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Influence of Preparation Mode and Depth on the Fracture Strength of Zirconia Ceramic Abutments Restored with Lithium Disilicate Crowns

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Purpose: *Zirconia implant abutments offer enhanced esthetics and promote biologic sealing; however, the effect of laboratory or intraoral preparation on the mechanical stability of zirconia has not been investigated. The purpose of the study was to evaluate the influence of the preparation mode and depth on the fracture strength of zirconia abutments restored with lithium disilicate crowns.* ***Materials and Methods:*** *To replace a maxillary central incisor (11.0 mm in height and 8.0 mm in width), 35 lithium disilicate crowns were cemented onto zirconia abutments on 4.5- × 15-mm titanium implants. Lithium disilicate implant crowns were divided into five study groups (n = 7) according to the abutment preparation mode (milling by the manufacturer or milling by the Celay System [Mikrona] [P]) and preparation depth (0.5 mm [A], 0.7 mm [B], or 0.9 mm [C]). All groups were subjected to quasi-static loading (S) at 135 degrees to the implant axis in a universal testing machine.* ***Results:*** *Mean fracture strengths were: group SA, 384 ± 84 N (control); group SB, 294 ± 95 N; group SPB, 332 ± 80 N; group SC, 332 ± 52; group SPC, 381 ± 101 N. All specimens presented a typical fracture mode within the implant/abutment internal connection. Multiple regression analysis revealed that preparation depth up to 0.7 mm statistically influenced the fracture strength (*P *= .034), whereas the preparation mode did not seem to play an important role (*P *= .175).* ***Conclusion:*** *Regardless of preparation mode, circumferential preparation of zirconia abutments might negatively affect the fracture strength of adhesively cemented single-implant lithium disilicate crowns.* Int J Oral Maxillofac Implants 2012;27:839–848.

Key words: *abutment, fracture mode, fracture strength, implant, internal-connection implants, lithium disilicate, preparation, zirconia*

Recent systematic reviews confirmed an improved long-term prognosis regarding both the implant and the crown components of single implant crowns (5-year: 94.5%) similar to conventional fixed dental prostheses (FDPs).[1,2] Furthermore, all-ceramic implant crowns presented high survival rates (91.2%), but they were significantly lower than those achieved with metal-ceramic crowns (95.4%). However, the survival of all-ceramic crowns seems to be comparable regardless of whether the restorations were placed on implant or natural tooth abutments.[2–4]

Newer implant ceramic abutments provided by constantly developing zirconia technology may change the status of modern implant dentistry and evolve new bioesthetic standards.[5] Known esthetic problems with titanium abutments, such as the management of the grayish appearance with translucent all-ceramic crowns or of thin (less than 2 mm) peri-implant mucosa, can be overcome by the clinical application of high-strength abutments made of yttria-tetragonal zirconia polycrystals (Y-TZP).[6–8]

Y-TZP abutments have replaced aluminum oxide abutments,[9–11] which were introduced in the mid-1990s, mainly because of the material's exceptional biomechanical characteristics, which include a fracture strength that is three times higher than that of alumina.[12,13] Zirconia as an abutment material offers radiopacity and reduced plaque accumulation (and therefore a reduced risk of inflammation).[14–17] Because of its excellent biocompatibility, zirconia ceramic

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Table 1 Test Groups

Group	Preparation depth (mm)	Preparation mode (milling)	N
SA	0.5	Manufacturer	7
SB	0.7	Manufacturer	7
SC	0.9	Manufacturer	7
SPB	0.7	Celay system	7
SPC	0.9	Celay system	7

abutments promote the integration of the peri-implant soft tissues around implant crown restorations,[18,19] while the bone level around implants is maintained equally well versus other abutment materials such as titanium, gold, or aluminum oxide.[20] Attachment, spreading, and proliferation of human gingival fibroblasts depends significantly on the quality of the abutment surface after different laboratory procedures (ie, milling, polishing, or veneering).[21]

