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Fracture strength of lithium disilicate cantilever resin bonded fixed dental prosthesis

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ABSTRACT

Objectives: Metal and Zirconia cantilever resin bonded fixed dental prosthesis (RBFDPs) are extensively used when missing anterior teeth. Lithium disilicate is not used a lot as it is not indicated by the manufacturers. The aim of this in vitro study was to investigate the fracture strength of lithium disilicate cantilever RBFDPs with different configurations and compare them to metal and zirconium RBFDPs.

Methods: Sound extracted human canines ($N = 60$) were divided into six groups, to be restored with a cantilever RBFDP. Specimen were randomly divided over 6 groups ($n = 10$): Full crown of lithium disilicate (FCL); Veneer wing of lithium disilicate (VL); Connector of lithium disilicate (CL); Palatal wing of lithium disilicate (PL); Palatal wing of zirconia (PZ) and Palatal wing of metal ceramic (PM). All bridges were bonded with an adhesive system. After thermalcyclic ageing (20×10^3x, 5–55 °C) all samples were loaded until fracture occurred. Failure types were classified and representative SEM done.

Results: The mean fracture strength results per group were: 588N (FCL) 588N (PM), 550N (CL), 534N (PL), 465N (VL), 38N (PZ). A significant ($p = 0.001$) difference was found between the groups, all groups had a higher fracture strength than the zirconia RBFDPs. Failure type analysis showed some trends among the groups. Irrepairable fractures of the root were only seen in samples restored with lithium disilicate. Metal and zirconia RBFDPs predominantly failed on the adhesive interface, where 60% of the zirconia samples had pretest debondings.

Significance: No differences in fracture strength were found between cantilever RBFDPs made from metal or lithium disilicate. Metal (0% pre-test failures) and zirconium (60% pretest failures) RBFDPs failed predominantly on the adhesive interface whereas the lithium disilicate (0% pre-test failures) samples showed fractures in the contact area. The least invasive connector (CL) and Metal (PM) RBFDP obtained a high fracture strength and optimal fracture pattern.

1. Introduction

Agenesis of teeth is the most common congenital craniofacial abnormality in humans (Matalova et al., 2008; Modesto et al., 2008). 2.6–11.3% of the world's population lacks one or more permanent teeth (Matalova et al., 2008; Modesto et al., 2008). The absence of third molars is not included in this percentage. The most common agenesis concerns the second premolar in the lower jaw (2.91–3.22%), the lateral incisor in the maxilla (1.55–1.78%) and the second premolar in the upper jaw (1.39–1.61%) (Polder et al., 2004). In addition, bilateral

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agenesis of the lateral superior incisors is more common than unilateral (Polder et al., 2004). Besides agnesis, trauma and endodontic failures are the cause of losing maxillary lateral incisors. The absence of teeth from the permanent dentition can be an emotional and social burden for people, especially when this concerns teeth in the aesthetic zone, such as the superior lateral incisor (Hvaring et al., 2014).

Closing diastema in the absence of the lateral incisor involves several challenges. Implantology is not recommended in young patients who are still growing (Percinoto et al., 2001). After the patients growth cycle the agnesis areas don't have a favourable bone condition and bone grafts are often needed. A common solution to restore aesthetics is to make a removable prosthesis or a resin bonded fixed dental prosthesis (RBEFDP). The RBFDP was introduced as minimally invasive, as no - or only a small - preparation is needed (Pjetursson et al., 2008). It was custom to attach the RBFDP to the two neighbour teeth using metal wings. The five-year survival of these restorations is around 48% (Zalkind et al., 2003). If re-cementation is included, the five-year survival rises up to 67% (Zalkind et al., 2003). Van Dalen et al. (van Dalen and Feilzer, 2003) conducted a review on conventional RBFDPs and cantilever RBFDPs. In this study it is described that one loose connector is not always noticed and this creates a risk of creating a carious lesion. This risk does not exist for a cantilever RBFDP. Thereby the RBFDP is also less invasive only having a preparation on one tooth. In a literature review by Pjetursson et al. (2007) the five-year survival of cantilever RBFDPs was found 86.9–94.4% and the ten-year survival 75.2–84.4%.

