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Fracture Resistance of Single Tooth Implant Supported All Ceramic Restorations: An In Vitro Study

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ABSTRACT

Background: The purpose of this in vitro study was to evaluate the fracture resistance of single-tooth implant - supported all-ceramic restorations consisting of alumina all-ceramic restorations on different implant abutments and to identify the weakest component of the restorative system.

Keywords: Fracture resistance, single tooth, implant, abutments.

INTRODUCTION

In aesthetically demanding anterior regions, restoring single missing tooth with an implant-supported crown is a major challenge for the clinician (1–3). Success depends not only on intact osseointegration and on the implant having a functional load-bearing capacity, but also on a harmonious integration of the crown into the dental arch. Implant-supported single-tooth restorations are subjected, especially in patients with a gummy smile or a high lip line, to direct visual comparison with the adjacent natural teeth. High-strength ceramic materials can be used to fabricate esthetic and stable implant supported single-tooth restorations. No study was identified that compared the fracture resistance of individual components of single-tooth implant-supported all-ceramic restorative systems after artificial aging.

MATERIALS AND METHOD

Forty-eight implants with a diameter of 4.3 mm and alength of 15 mm (*) were used in this study. The implants were divided into three groups of 16 specimens each. Sixteen titanium abutments (†) were used for the control group (Ti) whereas 16 industrially pre-fabricated Al2O3 abutments (‡) and 16 industrially pre-fabricated ZrO2 abutments (§) served as test groups (Al, Zr). All abutments had standard dimensions; a deep chamfer finish line of 0.5-mm depth and a total height of 9 mm.An incisal reduction of 2 mm (definitive total height of 7 mm) was made for all abutments using diamond rotary cutting instruments(¶) with water spray application and the help of a silicone index (**). Then, all abutments were scanned using a mechanical scanner that operates by surface detection (††). ZrO2 copings were designed (CAD) using the software Procera‡‡ withan overall thickness of 0.6 mm. The data were sent via modem to Procera Sandvik AB (§§) where the fabricationof ZrO2 copings took place. After delivery, all copings were tried on and veneered using silicate-based veneering ceramic (¶¶). Forty-eight standardized maxillary central incisor crowns were fabricated using a silicone index (height 11 mm, width 8 mm). Afterwards, all implants were embedded with auto polymerizing

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acrylic resin (***) at an angle of 135 to the horizontal plane to simulate clinical conditions. The resin has a modulus of elasticity of approximately12 GPa which approximates that of human bone(18 GPa).All abutments of the test and control group(s) were placed on the implants using titanium screws (†††) and torqued to 35 Ncm according to the manufacturer's recommendation using the torque control system (‡‡‡).After 1 min, the occlusal screws were retightened. To ensure maximum bond strength between the ZrO2 crowns and the different abutments, the abutment surfaces and the inner surfaces of the crowns were tribochemically silicoated with the modified Rocatec method (§§§) before definitive placement of the crowns.Then, all crowns were definitively placed on the abutments with finger pressure using a resin luting cement .All test specimens were exposed to 1 200 000 cycles of thermomechanical fatigue in a computer controlled dual-axis chewing simulator (****) to simulate 5 years of clinical function. The force was applied 3 mm below the incisal edge on the palatal aspect of the crown at a frequency of 1.6 Hz using a ceramic ball with a 6-mm diameter (††††). The ceramic ball has a Vicker's hardness that is similar to that of enamel. A force of 49 N was chosen to simulate a load within the clinical range. During testing, all specimens were subjected to simultaneous thermal cycling between 5 and 55 _C for 60 s each,with an intermediate pause of 12 s, maintained by a thermostatically controlled liquid circulator (‡‡‡‡). After that all specimens were loaded compressively in a universal testing machine (§§§§) with force application at an angle of 130_ to the horizontal axis and a crosshead speed of 2 mm min)1. The semispherical loading stamp was centrally positioned in the median plane of the crown between the upper end of the cingulum and the incisal edge. A 1-mm-thick tin foil was placed between loading stamp and crown to achieve homogenous stress distribution (Fig. 1). The applied force was graphically recorded on an x-t recorder, with failure defined as a deviation from graphic linearity.

After loading in the universal testing machine, the location and mode of failure for each test specimen were recorded by visual examination with the help of a 5· magnifying glass (*****).Results of the load-to-fracture test were recorded with the help of box plots. Pair-wise Wilcoxon ranktests were performed to test for differences in fracture resistance values between all groups. The global significance level of 0.05 was achieved by correcting the P-values according to the Bonferroni–Holm method.

RESULTS

All test specimens survived 1,200,000 cycles of dynamic loading and thermal cycling in the oral simulation device and environment. No screw loosening was recorded. The smallest fracture resistance value after oral simulation and application of the load-to-fracture testing was observed in group Zr (ZrO_2 abutments/Al_2O_3 crowns), whereas the highest value was observed in group Ti (titanium abutments/Al_2O_3 crowns) (Table I). The fracture resistance measurements resulted in an asymmetric distribution of the data. Therefore, instead of the mean, the median was used for the statistical analysis of the fracture resistance data. The highest median fracture resistance value occurred in group Ti, followed by group Zr and group Al (Table I). The fracture resistance values after artificial aging are presented using box plots (Fig. 2). The Kruskal-Wallis test showed a significant group effect (*P*<.001). Wilcoxon rank sum tests were significant for the comparisons of group Ti with groups Al (*P*<.001) and Zr (*P*<.001). The comparison of group Al and Zr yielded no significant differences (*P*=.3423).

