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Cement layer thickness and load-bearing capacity of tooth restored with lithium-disilicate glass ceramic and hybrid ceramic occlusal veneers

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ABSTRACT

Objectives: To evaluate the influence of cement layer and veneer thickness on load-bearing capacity of tooth restored with hybrid ceramic (HC) and lithium-disilicate glass ceramic (LDGC) occlusal veneer restorations.

Methods: Cement layer thickness was set at either 50 μm or 200 μm and tooth restored either with 0.5 mm or 1.8 mm thick HC Cerasmart270 (GC) or LDGC IPS e.max CAD (Ivoclar Vivadent) occlusal veneers. For this study, 64 extracted human molar teeth were selected and divided into 8 groups. Prepared teeth were scanned, and occlusal veneers were manufactured using CAD/CAM technology (Cerec, Dentsply-Sirona). Finished veneers were luted to preparations using self-adhesive resin cement (G-CEM ONE) according to manufacturers' instructions. Teeth were loaded quasi-statically and ultimate fracture loads were recorded. Fracture types were analyzed and classified visually. Statistical analysis was performed using two-way ANOVA.

Results: With HC occlusal veneers, thickness of both veneer and cement layer had no significant influence on fracture load. The lowest mean ultimate fracture load value was found in 0.5 mm thick LDGC veneers group with 200 μm cement layer, which was significantly lower loading value compared with that of 1.8 mm thick LDGC veneers or any of HC veneers ($p \leq 0.0280$). LDGC veneers with 0.5 mm thickness showed fractures within the veneer, whereas in other groups fractures of the tooth substance was also detected.

Conclusions: Within the limitations of this study, it can be concluded that thin HC occlusal veneers provided higher load-bearing capacity than LDGC counterparts of the same thickness. HC veneers were also less sensitive to the effect of cement layer thickness.

1. Introduction

Tooth wear has been increasing especially in adult populations [1–3]. This is due to loss of non-renewable dental hard tissue, rehabilitation of occlusion might be indicated, although European consensus statement recommends delaying restorative treatment for severe tooth wear as long as possible [4]. To date, crowns and resin composite restorations have been used to restore worn dentitions [5]. Direct resin composite restorations do not require preparation, but are prone to fracture and require constant follow-up, whereas crowns are an irreversible solution which requires additional preparation and might lead to further complications [5]. Occlusal veneers, which provide alternative restorative solution to conventional crowns, have increased interest among clinicians in recent years as novel materials make adhesive

dentistry possible and thus, require minimally invasive tooth preparation. Occlusal veneers have been studied to be a viable option to restore worn teeth [6]. Conservative and minimally invasive approaches are recommended for severe tooth wear [4].

Nanofiller-containing hybrid ceramics (HC) have been developed as an alternative restorative option to combine the advantages of technologies of conventional microfilled resin composites and ceramics [6]. HC consists of both polymer and ceramic particles and has mechanical properties, close to ceramic materials due to high weight percent of ceramic material and high conversion degree of resin matrix. By increasing the amount of filler particles in the polymer matrix, HCs are less brittle compared with conventional dental ceramics, which improves also machinability and optical and mechanical properties compared with conventional resin composites [7–9]. Along with

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composites, ceramics in dental applications have also evolved rapidly over the last decades. Especially the use of lithium-disilicate glass ceramic (LDGC) has increased in recent years due to its natural looking appearance and esthetics, mechanical properties, and ease of use [10]. Microstructure of fully crystallized LDGC is reported to consist of 70 % of 5 μm long and 0.8 μm diameter lithium-disilicate crystals with an aspect ratio of 4 to 10 [10]. For glass ceramics containing smaller or larger lithium-disilicate crystal sizes have not shown increased flexural strength [11]. Randomly oriented needle-like crystals deflect, branch and blunt cracks and thus, increase the flexural strength of glass ceramic [12].

When maximum load-bearing capacity of minimally invasive occlusal veneers were compared with conventional crowns *in vitro*, occlusal veneers made from LDGC or HC represented similar loading values than porcelain-fused to metal crowns [13]. In clinical settings, however, it has been observed that ultrathin indirect nanofiller-containing resin composite occlusal veneers are more prone to minor partial failures compared to LDGC veneers in medium-term clinical use, although no statistically significant differences were found in the clinical performance between the materials [14].

Rekow et al. suggested in FEA-analysis, that crown material and its thickness are the most influential factors determining the maximum principal stress in full-ceramic crowns [15]. Thickness of the material is known to influence fracture load of LDGC restorations [16–18]. Thin HC occlusal veneers have been suggested as a beneficial option for thin occlusal veneers, and both HC and full-ceramic occlusal veneers with a thickness of 0.3–1.0 mm have shown to withstand higher loads than human maximal masticatory forces [19,20]. It is suggested that thicknesses between 0.7–1.0 mm can be recommended for ceramic occlusal veneers, whereas thicknesses of less than 0.7 mm can be applied to polymer based composite materials [6]. However, consensus of minimal thickness of occlusal veneers according to material has not been found, as research data on the minimal thickness of an occlusal veneer is scarce.