Currently, different prefabricated Y-TZP abutments are commercially available from many manufacturers, while some implant systems can also support the fabrication of customized abutments through computer-aided design/computer-assisted manufacture technology. The implant–zirconia abutment connection can be direct between the two components or indirect, by the use of an intermediate titanium seating post[22,23] or ring[24] that is adhesively cemented to the zirconia abutment and a fastening screw.[25]

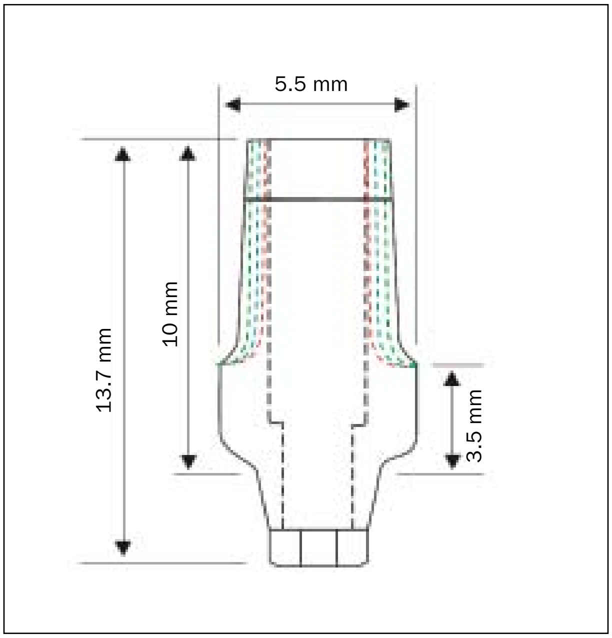
In vitro studies of single-implant all-ceramic crowns supported by prefabricated[26–28] and custom-made[29,30] abutments have revealed that they can successfully resist physiologic functional loading during a 5-year chewing simulation.[31] In vivo data, as shown in a systematic review, showed excellent survival rates for zirconia abutments supporting single-implant all-ceramic crowns and estimated 5-year failure rates that were similar to those for metal-ceramic crowns supported by metal abutments.[32]

Both prefabricated and custom-made abutment types may accept further modifications by extraoral or intraoral preparation to the appropriate shape using fine-grain diamond cutting instruments under water coolant.[33,34] Especially for zirconia abutments with an internal titanium seating post, laboratory preparation seems not to alter the contact surface between an abutment and an implant.[35] General recommendations for preparing zirconia abutments concern either a shoulder or a deep chamfer preparation design with rounded inner angles. However, data regarding the influence of preparation depth and mode on the fracture strength of zirconia abutments supporting single-implant all-ceramic crowns are missing in the literature. Therefore, the present study investigated the influence of different circumferential chamfer preparation depths of zirconia abutments made using two different preparation modes on the fracture strength of zirconia abutments restored with lithium disilicate glass-ceramic crowns.

MATERIALS AND METHODS

Thirty-five single implant–supported all-ceramic crowns were made from IPS e.max Press lithium disilicate glass-ceramic (Ivoclar Vivadent) to replace a maxillary right central incisor. For the purposes of the study, 28 ZirDesign (4.5/5.0 mm; Astra Tech) zirconia abutments were prepared in two depths (0.7 mm or 0.9 mm) following two preparation modes: milling by the manufacturer or milling by the Celay System (Mikrona). Seven additional abutments with a preset (by the manufacturer) preparation depth of 0.5 mm served as a control group. The zirconia abutments were connected to 4.5- × 15.0-mm titanium implants (OsseoSpeed 4.5, Astra Tech). All lithium disilicate crowns were then adhesively cemented (Multilink Automix, Ivoclar Vivadent) onto the zirconia abutments. Study specimens were divided into five test groups of seven specimens each, as shown in Table 1. All test groups were subjected to quasi-static loading at a crosshead speed of 0.5 mm/min at a 135-degree angle to the implant axis until fracture occurred. The fracture loads were recorded and the results evaluated statistically. Fracture modes were evaluated under low-power magnification using an optical microscope.