Kern et al. (Kern, 2005a) studied full ceramic RBFDPs in vivo, made of Alumina in-ceram. The five-year survival of the two-wing RBFDP was 67.3%. However, it should be noted that in a number of cases a fracture occurred at one of the connector sites, but that the EBFDPs then functioned as a cantilever. This considered, the five-year survival was 73.9%. The percentage of cantilever RBFDPs that was still functional after five years was 92.3%. Follow-up studies up to ten and fifteen-year survival had both survival rates of 95,4% (Kern and Sasse, 2011; Kern, 2017a). The difference in survival between a conventional and a cantilever RBFDPs is explained by the freedom of movement (Kern and Sasse, 2011). Differences between metal and ceramic failures were characterized by debonding and fracture of the connector site respectively (van Dalen and Feilzer, 2003).

A material which is often used for single crowns and partial ceramic restorations is lithium disilicate, which has good material properties for its use (Hallmann et al., 2018; Edelhoff et al., 2019). However recent studies have shown that the survival of posterior three unit bridges is around 48% (Garling et al., 2019). Tirlet et al. (Tirlet and Attal, 2015) published a case series using lithium disilicate to fabricate anterior cantilever RBFDP. However, there is little experience with this material since the manufacturer does not support a cantilever RBFDP made of lithium disilicate (Sun et al., 2013). Thirty-five restorations were made and evaluated with an average of 46,57 months reaching a survival rate of 100% (Sun et al., 2013). In another retrospective study also 100% of survival was reached with lithium disilicate RBFDP after a mean follow-up of 6 years (Sailer et al., 2013).

Sometimes it can be decided to have an alternative preparation in making a laminate veneer instead of the palatal wing. One of the reasons for choosing a cantilever RBFDP made of lithium disilicate is that a strong bond can be made between this material and the tooth (Edelhoff and Sorensen, 2002). A smaller preparation yields a more favourable prognosis for the vitality of the tooth, especially in young patients (Tian et al., 2014).

The objective of this study therefore was to compare the fracture strength of lithium disilicate ($Li_2Si_2O_5$) RBFDPs in different configurations to metal and zirconium RBFDPs. The 0-hypothesis tested was that the configuration of the RBFDP or material would not contribute to the fracture strength or failure type.

2. Material and methods

2.1. Specimen preparation

The brands, types, manufacturers, chemical compositions and batch numbers of the materials used in this study are listed in Table 1 Schematic description of the experimental design is presented in Fig. 1.

Sound human canines ($N = 60$) of similar size, free of restorations, fractures, caries and root canal treatment were selected from a pool of recently extracted teeth (<6 months) and stored in water. All teeth were screened on the presence of cracks through light illumination and those with cracks were eliminated. The selected teeth were placed in polyvinylchloride (PVC) tubes (height: 12 mm; diameter: 15 mm) and filled with polymethylmethacrylate (Probase Cold, Ivoclar Vivadent, Schaan, Liechtenstein) up to 3 mm below the cement-enamel junction (CEJ). The specimen were stored in distilled water at 37 °C during the time of the study.

Teeth were randomly divided (sealed envelope) into six groups to receive the bonded bridges with a cantilever bridge to the lateral incisor: Group FCL: Full crown preparation, lithium disilicate; Group VL: Buccal laminate veneer preparation, lithium disilicate; Group CL: Only connector area, lithium disilicate; Group PL: palatal wing, lithium disilicate; Group PZ: palatal wing, zirconium oxide; Group PM: Palatal wing, metal ceramic.