Also, mechanical properties and thickness of the adhesive resin cement influence the stress distribution at the interface [15,21]. Thicker cement layer decreases failure loads of ceramic crowns by increasing tensile stresses within the crown [22,23]. However, water absorption of luting cement also affects the mechanical properties of the restoration-tooth system. After water absorption stress caused by polymerization shrinkage of the cement is released and hygroscopic expansion stress may occur [23]. Increasing cement layer thickness has been reported to decrease bond strength between dentin and LDGC in aged test samples [24]. Water absorption has also been studied to reduce mechanical strength of polymer by degrading the polymer network through hydrolytic reactions [25]. However, significance of cement layer thickness is unclear when it comes to varying thicknesses under the restoration.

Available data are scarce when it comes to describing changes in load-bearing capacity and mode of fracture as a function of thickness of the occlusal veneer and cement layer. Hence, the aim of this study was to evaluate the co-influence of veneer thickness and cement layer thickness on the load-bearing capacity of tooth restored either with HC or LDGC occlusal veneer restorations.

2. Materials & methods

For this study, 64 extracted human molar teeth as similar size as possible were selected and divided into 8 groups ($n = 8/\text{group}$). Flat occlusal surfaces were prepared using a diamond instrument (Komet Dental, Gebr. Brasseler GmbH&Co) until only dentine was visible surrounded by enamel margin. Small, 1.2 mm chamfer was prepared using a tapered chamfer bur (size 021, Komet Dental), to create a cutting depth of 0.54 mm at the enamel crown margin. Occlusal veneers were milled either from HC Cerasmart270 (GC Corporation, Aichi, Japan) or LDGC IPS e.max CAD (Ivoclar Vivadent, Schaan, Liechtenstein).

Preparations were scanned using an Omnicam scanner (Sirona

Dental Systems GmbH, Bensheim, Germany) and occlusal veneers designed either 0.5 mm or 1.8 mm thick from the central fossa (Fig. 1, Cerec SW 5.1.3 software, Sirona Dental Systems GmbH). One tooth was scanned as a model, according to which anatomically similar occlusal veneers could be designed for each tooth. During the designing process, cement layer thickness was set either 50 μm or 200 μm . Restorations were milled using Cerec MC XL milling unit (Sirona Dental Systems GmbH).

Description of the groups (material, veneer thickness, cement layer thickness):

- 1) HC, 0.5 mm, 50 μm
- 2) HC, 0.5 mm, 200 μm
- 3) HC, 1.8 mm, 50 μm
- 4) HC, 1.8 mm, 200 μm
- 5) LDGC, 0.5 mm, 50 μm
- 6) LDGC, 0.5 mm, 200 μm
- 7) LDGC, 1.8 mm, 50 μm
- 8) LDGC, 1.8 mm, 200 μm

After restoration milling, LDGC restorations were polished using diamond polisher cups (Optrafine, Ivoclar Vivadent) and glazed with IPS Glazing Paste (Ivoclar Vivadent) and crystallized in a Programat P300/G2 furnace (Ivoclar Vivadent). Auxiliary firing paste (IPS Object fix, Ivoclar Vivadent) was placed onto milled IPS e.max restorations to avoid direct contact with the crystallization tray in the furnace. After crystallization, LDGC restorations were cleaned with a steamer (Wasi-Steam, Wassermann Dental-Maschinen GmbH, Hamburg, Germany). HC restorations were polished using yellow rubber polishers and spirals (Sof-Lex, 3 M ESPE, Neuss, Germany).

2.1. Restoration bonding

For pretreatment, occlusal veneers of both used materials were etched using 4.5 % hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent), 60 s for HC occlusal veneers and 20 s for LDGC occlusal veneers according to manufacturers' instructions. G-Multi Primer (GC Corporation) was applied onto etched ceramic surface and gently air-dried. The enamel of prepared teeth were pre-treated selectively with 37 % phosphoric acid (Scotchbond Universal Etchant, 3 M ESPE) for 15 s, rinsed with distilled water and air-dried. Self-Adhesive Resin Cement (GC Corporation) was applied onto the surfaces of occlusal veneers and the veneers were placed on the preparations. Excess cement was removed, and cement was photopolymerized for 20 s occlusally and 10 s on each side of the veneer (1400 mW/cm^2 , D-Light Pro, GC Corporation) by keeping the light tip in contact to the restoration. The materials used for bonding are shown in Table 1.