All zirconia abutments used in the present study were ivory colored and straight, had a diameter of 5.5 mm, and, as previously described, were prepared with a circumferential chamfer margin of 0.5 mm in depth with respect to the maximum radius of the abutment. The transgingival height of the specific abutments was 3 mm at the labial aspect; however, palatal heights were 1 mm more coronal than the labial height to provide a scalloped margin. The aforementioned abutments were used as a control group (group SA), while in the other study groups, selected circumferential chamfer preparations were extended by 0.2 mm (groups SB and SPB) and 0.4 mm (groups SC and SPC) in depth from the original abutment size. Consequently, the 35 abutments used for the purposes of the study were prepared as follows: *(1)* preparation depth of 0.5 mm for group SA (control), *(2)* preparation depth of 0.7 mm for groups SB and SPB, and *(3)* preparation depth of 0.9 mm for groups SC and SPC. A schematic drawing of the different abutment preparations is shown in Fig 1. Abutment preparations were performed either by the manufacturing milling procedure used for all commercially available abutments (groups



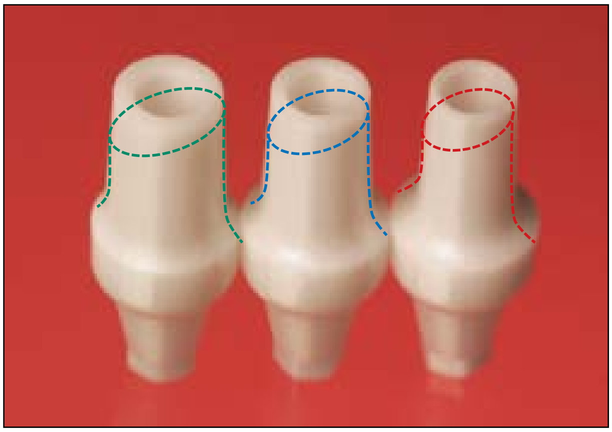


Fig 1 *(Left)* Schematic drawing of the three different abutment preparations. Dashed lines show the reduction from the original abutment size: green = 0.5 mm (group A), blue = 0.7 mm (group B); red = 0.9 mm (group C).

Fig 2 *(Above)* The three types of abutment preparations made by the manufacturer. *Left to right:* group A, group B, group C. Height reductions were made using the Celay system (dashed lines).

SA, SB, SC) or in a laboratory environment with the use of the Celay System (groups SPB, SPC). Celay is a copy-milling machine that is capable of milling different dental frameworks from prefabricated industrial ceramic blocks by copying indirect patterns. Every prefabricated abutment was precision-machined from a solid blank of medical-grade zirconia and polished. Preparations made by the Celay System followed known copy-milling protocols and used specially designed fine-grain cutting diamond instruments (Vita Celay Milling pins ZY-54, Mikrona) under water coolant. Appropriate height modifications in all groups were made using the Celay System. The incisal edge of the abutments was reduced to proximal labial and palatal heights of 5.0 mm and 3.0 mm, respectively (Fig 2).

In general, every zirconia implant abutment received a 360-degree circular chamfer preparation with rounded inner angles to the selected depth using the appropriate rotating instruments. All prepared abutments had a standardized 6-degree convergence, and angled surfaces between the axial and palatal surfaces were rounded, as were the incisal surfaces (minimum radius: 0.5 mm). However, a minimum width of 1.0 mm of the incisal edge in the labiolingual direction was retained to guarantee an exact reproduction of the internal framework surfaces by the milling unit. To achieve identical dimensions during preparation of the abutments with the copy-milling technique, master metal abutments, prepared to the selected size and depth, were attached to the tracing chamber of the Celay System. Finally, 4.5-mm milling implant analogs (Implant Replica 4.5/5, Astra Tech) were used to facilitate tracing and copy milling.