Four different preparations (73690, Komet Dental, Lemgo, Germany) were made for the different groups (Fig. 2.). In group FCL a full circumferential preparation of 1 mm reduction of enamel was made with a chamfer outline of 0.3 mm, no dentin was exposed. In group VL a laminate veneer preparation without overlap (0.3 cervical chamfer-1.0 mm buccal reduction) was made with the preparation extended to the connector area on the mesial side. In group CL no preparation or chamfer was made, only sandblasting at delivery, this is the least invasive possible approach. Group PL, PZ and PM were made with a preparation on the palatal side where 0.3 cervical to 1 mm palatal of enamel was removed and a chamfer was made with an extension to the connector side. After preparation an impression was made of polyvinylsiloxane ultralight body (Aquasil Ultra XLV, Dentsply, York, Pennsylvania, USA) and heavy body material (Aquasil Ultra Heavy, Dentsply). All impressions were poured in hardstone for the fabrication of the indirect cantilever restorations. All samples were stored in water at 37° Celsius with a temporary restoration (Protemp 4, 3M ESPE) cemented using a poly-carboxylate cement (3M ESPE, Seefeld, Germany) (see Table 2 and Table 3).

2.2. Bonded bridges

One dental technician fabricated the bonded bridges according to the instructions of the manufacturer. Ceramic restorations were made in wax and then pressed and glazed in a ceramic oven (Programat EP5000, Ivoclar Vivadent) while zirconia restorations were milled in a 5-axis milling machine (Lava 3M CNC 500, 3M ESPE) and layered using a feldspathic material (IPS e.max Ceram, Ivocar Vivadent). The Metal bridges were made of d.SIGN 59 which is a silver-paladium material which was layered with ceramic IPS Style (Ivoclar Vivadent). The connection area (approximal) was made 21 mm^2 (7 × 3 mm) for all restorations.

2.3. Adhesive luting

Before adhesive luting the temporary restoration and cement were removed using a scaler and a brush with pumice. In this study different materials were used for the bonded bridges therefore different adhesive procedures and conditioning methods were used for the specific materials.

Groups with lithium disilicate restorations were fitted and then conditioned using a 9% Hydrofluoric acid (Porcelain Etch, Ultradent

Table 1
The brands, types, chemical compositions, manufacturers and batch numbers of the main materials used in this study.

Brand	Type	Manufacturer	Composition	Batch number
Bis-Silane	Silane	Bisco	3-methacryloyloxypropyltrimethoxysi- lane, ethanol, acetic acid	1600007289 1600007758
CoJet Sand	Particle for air-abrasion	3M ESPE	Aluminium trioxide particles coated with silica, particle size: 30 μm	
Durelon	Carboxylate cement	3M ESPE, St. Paul, Minnesota, USA	Powder: Zinc oxide, stannous fluoride, tin dioxide. Liquid: Water and polyacrylic acid	620991 628842
ED Primer	Bonding agent	Kuraray	Void, N-Methacryloyl-5-aminosalicylic acid, Water, Catalysts, Accelerators	Liquid A: 960033 Liquid B: 970033
Enamel HFO	Photo-polymerized resin composite	Micerium	1,4-Butandioldimethacrylate, urethandimethacrylate, Diurethandimethacrylate, Isopropyliden-bis (2(3)-hydroxy-3(2)-4(phenoxy)propyl)-bis(methacrylate), glass filler: mean particle size 0.7 μm; highly dispersed silicone dioxide	2017001302
ESPE-Sil	Silane	3M ESPE	Ethyl alcohol, methacryloxypropyl, trimethoxysilane	551520 550016
Glycerin Gel	Glycerin gel	Johnson & Johnson, Sezanne, France	Glycerin gel	3099VA
IPS Ceramic Neutralizing Powder	Neutralizing powder	Ivoclar Vivadent	25–50% sodium carbonate, 25–50% calcium carbonate	U17360
IPS e.max Press	Lithiumdiscilicate (Shade LT A1)	Ivoclar Vivadent	SiO_2, Li_2O, K_2O, MgO, ZnO, Al_2O_3, P_2O_5 and other oxides	U27101 U54261 U36199
Lava Plus	(HIP) 3Y TZP	3M ESPE	3 mol% Y-TZP + Al2O3 0.1% + ionic staining components	
Metal	White Palladium-based Alloy	Ivoclar Vivadent	Pd 59.2%, Ag 27.9%, In 2.7%, Sn 8.2%, Zn 1.3%	W03188SV
Optibond FL	Bonding agent	Sirona Kerr	Primer: HEMA, GPDM, PAMM, ethanol, water, photo-initiator Adhesive: TEGDMA, UDMA, GPDM, HEMA, bis-GMA, filler, photo initiator	6113545 6182699
Panavia F2.0	Resin composite cement	Kuraray	Sodium fluoride, Hydrophobic aromatic dimethacrylate, Hydrophobic aliphatic dimethacrylate, Hydrophilic aliphatic dimethacrylate, Silanated barium glass filler, Catalysts, Accelerators,Pigments	Paste A: 2B0091 Paste B: 240042
Porcelain Etching Gel	9% Hydrofluoric Acid	Ultradent Products	9% Hydrofluoric ccid	BDQX2
Ultra-Etch	Etching gel, 38% Phosphoric acid	Ultradent Products	38% phosphoric acid (H_3PO_4)	BD5LZ