2.2. Loading test

For the occlusal loading test of the restoration-tooth system, auto-polymerizing poly(methyl methacrylate) PMMA blocks were manufactured by mixing polymer powder and monomer liquid (Self Curing, Vertex-Dental B.V.; AV Soesterberg, The Netherlands) at the powder/liquid ratio of 1.7 g/1 ml. Restored teeth were attached in cavities drilled to acrylic blocks with additional PMMA.

The quasi-static loading test was performed in air at room temperature (RTP) using an LR30K Plus loading machine with a 30 kN loadcell (Lloyd Instruments/Ametek Inc., Fareham, UK). Each tooth was loaded through a 5.5 mm diameter steel ball along the long axis of the tooth using the crosshead speed of 1 mm/min until fracture. An aluminum foil cushion was used for each tooth during loading to avoid local stress concentration. Ultimate fracture load in Newtons was recorded and fracture types were analyzed and classified visually.

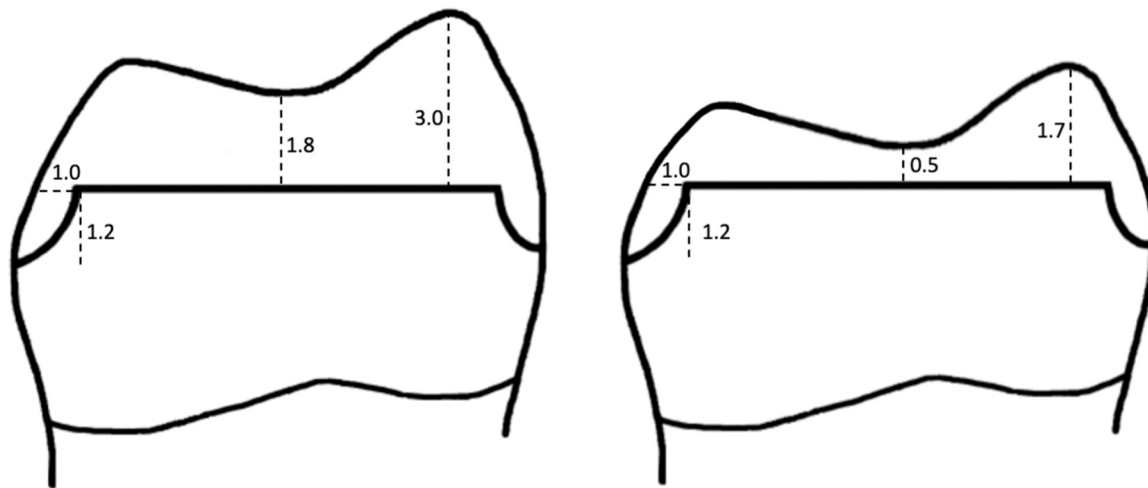


Fig. 1. Dimensions of occlusal veneers (mm).

Table 1
Materials used in this study.

Material	Composition	LOT	Manufacturer
IPS Ceramic Etching Gel	4.5 % Hydrofluoric acid	Z037BV	Ivoclar Vivadent, Schaan, Liechtenstein
Scotchbond Universal Etchant	37 % Phosphoric acid	9250920, 9250920	3M ESPE, Neuss, Germany
G-Multi Primer	Ethyl alcohol (90–100 %), MDP, MDTP, silane	2202071	GC Europe, Leuven, Belgium
Adhesive Enhancing Primer	Ethyl alcohol (25–50 %), MDP, 4-MET, MDTP	2206271	GC Corporation, Aichi, Japan
Self-Adhesive Resin Cement	UDMA, DMA, MDP, inhibitor, initiator, fluoro-alumino-silicate glass, silicon dioxide	2201121, 2304121	GC Europe, Leuven, Belgium
Cerasmart270	75 wt% silica (20 nm) and barium glass (300 nm) nanoparticles, Bis-MEPP, UDMA, DMA	2103011	GC Corporation, Aichi, Japan
IPS e.max CAD	SiO ₂ 57–80 wt%, Li ₂ O 11–19 wt%, K ₂ O 0–13 wt %, P ₂ O ₅ 0–11 wt% and other oxides.	YB54P7	Ivoclar Vivadent, Schaan, Liechtenstein

MDP=10-Methacryloyloxydecyl dihydrogen phosphate; MDTP =10-methacryloyloxydecyl dihydrogen thiophosphate; 4-MET =4-[2-(methacryloyloxy)ethoxycarbonyl]phthalic acid; Bis-MEPP = bisphenol A ethoxylate dimethacrylate UDMA= urethane dimethacrylate; DMA= dimethacrylate.