Prior to the fabrication of the master dies, all 35 prepared zirconia abutments were connected to identical titanium implants (OsseoSpeed 4.5), 4.5 mm in diameter and 15.0 mm in length. According to the manufacturer's recommendation, every abutment was fixed with a standard titanium abutment screw (2.35 mm in diameter, 10.30 mm in length) using a torque control screwdriver with a torque of 25 Ncm. Then, the implant/abutment specimens were embedded in a three-component, self-curing polyester resin (Technovit 4000, Heraeus Kulzer) using a prefabricated silicon index that provided a horizontal inclination of 135 degrees. Polyester resin material was poured into special copper cylinders, which also served as the specimen holders during testing.

For the fabrication of the 35 lithium disilicate crowns, full wax-ups of the complete crown restorations were made onto the zirconia abutments to replace a right maxillary central incisor. Identical wax-ups were performed with respect to the external crown dimensions (11.0 mm in height and 8.0 mm in width). The latter were achieved with the use of a silicon index, which was taken from a master diagnostic wax-up and verified with the use of a digital caliper (FINO H-59112, FINO GmbH). After burn-out of the wax crown analog, an IPS e.max Press lithium disilicate glass-ceramic ingot was heated and pressed into an investment mold using the heat-pressing technique. Finally, all crowns were fitted to the master dies and completed by appropriate grinding and polishing.

For adhesive cementation, the zirconia implant abutments were air-abraded with 50-µm alumina particles at 0.5 bar until a marker coating (green shade)

Fig 3a A prepared zirconia abutment is covered by a special varnish to control air-abrasion prior to adhesive cementation.

Fig 3b The prepared zirconia abutment after air-abrasion.

Fig 3c Bonding a lithium disilicate crown over a zirconia abutment.

Fig 3d Photopolymerization during the bonding procedure.

Fig 3e Bonded implant crown before testing.

Fig 3f Quasi-static loading test.

was completely removed (Figs 3a and 3b). Moreover, they were ultrasonically cleaned in 96% isopropanol (German Federal Monopoly Administration for Spirits) for 2 minutes and dried. Bonding surfaces were pretreated with a special primer (Metal-Zirconia primer, Ivoclar Vivadent). In addition, the inner surfaces of the lithium disilicate crowns were etched according to the manufacturer's instructions for 20 seconds with hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) and silanated (Monobond S, Ivoclar Vivadent). Then the crowns were bonded to the abutments using the dual-curing adhesive resin cement Multilink Automix, under a constant pressure of 50 N during a 3-minute setting period (Fig 3c). However, after excess cement was removed, light curing (Optilux 500, Demetron) was applied for 20 seconds at each side (labial/palatal) according to the manufacturer's recommendations (Fig 3d).

According to the study outline (Table 1), all groups were subjected to quasi-static loading until fracture using a universal testing instrument (Z010/TN2S, Zwick) (Fig 3e). A semispherical loading stamp was centrally positioned in the median plane of the crown between the upper end of the tuberculum and the incisal edge (Fig 3f). However, a 1-mm-thick aluminum foil was placed between the loading stamp and the crown to ensure homogenous stress distribution. Then, a compressive force was applied at the same angle of 135 degrees to the horizontal axis under stroke control with a crosshead speed of 0.5 mm/min until fracture (quasi-static loading).

After the quasi-static loading test, all fractured specimens were ultrasonically cleaned in 96% isopropanol and examined under low-power (×50) stereomagnification and incident light with the use of an optical microscope (Carl Zeiss); representative photographs were made. All tested specimens were examined for incipient fractures and the mode of failure was classified according to the locations of the fractures. Fracture strengths during the quasi-static loading test were recorded and statistically evaluated using multiple regression analysis.