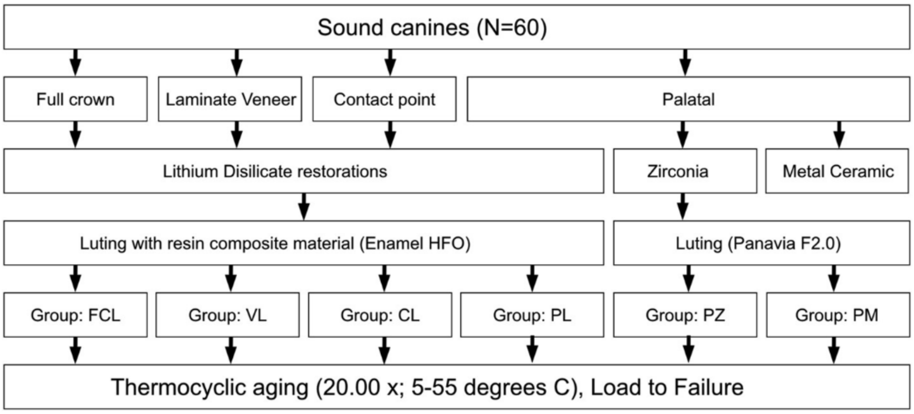


Fig. 1. Flow-chart showing experimental sequence and allocation of groups.

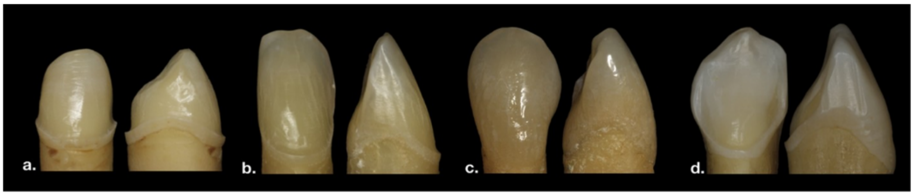


Fig. 2. Preparation made for the different groups: a. full crown preparation in enamel, b. Buccal laminate veneer preparation in enamel, c. no preparation, d. palatal chamfer preparation.

Inc., South Jordan, UT, USA), cleaned using a 38% phosphoric acid (Ultra Etch, Ultradent Inc.), ultrasonically cleaned in a bath with distilled water and then Silanized (BisSilane A&B, Bisco, Schaumburg, Illinois, USA) and heated in an oven (DI 500, Coltene Whaledent, Altstatten, Switserland) of 100° Celsius for 3 min. Enamel of the teeth was conditioned using 29 μm Aluminium Oxide (Aquacare, Velopex, London, England), 38% phosphoric acid (Ultra Etch, Ultradent Inc.) and adhesive applied (Optibond Fl Adhesive, Kerr). Before luting the restoration a bonding agent was applied on the restoration and the luting agent used is a heated (55° celsius, EnaHeat, Micerium, Avegno, Italy) direct restorative composite (Enamel HFO UD1, Micerium).