2.3. Surface indentation of the cement disks

For the cement microindentation tests, 1 mm thick cement disks were manufactured from Self-Adhesive Resin Cement (GC Corporation). Half of the disks ($n = 10$) were stored in a desiccator and the other half of disks ($n = 10$) were stored in distilled type 1 water at 37 °C for a duration of 12 days until the weight % was stabilized and no more water was absorbed. To test surface hardness of dried and wet cement disks, disks were attached to a metal plate and loaded with a diamond tip for 30 s using 10 N maximum force with both loading and unloading time being 30 s. Each cement disk was loaded 4 times and testing was performed using indentation tester (SMT-5000, Rtec instruments, Oakland, San Jose, USA).

2.4. Microscopic analysis

After the loading test, one specimen from each group was further

examined by SEM (JSM 5500, JEOL Ltd., Tokyo, Japan) for determining fracture pattern and cement layer thickness. For the examination and imaging pieces of the fractured veneer and tooth structure were stored in a desiccator for one week and coated with a gold layer using a sputter coater in a vacuum evaporator (BAL-TEC SCD 050 Sputter Coater, Balzers, Liechtenstein). Fractured pieces of the restored tooth structure were examined visually from SEM micrographs with magnification of 25x (Fig. 5).

2.5. Statistical analysis

Statistical analysis was performed using two-way ANOVA followed with multiple comparisons by Tukey HSD test. Data was analyzed using JMP®, Version 17. SAS Institute Inc., Cary, NC, 1989-2023.

3. Results

The highest fracture load was recorded among 1.8 mm thick occlusal veneers, which was similar in both materials regardless of the cement layer thickness (Fig. 2). When analyzing thin veneers, HC veneers showed higher loading values compared to LDGC veneers, but statistically significant differences were only detected between 0.5 mm thin HC veneers with cement layer thickness of 50 μ m and 0.5 mm thin LDGC veneers with cement layer thickness of 200 μ m ($p = 0.0155$). However, increase in cement layer thickness decreased significantly load-bearing capacity of 0.5 mm thick LDGC samples compared with 1.8 mm thick samples ($p \leq 0.0140$), whereas in HC samples, statistically significant differences were not detected between groups regardless of the cement layer and veneer thickness (Fig. 2).

Load-deformation curves show that HC occlusal veneers had higher deformation compared with LDGC veneers during loading test (Fig. 3). Interestingly, irregularity between loading force and deformation was observed in both materials indicating pre-cracks, but especially with 1.8 mm thick HC veneers and in group 1 (HC, 0.5 mm, 50 μ m, Fig. 3).

When analyzing fracture types of the restoration-tooth system, in each of the 1.8 mm thick restorations and majority of the 0.5 mm thick HC restorations, tooth fractures were observed, whereas in a majority of the 0.5 mm thick LDGC restorations, fracture occurred in the occlusal veneer (Fig. 4). SEM-micrographs of the fractured pieces of restored tooth were analyzed using SEM and cement layer thicknesses were measured to be approximately 200 μ m and 300 μ m instead of 50 μ m and 200 μ m respectively (Fig. 5). Smoother fracture surfaces were visible in LDGC veneers compared with the HC samples, which showed a more irregular fracture surface within the restorative material (Fig. 5).