Table 2 Fracture Strengths (Means, Standard Deviations [SDs], Minima, Media, and Maxima, in Newtons) of All Test Groups

Group	Mean	SD	Min	Median	Max	Range
SA	383.9	83.9	292	372	544	252
SB	294.3	95.4	198	270	474	276
SC	331.7	52.4	270	332	421	151
SPB	332.4	79.9	230	299	436	206
SPC	380.7	101.5	255	341	566	311
Average	344.6	82.6	249.0	322.8	488.2	239.2

Table 3a Multiple Regression Analysis: Model Summary

Model	*R*	R^2	Adjusted R^2	SEE
1	0.396*	0.156	0.075	83.019

*Predictors: (constant), preparation mode: C = 0.9, A = 0.5; SEE = standard error of the estimate.

Table 3b Multiple Regression Analysis: Analysis of Variance*

Model	Sum of squares	*df*	Mean square	F	*P*
1					
Regression	39,631.257	3	13,210.419	1.917	.147†
Residual	213,659.1	31	6,892.230		
Total	253,290.4	34			

*Dependent variable: fracture strength; †predictors: (constant), mode: C = 0.9, A = 0.5.

Table 3c Multiple Regression Analysis: Coefficients*

	Unstandardized coefficients		Standardized coefficients		
Model	**B**	**SE**	**Beta**	***t***	***P***
1					
(constant)	291.571	27.174		10.730	.000
A (0.5 mm)	92.286	41.510	0.434	2.223	.034
C (0.9 mm)	42.857	31.378	0.247	1.366	.182
Preparation mode	43.571	31.378	0.251	1.389	.175

*Dependent variable: fracture strength; SE = standard error.

RESULTS

Fracture strength values of all test groups recorded during quasi-static loading are shown in Table 2.

The multiple linear regression statistical method followed in the current study employed a linear model that examined the significance of preparation depth and the preparation mode in relation to the fracture strength data (dependent variable) obtained from the static loading test. Therefore, a backward selection method of the independent variables was carried out to achieve the final statistical model.[36] For the preparation mode, “preparation by the manufacturer” was entered into the model as baseline. In addition, for the variable “preparation depth,” the level labeled as B = 0.7 was entered into the linear regression model as the baseline, and two dummy variables were labeled as A = 0.5 and C = 0.9. The application of the specific statistical method was validated by performing a series of different tests of independence of data, normality of residuals, linearity, and homoscedasticity. The statistical results following application of the data to the multiple linear regression model are demonstrated in Table 3.

Statistical analysis revealed that, although the mean fracture strength of the lithium disilicate implant crowns over manually prepared zirconia abutments was slightly higher than that of the crowns on abutments prepared by the manufacturer; preparation mode did not significantly influence the fracture strength ($P = .175$). In addition, of the two levels (A and C) for the variable "preparation depth," only level A (0.5 mm), which increased the mean fracture strength of the lithium disilicate implant crowns, was found to be statistically significant ($P = .034$).

DISCUSSION

The design of the present study followed preparation guidelines for lithium disilicate crowns; therefore, a shallow chamfer preparation without any sharp transitions, inner angles, and feather edges was selected. Because preparation design affects crown marginal adaptation,[37] chamfer preparation in comparison to the shoulder preparation seems to facilitate seating of adhesively cemented crowns[38] and to improve marginal fit.[39,40] Moreover, a 6-degree-convergence axial preparation of the abutments offers good mechanical retention.[41,42] The different preparation depths of 0.5, 0.7, or 0.9 mm used in the present study were shallower than what is normally used for natural teeth. Regarding color performance of an implant-supported all-ceramic crown, this specific limited preparation depth might result in a restrained space for the veneering material but this disadvantage might be outweighed by the favorable color of the underlying zirconia abutment. In addition, axial reduction up to 1 mm has the potential to increase the stability of the zirconia abutment and therefore to preserve the remaining abutment in case further inclination of the labial aspect is needed for esthetic purposes.