The groups with the metal and zirconia bridges were cemented using Panavia F2.0 (Kuraray Noritake Dental, Tokyo, Japan). Cementation surfaces both groups were sandblasted (Aluminium oxide 29 μm) for 10 s with nozzle angle of 45°, distance of 10 mm at 2 bar pressure using a chairside air-abrasion device (Aquacare, Velopex, London, England). Thereafter the surfaces were silanized (metal/zirconia primer, Kuraray Noritake Dental). Teeth were conditioned using 38% phosphoric acid (Ultra Etch, Ultradent Inc.) and adhesive applied (ED primer, Kuraray Noritake Dental). Thereafter the bonded bridges were cemented using a dual cure cement (Panavia F2.0, Kuraray Noritake Dental).

After removing the excess, photo-polymerization was performed for 10s (Bluephase 20i, Ivoclar Vivadent), glycerin applied (Johnson & Johnson, Sezanne, France) and further light polymerized for 90s on each side. The output of the polymerization device was >1000 mW/cm^2 throughout the experiment verified by a radiometer (Bluephasemeter, Ivoclar Vivadent). The restorations were finished (Arkansas white stone, Shofu) and polished (Ceragloss Yellow, Edenta).

2.4. *Aging and fracture test*

All specimens were hydrolytically aged (20 × 10^3 cycles between 5 and 55 °C, dwell time 30 s) in distilled water. Changes in marginal gap, fractures of the ceramic and debonding were evaluated under optical microscope (x40, Leica Wild Heerbrugg, M3Z Schott Zeiss KL200).

The specimens were then mounted in the jig of the Universal Testing Machine (810 Material Test System, MTS, Eden Prairie, USA) and loaded with an 5 mm flat steel cylinder perpendicular to the incisal edge of the lateral incisor at a crosshead speed of 1 mm/min (Fig. 3). The maximum force to produce fracture was recorded.

Fig. 3. Figure how the loadcell was applied on the incisal edge of the pontic.

2.5. *Failure analysis*

Failure sites were initially observed using an optical microscope (Leica Wild Heerbrugg, M3Z Schott Zeiss KL200) at x40 magnification and classified as an ordinal variable with increasing severity as follows: Type fracture: I: Root fracture (non repairable); II: Tooth fracture; III: Connector – Tooth fracture; IV: Connector – Adhesive fracture; V: Connector fracture; VI: Adhesive fracture; VII: Pretest Failure. Additionally, representative specimens from each group were sputter-coated with a 3 nm thick layer of gold (80%)/palladium (20%) (90 s, 45 mA; Balzers SCD 030, Balzers, Liechtenstein) and analysed using cold field emission Scanning Electron Microscope (SEM) (LEO 440, Electron Microscopy Ltd, Cambridge, United Kingdom).

2.6. *Statistical analysis*

Data were analysed using a statistical software package (SPSS 25, PASW statistics 0.0.0, Quarry Bay, Hong Kong, China). Kolmogorov-Smirnov and Shapiro-Wilk tests were used to test normal distribution of the data. The data was not normally distributed, however the power of the non-parametrical test is lower than the parametrical test. Therefore we choose the One-way ANOVA test (p = 0.05) with Bonferroni and LSD as post-hoc tests. Chi-Square test was used to analyse the failure configuration of the lithium disilicate RBFDPs.

3. Results

After aging conditions, no apparent changes were observed in marginal integrity or fractures however in the group of zirconium bridges 6 out of 10 bridges debonded at the adhesive interface. The pretest failures were set at 0 for the analysis. Mean fracture strength results showed significant differences between the groups ($p < 0.05$). Material type significantly affected the results (ANOVA, $p = 0.000$). Mean fracture strengths of the groups: 588 N (FCL), 588 N (PM), 550 N (CL), 534 N (PL), 465 N (VL), 38 N (PZ) (Table 2). Only group PZ had a significant lower fracture strength from the other groups. VL had a significant ($p = 0.02$) lower fracture strength from group FCL and PM.