Mean water absorption of the luting cement was 1.2 wt% and

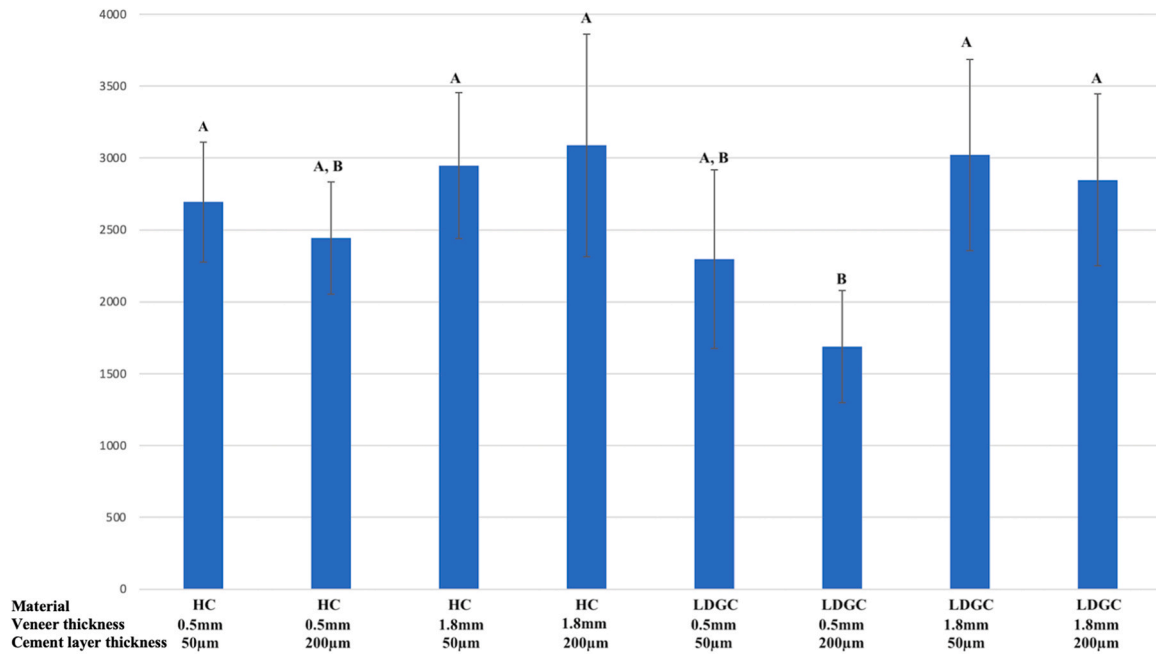


Fig. 2. Mean ultimate fracture loads according to veneer material (HC and LDGC), thicknesses of veneer (0.5 mm or 1.8 mm) and cement layer (50 µm or 200 µm), respectively. Groups not connected by the same letter are statistically significantly different.

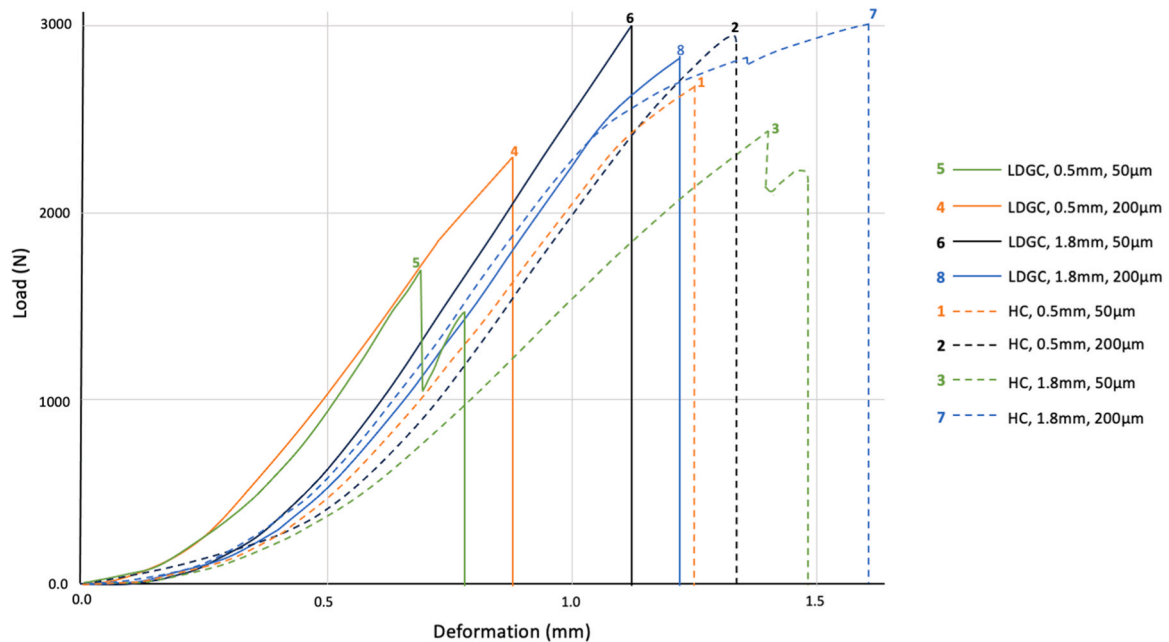


Fig. 3. Load-deformation curves according to each group.

saturation was reached in ten days (Fig. 6). Surface microindentation tests of the cement disks showed that dried cement disks had a slightly higher mean hardness (0.51 GPa) compared with water-aged samples (0.48 GPa) (Fig. 7). Also, according to load-displacement curve, elastic recovery of dried cement disks seemed to exceed that of water-aged samples (Fig. 8).

4. Discussion

This study aimed to analyze the effect of cement layer thickness, thickness of the restoration, and type of the restorative material on load-bearing capacity of teeth restored with occlusal veneers. This study

revealed that thin LDGC veneers with a thick adhesive cement layer had significantly impaired fracture load. Various fracture load values have been presented in the literature, which might be due to varying loading test setup, used materials and sizes of restored teeth. However, in general, earlier research findings agree with the results of this study which showed that the decrease in the cement layer and increase in restoration thicknesses were associated with higher fracture load especially with ceramic materials [26–28].