Industrial milling results in a high-quality surface, but manual abutment preparation, possibly with the use of a corresponding system such as the Celay System, could be very beneficial to achieve appropriate abutment customization. Conversely, zirconia grinding or milling might induce surface flaws or microcracks, which might influence the mechanical properties of the material.[43] It has been confirmed that the aforementioned surface treatment generally triggers a phase transformation from the tetragonal to the monoclinic state, which negatively influences the mechanical properties of the material after coarse grinding.[44,45] Stress-free abutment preparation under water cooling using a fine-grained cutting diamond, as was done in the current study, may decrease the critical flow size and increase the surface compressive layer, which improves strength.[46,47]

Table 4 Comparison of In Vitro Studies That Examined

Study	Implant or implant analog: Trade name	D (mm)	L (mm)
Yildirim et al (2003)[54]	Brånemark external analog, Nobel Biocare	NR	NR
Butz et al (2005)[55]	Osseotite (external), Biomet 3i	4.0	13
Att et al (2006)[56]	Replace Select, Nobel Biocare	4.3	15
Att et al (2006)[57]	Replace Select, Nobel Biocare	4.3	15
Aramouni et al (2008)[58]	Certain, Biomet 3i	4.0	13
Adatia et al (2009)[59]	OsseoSpeed analog, Astra Tech	NR	NR
Kim et al (2009)[60]	Replace Select analog, Nobel Biocare	RP	NR
Mitsias et al (2010)[61]	OsseoSpeed, Astra Tech	4.5	15
Present study	OsseoSpeed, Astra Tech	4.5	15

NR = not reported.
*Dynamic loading followed by static loading of the surviving specimens;
**Maximum value between the two preparation modes.

The unprepared part of the zirconia abutment that faces the implant platform and the peri-implant mucosa remained polished, as originally provided by the manufacturer. In general, fine polishing after grinding may remove the compressive layer of monoclinic phase from the surface, while further polishing may minimize the sizes of flaws and result in greater flexural strength.[48]

In the present study, the preparation mode did not influence the fracture strength of zirconia ceramic abutments restored with adhesively cemented lithium disilicate crowns, but the preparation depth had a negative effect when the zirconia abutments were prepared to a depth of 0.7 mm. The latter could serve as a restriction for lab technicians to gain the appropriate space for the veneering materials.

The adhesive cementation of lithium disilicate implant crowns over the prepared and air-abraded part of the zirconia abutments may enhance the fracture strength because the procedure seals the prepared surface and potential superficial microcracks. In the case of zirconia, etching and silanating seem to be ineffective,[49] since zirconia features a very dense crystalline structure that contains no glass phase.[12] Similarly, it has been reported that silica coating provides a nondurable bond to Y-TZP.[49] Bonding systems that contain a special adhesive monomer have been found to provide an acceptable, strong, stable bond to airborne-particle-abraded Y-TZP; however, the retention can be the Fracture Strength of Single Anterior Implant Crowns Over Zirconia Abutments

Abutment	Preparation and depth (mm)	Crown	Loading direction	Loading test	Mean fracture strength ± SD (N)
Wohlwend Innovative	Chamfer 1.0	Empress	150 deg	Static	737 ± 245
Zireal	Chamfer 0.5	Nonprecious alloy	130 deg	Dynamic*	281 ± NR
Esthetic Zirconia Abutment	Chamfer 0.5	Procera Alumina	130 deg	Dynamic*	470 ± 152
Esthetic Zirconia Abutment	Chamfer 0.5	Procera Zirconia	130 deg	Dynamic*	593 ± 292
Zireal	Chamfer 1.0	Empress2	135 deg	Static	793 ± 123
ZirDesign	Chamfer 0.5 Chamfer 1.0	Without crown	150 deg	Static	576 ± 140 547 ± 139
Procera Zirconia	NR	e.max Press	150 deg	Static	480 ± 174
ZirDesign	Chamfer 0.5	Nonprecious alloy	150 deg	Static	690 ± 430
ZirDesign	Chamfer 0.5 Chamfer 0.7 Chamfer 0.9	e.max Press e.max Press e.max Press	135 deg 135 deg 135 deg	Static Static Static	384 ± 83 332 ± 80** 380 ± 101**