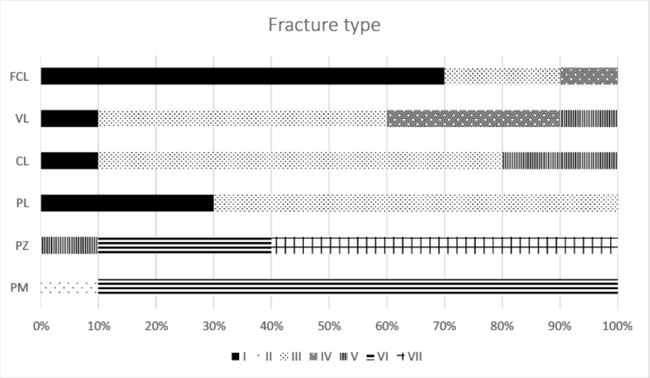
Chi-Square test showed some significant differences between the lithium disilicate groups: $X^2(9,N = 40) = 20{,}857, p = 0.013$. The full crown preparation, although having a high fracture strength, showed

Table 2
Fracture strength results (Mean ± standard deviation) (Newton) of experimental groups after thermo-cyclic aging and axial loading, minimum, maximum and Confidence Intervals (95%). Same lower-case letters in each column indicate no significant differences within each column ($p > 0.05$). For group descriptions see Fig. 1.

Experimental Groups	n	Mean (SD)	Minimum	Maximum	Confidence Interval	
					Lower Bound	Upper Bound
Full Crown LS	10	588 ± 111^a	432	750	508.57	666.93
Veneer LS	10	465 ± 128^a	325	673	373.65	556.29
Connector LS	10	550 ± 134^a	364	745	447.72	653.21
Palatal LS	10	534 ± 124^a	300	727	444.61	622.62
Palatal Z	10	38 ± 66^b	0	164	−9.39	85.73
Palatal M	10	588 ± 115^a	441	806	505.48	669.82

Table 3

Failure types experienced after fracture: I: Root fracture (non repairable); II: Tooth fracture; III: Connector – Tooth fracture; IV: Connector – Adhesive fracture; V: Connector fracture; VI: Adhesive fracture; VII: Pretest Failure..



significantly more root fractures (unrepairable) (Table 3). Most of the zirconia RBFDP did not survive the thermocyclic aging and had all adhesive fractures on the zirconia substrate. The metal and zirconia RBFDPs fractured all repairable on the adhesive interface. The connector RBFDP had most often fractures at the connector area including parts of enamel, only one tooth was not restorable. Representative SEM analysis show fractures at the connector site of the PL group (Fig. 4a–b) and total debonding of the zirconia RBFDP from the tooth with the cement (Fig. 5a–b).

4. Discussion

This in vitro study studied the influence of the different materials and the configuration of cantilever fixed partial dentures (RBFPD) on fracture strength. In addition, the type of fracture and repairability after fracture test was examined. The first null hypothesis - the configuration of the RBFDP has no influence on fracture strength, fracture type and clinical repairability – has to be rejected. Groups 1 to 4 have been restored with lithium disilicate, but treated with different preparation designs. The results show that according to the LSD post-hoc test there is a significant ($p = 0.02$) difference in fracture strength between group VL and the other groups. Analysing the failure type results the full crown modality had significantly more unrepairable fractures than the other groups.