Several studies have shown that an increase in crown thickness increases load-bearing capacity of restored teeth in different loading test setups [15,29,30] although some contradicting results with thicker (1.0–1.5 mm) restorations have been reported [31]. This might indicate

	Fractured tooth	Fractured veneer
HC, 0.5mm, 50µm	6/8	2/8
HC, 0.5mm, 200µm	8/8	
HC, 1.8mm, 50µm	7/8	1/8
HC, 1.8mm, 200µm	8/8	
LDGC, 0.5mm, 50µm	1/8	7/8
LDGC, 0.5mm, 200µm	3/8	5/8
LDGC, 1.8mm, 50µm	8/8	
LDGC, 1.8mm, 200µm	8/8	

Fig. 4. Fracture type analysis of the groups.

that thickness of occlusal veneers becomes a crucial factor in thicknesses of less than 1.0 mm especially with LDGC material. Johnson et al. studied fracture resistance of 0.3 mm/0.6 mm/1.0 mm thick occlusal veneers made from indirect restorative composite and HC material and concluded that unlike veneer thickness, type of the veneer material is the critical factor to the fracture strength of the restored tooth [19]. The results of the present study and earlier investigations indicate that load-bearing capacity of an HC veneer is less sensitive to variation in restoration thickness. This might be explained by the microstructure of the thin composite restoration, as it is more favorable to adapt to the stress than that of more brittle ceramic-based restorations, which are prone to fractures [32]. However, also opposing results have been presented, that occlusal veneer fissure/cusp thickness of 0.5 mm/0.8 mm restored with LDGC presented higher fracture strength compared with polymer-infiltrated ceramic occlusal veneers [33]. Conflicting results might be due to differences in restorative materials used and loading test setup. Thus, more research is needed to support the implementation of thin occlusal veneers in clinical situations.

Comparing mechanical properties of the materials used in this study,

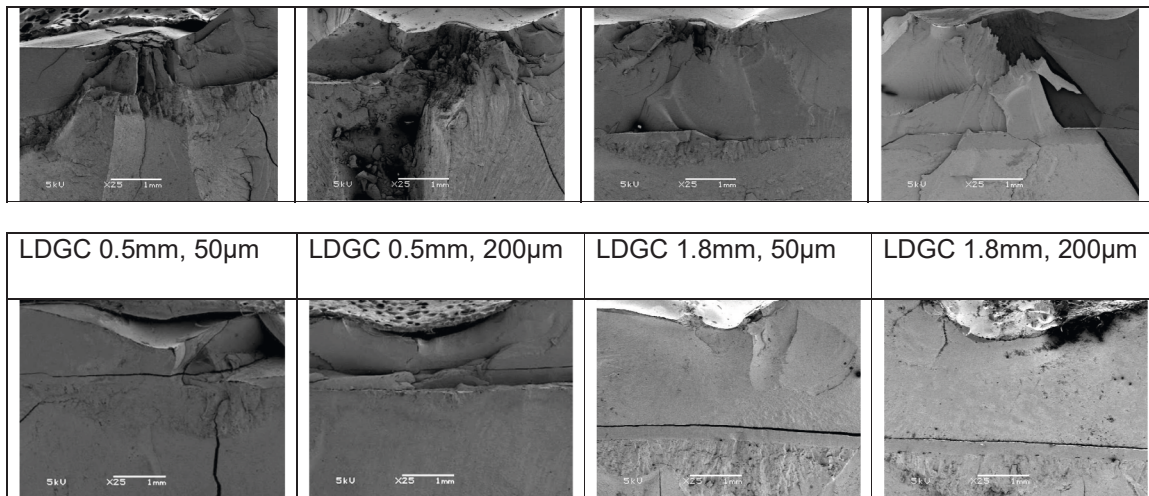


Fig. 5. SEM-analysis of the restoration-tooth systems according to each group (magnification 25x, bar 1 mm).