further increased by airborne-particle abrasion with 50-µm alumina particles.[50] In the present study, after implant abutments were airborne-particle abraded at 0.5 bar pressure with 50-µm alumina particles, a phosphoric/phosphonic acid reagent (Metal/Zirconia Primer, Ivoclar Vivadent) was used to promote chemical bonding to the zirconia abutment.[51,52] Finally, bonding to the silica-based ceramic was very effective with a dual-curing adhesive resin cement (Multilink Automix, Ivoclar Vivadent) after hydrofluoric etching, which creates a microretention pattern on the ceramic internal surface of the crown by dissolving silicate components, and silanization (Monobond S, Ivoclar Vivadent), which provides wetting and chemical bonding to the lithium disilicate ceramic surface.[53]

Quasi-static loading, as used for testing in the current study, is the most definitive method of determining the load capacity (maximum allowable load) of a restoration. Quasi-static loading refers to slow loading where inertial effects are negligible. Any macroscopic system such as an implant crown is much more complicated than any idealized mathematical model describing it. To simplify actual situations, some effects are generally regarded as insignificant because their magnitude is so small as to be negligible. Testing an implant crown to failure provides valuable information to the design engineer and is recommended prior to designing the foundation. Moreover, testing the system implant/abutment/crown as an entire restoration is a realistic approach to the clinical situation and adds clinical significance to the present results.

Static loading tests regarding implant crowns over zirconia abutments can be found in several in vitro studies (Table 4),[54–61] in which the resultant fracture strengths were strongly dependent on the precise design of the test setup. In such tests, different geometries of the specimen regarding abutment design, height, or convergence; crown dimensions; point of loading force; or small misalignments during testing may result in strong sensitivity (ie, increased standard deviations); this might explain the differences found among the aforementioned studies. In addition, the use of original implants instead of implant analogs, the use of pure zirconia or metal-reinforced abutments (at the implant/abutment interface), the use of implant crowns instead of zirconia implant abutments without crowns, and the use of different crown materials (ie, nonprecious metal, alumina, zirconia) might introduce additional influential parameters; these indicate the future need for a minimum in vitro testing consensus regarding dental restorations.

The present study explored the fracture strength of lithium disilicate implant crowns under 135-degree loading and examined the influence of three different preparation depths under two preparation modes. The mean fracture strengths found in all test groups were

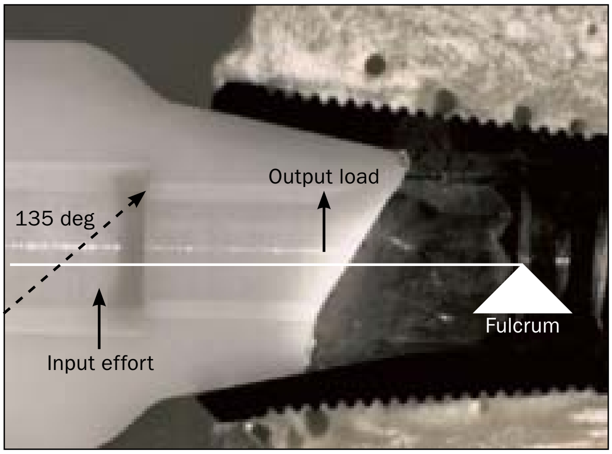


Fig 4 Second-class levering effects within the internal connection of the zirconia abutment (dashed line represents the loading direction).

lower than those reported by previous studies (Table 4). The aforementioned differences in testing parameters may explain these differences. However, the mean values found in the present study have the least sensitivity, since the standard deviations were the smallest among all similar studies. Moreover, the specific mean values, which varied between 294 and 383 N, can be characterized as viable and realistic for the anterior region because they are above the referenced magnitude of applied physiologic functional forces.[31] Therefore, it can be concluded that single-implant anterior lithium disilicate crowns can be used for the esthetic restoration of anterior missing teeth.