Table I: Groupwise fracture resistance (N).

Abutment group	Minimum	1st quartile	Median	Mean	SD	3rd quartile	Maximum
Ti	661.3	1,049.0	1,454.0	1,344.2	402.0	1,558.0	1,963.0
Al	294.2	374.0	422.5	428.8	77.0	467.6	588.1
Zr	277.5	355.4	443.6	470.1	151.8	580.8	726.9

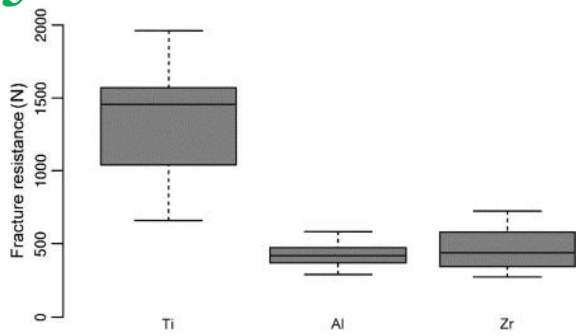

Fig. 2. Box plot of results after load-to-fracture test (N). *Ti*, Titanium abutments/Al_2O_3 crowns (control group Ti); *Al*, Al_2O_3 abutments/Al_2O_3 crowns (group Al); *Zr*, ZrO_2 Abutments/Al_2O_3 crowns (group Zr).

The location and mode of failure of the 3 test groups after exposure to clinical simulation are reported in Table II. In group Ti, 14 crowns fractured without any damage to the abutments. For 2 specimens, the crowns and screws fractured together. Only 1 identifiable implant neck distortion was recorded. In group Al, 7 abutments fractured without any damage to the crowns. In 9 test specimens, the crowns and abutments fractured together. In group Zr, 6 abutments fractured without any destruction of the crowns. In 10 test specimens, the crowns and abutments fractured together.

Table II: Location and mode of failure after load-to-fracture test.

Fractured component(s)	Ti	Al	Zr
Crown	13	0	0
Abutment	0	7	6
Screw	0	0	0
Crown and abutment	0	9	10
Crown and screw	2	0	0
Implant neck distortion	1	0	0

The fracture mode of the crowns in all groups was homogenous. The failure was in the form of a total destruction of the coping and veneering material. In all test specimens in which the Al_2O_3 and ZrO_2 abutments fractured (Table II), a uniform fracture mode response was recorded. The abutments failed in proximity to the implant interface and the metal aspect of the abutment, which connects the ceramic to the implant.

DISCUSSION

In this study, all specimens survived the exposure to the simulated oral environmental testing. The number of specimens tested and the use of water rather than artificial saliva during testing are limitations of this study. Single-tooth implant-supported restorations were exposed to this testing protocol in only 1 previous in vitro study.[39] However, the data from this previous study cannot be compared to those of the present study due to different test parameters and materials.

This study was not a test of materials, but rather an investigation of implant components of various diameters functioning together as a system. Therefore, results of the fracture resistance were presented in newtons, not in megapascals. The physiologic maximal incising forces may vary up to 290 N, depending on facial morphology and age.[56] Results of several studies reported a mean loading force of approximately 206 N in the anterior region.[54] In this study, all test groups showed minimum fracture resistance levels of greater than 200 N. Thus, all test specimens exceeded the minimum limits of the fracture resistance for anterior restorations.

The fracture resistance of all-ceramic restorations on implants was evaluated in another in vitro study.[27] Al_2O_3 and ZrO_2 abutments were prepared and restored with glass-ceramic crowns and placed on implants (Branemark). No artificial aging was applied. The statistical analysis showed significant differences between both groups, with mean fracture load values of 280.1 N for the group with Al_2O_3 abutments and 737.6 N for the group with ZrO_2 abutments. The ZrO_2-abutment group was more than twice as resistant to fracture as the Al_2O_3-abutment group. In this study, no differences were found between the fracture resistance values of Al_2O_3- and ZrO_2-abutment groups. In contrast to the former study,[27] ZrO_2 abutments did not enhance the fracture resistance. This may be related to the effect of the preparation and artificial aging in reducing the fracture resistance of ZrO_2 ceramics.[57 and 58] In comparison to Al_2O_3 ceramics, ZrO_2 ceramics usually have twice the flexural strength and fracture toughness.[22, 26 and 57] The main reason for the superior fracture strength of ZrO_2 ceramic lies in the metastable tetragonal crystalline structure at room temperature.[22 and 26] This structure represents an efficient mechanism against flaw propagation.

CONCLUSION

Within the limits of this in vitro study, all of the types of implant-supported restorations tested have the potential to withstand physiologic occlusal forces applied in the anterior region (200 N).

CONFLICTS OF INTEREST

The authors declare they have no potential conflict of interests regarding this article.

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