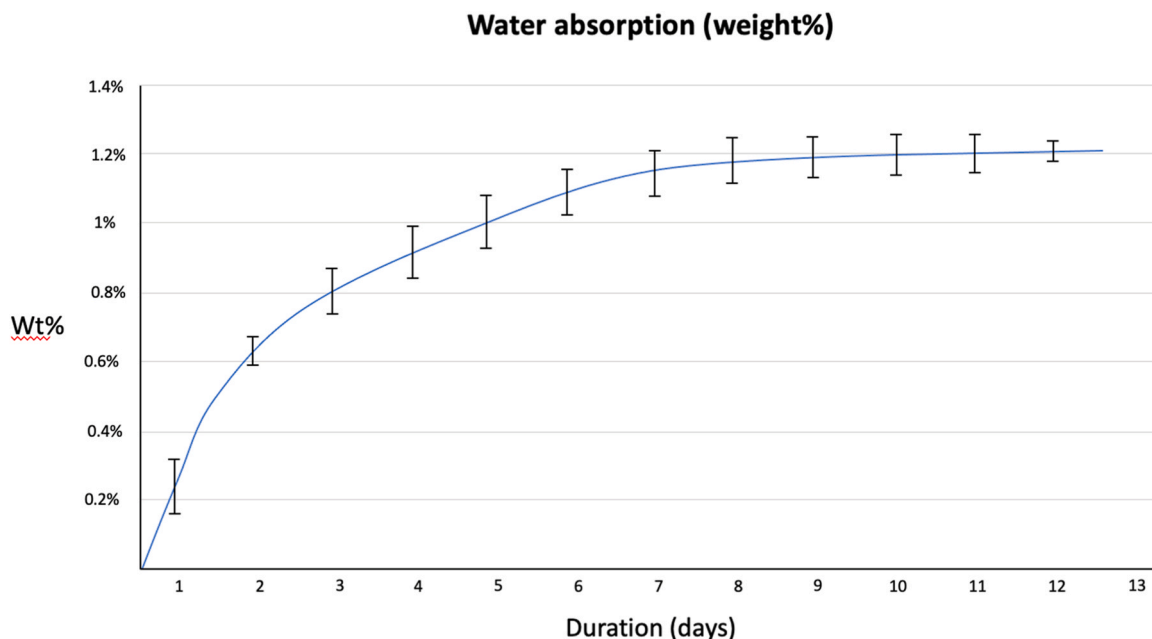


Fig. 6. Water absorption of cement disks.

Hardness (HIT)

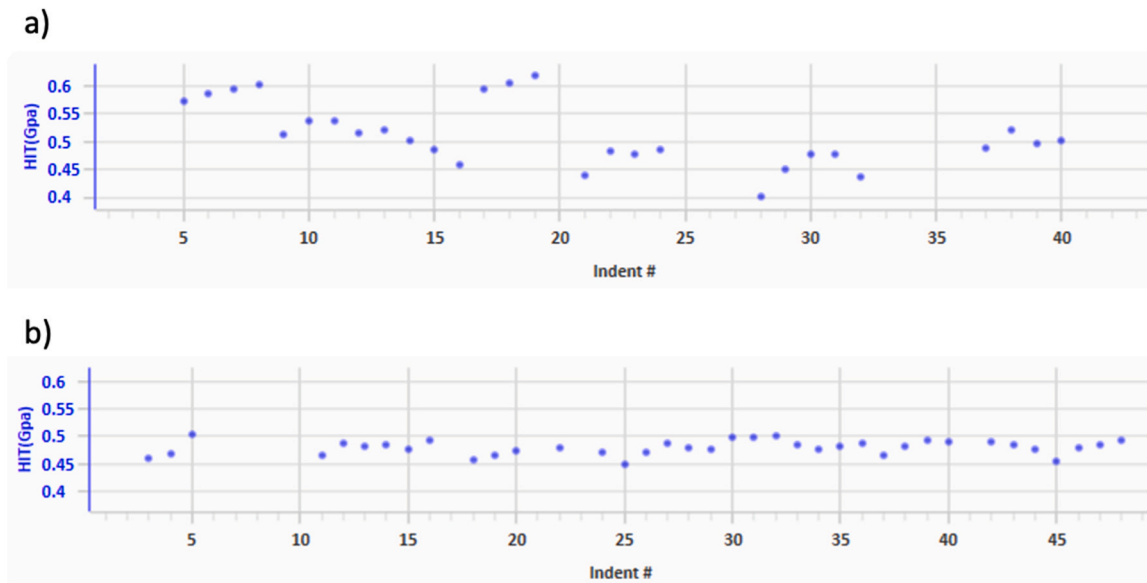


Fig. 7. Mean surface microhardness indentation (HIT in GPa) of the a) dry and b) water-stored cement disks.

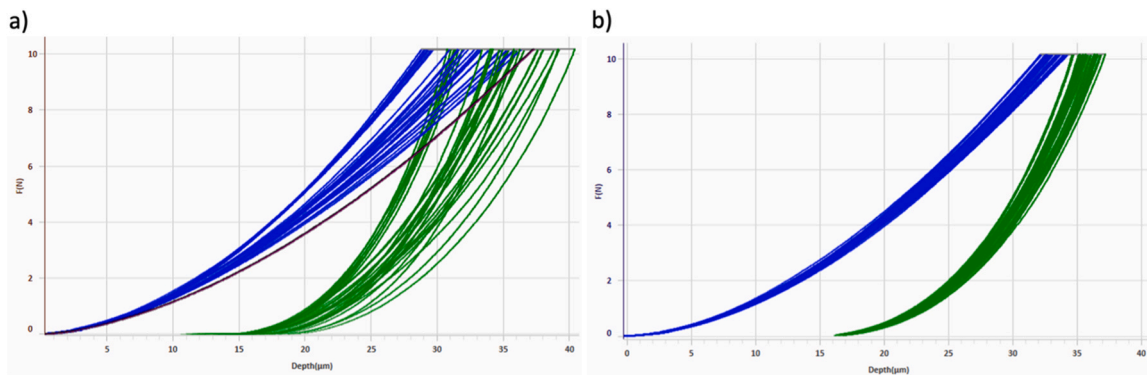


Fig. 8. Applied load and indentation depth (μm) of a) dry and b) water-stored cement disks.