The second null hypothesis - the type of restorative material does not influence fracture strength, the type of fracture and the clinical repairability – has to be rejected. To test this null hypothesis, groups PL, PZ and PM were analysed, since they are all provided with the same preparation, but have been restored with a different RBFDP material. From group PZ, 6 specimens could not be tested as these did not survive the thermocyclic aging. It appears that zirconia RBFDP's were not proper adhesively bonded in this study since 60% of the specimens did not survive thermocyclic aging and the other specimens failed at relatively low forces at the adhesive interface. In a recent review it was stated that for high-strength ceramic (alumina/zirconia) cantilever RBFDP the application of primers or composite resins that contain special adhesive monomers are necessary (Blatz et al., 2018). MDP is supposed to be the predominant contributor on the possibility of luting to zirconia, both in vitro and in vivo (Kern, 2015; Ozcan et al., 2013; ÖZCAN et al., 2009; Khan et al., 2017; Kern and Wegner, 1998). In this study, the RBFDP's of zirconium oxide were sandblasted with aluminum oxide and silanized before the MDP containing cement was applied. This adhesive methodology was also used by Kern M (Kern, 2005a, 2017b), however in these studies a 95.4% of clinical survival was reached in 15 years. In another study by Kern et al. zirconia cantilever RBFDP had a survival of 98.2%, succes of 92% (failures due to debonding) in 10 years (Kern et al., 2017). The difference between both studies was the preparation design and the restorative material used. A shallow groove/-pinhole on the cingulum and a small proximal box preparation was made for positioning in the study by Kern. This could have led to a more macro-mechanical retention than our non-retentive preparation. Using zirconia for resin bonded bridges needs some macro-mechanical retention and not a non-retentive preparation we used in our study. Another option used to bond zirconia is silica coating the intaglio of the zirconia which was performed by some authors, however this didn't lead to better outcomes of the zirconia resin bonded bridges (Shah and Laverty, 2017; Shahdad et al., 2018; Thoma et al., 2017).

With regard to the type of fracture and its repairability, the group with the circumferential crown preparation had a large proportion of non-repairable fractures. This could be due to the weakening of the tooth itself (loss of enamel) and some parts of the preparation could have been in dentin. No immediate dentin sealing was used in this study as the preparation was finished primarily in enamel (Gresnigt et al., 2016). However, dentin exposure at influential parts of the preparation could have had a negative influence on the fracture behavior. Overall more material and tooth fractures occurred in the groups with lithium disilicate RBFDP's this could be attributed to the high fracture strength reached and the good bond strength to enamel. In groups PM and PZ a dual cure resin cement was used following the manufacturer's instructions and was found to be the weakest link. Luting using a composite material was also found beneficial in a study by Gresnigt et al. where the fracture strength of laminate veneers was improved and failures predominantly happened in the tooth or restorative material (Gresnigt et al., 2017).

An unexpected finding of this study is the result of the connector bridge which was not studied in previous studies before. This

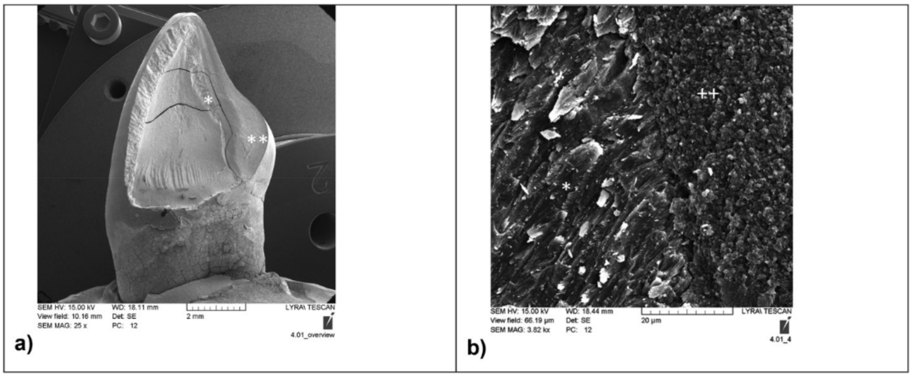


Fig. 4. a–b. SEM images of group PL after thermo-mechanical aging and fracture test **a)** overview with a fracture at the connector area, note the palatal wing intact (**) on the enamel substrate (*), **b)** higher magnification 3800x of the enamel (*) composite interface (++).

