Fig. 1: Screw distortion in 4.5 mm zirconia metal abutment

Fig. 2: Screw fracture in 3.4 mm titanium abutment

Fig. 3: Screw distortion and body fracture in 3.4 mm zirconia metal abutment

Fig. 4: Connection area fracture in 3.8 mm copy-milled abutment

and stated that zirconia abutment failed in 40% of the specimens prior to either the all-ceramic crown fracturing or gold screw bending. A crown may act as a shield to the effects of the load to the abutment, thus, permitting a greater load to be applied before failure occurs.[18]

Results of the current investigation indicate that in abutments of 3.8 and 4.5 mm diameter, no significant difference was observed among the experimental groups with the same diameter (prefabricated titanium, CAD/CAM zirconia, zirconia-metal and copy-milled zirconia) (Table 2). Therefore, either of the abutments in each diameter dimension group could be used instead of the other with no concern of fracture. Similar to this finding, a randomized controlled clinical trial showed that there was no difference in the survival of canine and posterior implant crowns supported by zirconia and titanium abutments at 1 year of clinical observation.[24] The survival rate of both abutments and crowns was 100% for zirconia and titanium abutments, as no fractures or loosening of screw was observed.[24] In another study, Moris et al stated that 3.8 mm (reduced size) abutments present satisfactory mechanical properties and strength compatible with 4.8 mm (conventional) abutments and can, therefore, be used clinically.[25] However in a recent study, one-piece zirconia abutments exhibited a significantly lower fracture resistance than titanium abutments while another study showed that fracture strength of zirconia abutments connected to titanium cores was significantly higher than the fracture strength of one-piece zirconia abutments.[16,26]

The mean fracture resistance for group prefabricated-zirconia with 3.8 mm diameter (PZ 3.8) in the current investigation was 688.48 N. Similar values was observed in a former study for one-piece zirconia abutments on 3.75 mm diameter implants.[18] No cyclic loading was performed in these investigations which might explain the superior fracture strength as compared to other studies.[27,28] However, Att et al showed a fracture resistance of 457 N for the 4.3 mm one-piece zirconia abutments after cyclic loading, which is much lower than the values reported for prefabricated zirconia abutments of 4.5 mm diameter in the current study.[29]

The present study demonstrates that diameter of abutments had a significant effect on their fracture resistance. Abutments with 5.5 mm diameters had the highest resistance while those with 3.4 and 3.8 mm diameters had the lowest resistance. This is in accordance with the findings of Stimmelmayr et al, where the fracture strength of the implant abutment increased with the implant diameter.[16] Therefore, diameter seems to play an important role in selecting the abutment material and design.

Comparison of zirconia and zirconia-metal abutments with two different diameters of 3.75 and 5.5 mm were assessed in a former study in which it is stated that the fracture resistance of the zirconia-titanium abutments was higher than that of zirconia abutments.[16] The fracture resistance for the diameter of 3.75 mm was about 2.4 times greater and, for 5.5 mm, it was about 1.2 times greater for the zirconia-titanium abutments than for the zirconia abutments. This finding is in agreement with this study that fracture resistance of zirconia group of 3.8 mm diameter is 1.6 times greater than zirconia-metal abutments of the same diameter.

However, there is a point of view suggesting that reductions in the diameter of abutments caused by preparation modifications do not adversely affect their resistance.[11] Adatia et al showed the preparation of zirconia abutments (prepared with 0, 0.5 or 1 mm of external axial reduction starting 1 mm above the height-of-contour) did not significantly impair the fracture resistance of simulated implant assemblies.[11] It seems that dimension of connection area is more important than the body walls. In their study, all implant abutments fractured at rates higher than the maximum incisal forces (90–370 N) estimated to occur in the anterior region of the mouth.[11] Findings of Adatia et al for regular abutments (4.5–5 mm diameter) are in agreement with findings of the current investigation for CAD/CAM abutments of 3.8 mm, which presents an acceptable clinical performance.[11]

Failure of the implant-abutment assembly can occur at different locations. Occurrence of these fractures at specific locations hint to some sort of stress concentration, which is caused by geometrical (design) effects.[30] The modes of failure observed in the current study include abutment fractures, abutment screw fractures, screw distortions and connection area fractures. The observed modes of failure were specific to the abutment design and material, which is in accordance with other studies.[11,16,18,21,26] Adatia et al reported that the weakest point of the abutment assemblies seemed to be the abutment/analog interface.[11] Yildirim et al tested external hex implant connections, and Mitsias tested conical seal design implant connections; both found that zirconia abutment assemblies were most likely to fail at the cervical portion of the abutment, near the gold screw and platform of the implant.[18] This area is assumed to be an area of the highest torque and stress concentrations due to the levering effects.[18] In the study of Foong et al, the mode of failure of the zirconia abutments was fracture at the apical portion of the abutment without damage or plastic deformation of the abutment screw or implant.[26] This is also consistent with results reported by Mitsias et al.[31] Findings of previous studies are in agreement with the results of the current investigation in which the weakest part of prefabricated titanium abutments was demonstrated to be the abutment screw; however, in the other three groups, the limiting component could not be recognized.[29] This finding is in contrast with findings of Stimmelmayr et al, who reported that the fractures of the zirconia abutments always initiated in the ceramic, partially followed by the abutment screws.[16]

It will be of great value to investigate the fatigue behavior of these implant assemblies at lower but repetitive loads, as opposed to the static loads used in the current study. The benefit of this type of examination is that applying a predetermined load for a defined number of cycles provides a better simulation of clinical conditions. Repetitive cycling at low loads causes small-scale plastic deformations that eventually accumulate over many cycles and result in implant failures at loads far below the static elastic limit of the material or assembly.[19] In fact, studies have showed that under fatigue testing (106 load cycles), titanium and titanium alloy specimens fracture at approximately 50% of the ultimate force required to fracture the same specimen under static loading.[32]

CONCLUSION

Within the limitations of this *in vitro* study, it could be concluded that diameter has a significant effect on fracture resistance of implant abutments, as abutments with greater diameters are more resistant to static loads. Abutments with the same diameter have similar strengths, regardless of their composition. Moreover, it was observed that copy-milled abutments showed lower fracture resistance though all implant abutments failed at higher rates than the maximum incisal forces (90–370 N), expected to happen in the anterior region of the mouth enabling their clinical use.

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