Moreover, it has been reported that the loading direction plays a very important role in the long-term prognosis of either tooth- or implant-retained crowns.[62,63] Watanabe et al showed relatively pronounced compressive stresses when a 135-degree loading direction and eccentric loading were tested.[63] Excessive loading conditions may lead to loosening or failure of implant restorations.[63] Controversially, it can be assumed that the specimens in the present study could present improved fracture strength if tested under a smaller inclination, eg, 150 degrees, similar to the protocol of Kim et al.[60] That particular study used the same crown material but slightly shorter crowns, which might also have altered the loading position and therefore the stress distribution on the implant crown versus the present study.[60] Last but not least, for the given load direction of 135 degrees, the mean fracture strengths found in the present study were within the range of the fracture loads described in a systematic review with respect to either the abutment and restoration materials or the internal implant-abutment connection.[32]

None of the studies included in Table 4 investigated the mode of preparation of the zirconia abutments as a factor that might influence fracture strength. In the present study, it became obvious that preparation through the Celay System (Mikrona) had no effect on the fracture strength of the specific implant crowns. This particular result should be confirmed by future studies; however, as previously noted, during laboratory zirconia abutment customization, the use of fine-grain (30-µm) cutting diamond instruments under water coolant seems to be imperative for better strength.[43–47]

Regarding the preparation depth, in most in vitro studies described in Table 4, an abutment preparation of only 0.5 mm is commonly used. The present study observed a statistically significant tendency that an increase in the preparation depth of a zirconia abutment from 0.5 to 0.7 mm seemed to decrease the resulting fracture strength of the lithium disilicate implant crowns. Nevertheless, static loading testing for groups with a preparation depth of 0.7 mm illustrated clinically irrelevant results, because the mean fracture strength values were still above clinically acceptable values.[31] In addition, the variability of the fracture strength values was almost 16% ($R^2 = 0.156$), while the same coefficient, adjusted to the data of the specific specimen population that was included in the study, identified much lower variability of 7.5% (adjusted $R^2 = 0.075$), leading to the assumption that there might be more parameters influencing fracture strength than those examined in the current study. For the same reason, the examined preparation depth C (0.9 mm) might also be statistically significant in case of a larger population. Therefore, the null hypothesis of the study that the preparation mode will influence the fracture strength of abutments restored with single-implant lithium disilicate crowns was rejected. Conversely, the null hypothesis that the preparation of zirconia abutments up to 0.9 mm in depth will influence the fracture strength of abutments restored with single-implant lithium disilicate crowns was accepted.

After testing, low-power magnification revealed a typical fracture mode of the zirconia abutments located at the implant/abutment internal connection. In all specimens, fractures occurred between the most tapered part of the abutment and the level of the implant platform. Under 135-degree loading, the internal cone of the tested zirconia abutments received torque and stress concentrations and crack propagation that seemed to be related to the magnitude, the application point, and the fulcrum location, as observed in a second-class lever (Fig 4). Obviously, output loads higher than 294 N cannot be compensated by the internal cone of the abutment, which has thinner walls. An internal connection of abutments might be favorable for laboratory and clinical studies.[32] However, designs that improve the reinforcement at this specific load-bearing area (ie, integration of metal abutment sleeves bonded into zirconia abutments)[22] can be a future research goal.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. The preparation mode, whether industrial or manual, of zirconia ceramic abutments using fine-grain (30-µm) cutting diamond instruments under water coolant did not affect the fracture strength of abutments restored with adhesively cemented lithium disilicate crowns.
2. Regardless of the preparation mode, circumferential preparation of 0.7 mm of zirconia abutments had a negative effect on the fracture strength of these abutments restored with adhesively cemented lithium disilicate crowns.
3. Typical fracture modes of the zirconia implant abutment involving the internal connection might signify future engineering goals for improved fracture resistance.
4. Adhesively cemented single anterior implant lithium disilicate crowns over minimally prepared zirconia abutments could withstand physiologic bite (incisive) forces; however, it is advisable that preparation depth should not exceed 0.7 mm.

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