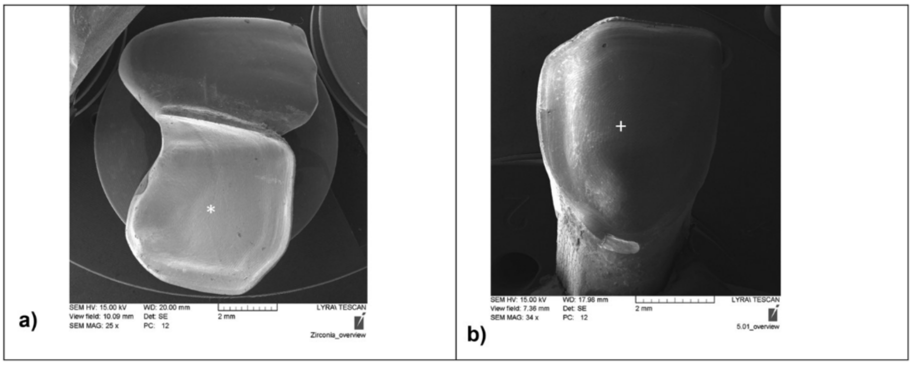


Fig. 5. a–b. SEM images of a representative specimen from group PZ after thermocycling and fracture test a) note the milled intaglio surface of the zirconia(*) without composite or adhesive, b) the tooth with the cement(+) on the enamel surface.

intervention group was included as this would be the least invasive option possible. This bridge at the connector area required only removing some undercut if needed. There was no chamfer outline prepared cervically in the test samples, in order to give the dental technician sufficient space and freedom to provide a connector of sufficient size (21 mm^2). In this group only enamel was sandblasted, which is known to yield better adhesion than to dentin (Pashley et al., 2011; Armstrong et al., 2017; Balasubramaniam, 2017). This kind of bridge would be very interesting for young patients missing teeth and where it is not possible yet to place an implant or when there is no occlusal space.

An attempt was made to simulate the clinical situation as close as possible. However, there are always discrepancies between the clinical and laboratory setting. The test samples were embedded in acrylic, whereby the periodontal ligament is not simulated. This has a negative influence on the results, since the periodontal ligament (PDL) acts as a shock absorber and can therefore absorb forces (Soares et al., 2005; Magne et al., 2011). The PDL is also responsible in giving the tooth a certain kind of freedom of movement (Kern and Sasse, 2011), which is also the reason why cantilever RBFDP's generally outperform the three unit RBFDP's in the clinic (van Dalen and Feilzer, 2003; Pjetursson et al., 2007; Tirlet and Attal, 2015; Kern, 2005b; Attal and Tirlet, 2015).

Another point of discussion and deviation from the clinical situation is the place of loading during the fracture test. In this study it was decided to load the samples on the incisal edge of the pontic. This is not the contact area representative to the clinic, as avoidance of loading directly on the pontic area is advised. The setup tested in this study would be the worst case scenario, as patients experience often debonding or fracture during edge to edge position in biting. With the results obtained from this study, overreaching the biteforces of 155–200 N experienced in the anterior region, it is possible to implement these kind of restorations in the clinic (Naeije et al., 1998). In a clinical situation, as described above, the pontic will be relieved as much as possible of its function, in order to try to ensure more durability of the RBFDP. When applying lithium disilicate for the fabrication as a resin bonded bridge, as these are not yet indicated by the manufacturers patients should always be informed on the possibilities and possible failures and effects.

5. Conclusions

From this study, the following could be concluded:

1. Lithium disilicate cantilever RBFDP had comparable fracture strength to metal ceramic RBFDP and had a significantly ($p < 0.000$) higher fracture strength than the zirconia RBFDP.
2. The veneer RBFDP had a significantly lower fracture strength than the full crown and metal ceramic RBFDP.
3. Full crown preparations had significantly more unrepairable failures. Metal (0% pretest failures) and zirconium (60% pretest failures) RBFDP failed predominantly on the adhesive interface whereas the lithium disilicate (0% pretest failures) samples showed predominantly fractures in the contact area.
4. The least invasive contact point and metal RBFDP obtained a high fracture strength and optimal failure pattern.

Declaration of competing interest

The authors did not have any commercial interest in any of the materials used in this study and each of the authors listed below declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jmbbm.2019.103615.

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