HC is reported to have lower flexural strength and elastic modulus compared with LDGC material [34,35]. When analyzing fracture initiation and progression in LDGC veneers, fracture typically initiates from internal surface of the veneer where the most tension is concentrated, whereas in HC samples, the material deforms, and more stress is transmitted to the cement layer and adjacent tooth [36,37]. This can be also seen in load-deformation curves of the present study (Fig. 3) as more brittle material LDGC has less deformation and hence, energy dissipation to the cement layer and the tooth tissue is less [35]. This might also explain fracture types in this study setup, as in case of 0.5 mm thick LDGC occlusal veneer with high elastic modulus fractures occurred in veneer instead of tooth. However, in 1.8 mm thick veneers, fracture of tooth was present. Fracture type analysis shows that in LDGC veneers with 0.5 mm thickness, fractures of veneer were the dominant failure mode, whereas in other groups tooth fractures were detected (Fig. 4). In ceramic restorations with the thickness below 1.0 mm, flexural radial cracking has been detected as the dominant failure mode [38]. SEM-micrographs revealed also smoother fracture surfaces in LDGC veneers compared with the HC samples, which showed more irregularity in fractures within the veneer (Fig. 5). Earlier fractography research also agrees that LDGC material shows crack propagation through glassy matrix and in HC material irregularity in fracture surface has been

detected [38]. Irregularity in the fracture surface of HC material could also work as a toughening mechanism, as cracks deflect from ceramic filler particles and the length of the crack increases [39].

When analyzing cement thickness, the present study indicated that thinner resin cement film was associated with higher fracture loads in LDGC material, which agreed with the findings of a previous study [40]. However, in the present study it was found that HC occlusal veneers were not as sensitive to the cement layer thickness than LDGC counterparts. The mechanism of weakening the restoration-tooth system by utilizing a thick cement layer, may be associated with the low elastic modulus of the cement layer compared with the elastic modulus of the tooth structure and the restorative material. When studying 1.8 mm thick restorations, cement layer thickness had no significant effect on the load-bearing capacity of restored tooth. According to Prakki et al., there was no difference in fracture load between different cement layer thicknesses (100, 200 and 300 μm) when it comes to 2 mm thick ceramic plates [26]. Consequently, by increasing occlusal veneer thickness, the relation of veneer thickness/cement layer thickness increases too and thus, the effect of cement layer thickness could become less significant especially in the case with LDGC material.

When the value of cement space of CAD/CAM-restorations in the present study was set at 50 μm and 200 μm , approximately 200 μm and

300 µm cement spaces were analyzed by SEM at magnification of 25x. This could be related to the fact that in case in uneven surfaces set cement thickness is not reached uniformly throughout the cement layer. Also, loading test, direction of fracture and angulation of image may complicate the estimation of cement layer thickness. Similar findings have been reported also earlier which indicates that variation in cement space might occur [21,41,42]. Cement layer thickness in CAD/CAM ceramic crowns is observed to be commonly between 100–250 µm [42, 43]. At thicknesses of more than 300 µm, gradual decrease of the load-bearing capacity has been detected [44]. However, within the limitations of this study, ultimate fracture load of all tested specimens exceeded the maximum human bite forces which have been reported to range between 585–880 N [19]. Reduction in load-bearing capacity after cement aging in water has been found due to decreased bond strength between cement and ceramic crowns and lowered elastic modulus and hardness of the luting cement [45]. Silane promoted adhesive interfaces are prone to degradation due to the hydrolytic effect of water affecting stress distribution of restored tooth [46]. Also, degradation in mechanical properties of composites and HCs occur after water sorption due to degradation of resin matrix and filler-matrix interface and the plasticization effect of water molecules in the polymer matrix [47,48].

In clinical studies, thin occlusal veneers made of indirect composite and ceramic materials have been used to successfully restore severe tooth erosion improved patients' oral health and appearance [49–52]. In a randomized clinical trial, Schlichting et al. followed 24 ceramic and 36 composite resin ultrathin veneers for 3 years and found a slightly higher survival rate for ceramic veneers (100%) compared with composite veneers (84.7%) [14]. They suggested that from the biomimetic perspective, ultrathin restorations with a similar elastic modulus to enamel, such as glass ceramics, could be favorable in terms of high occlusal load dissipation [14]. However, comprehensive clinical studies of minimally invasive occlusal veneers are scarce. At least non-retentive partial ceramic crowns with minimum thickness of 1.5 mm have given high success rates in long-term clinical trials [53].

This study gives valuable information evaluating thicknesses of cement layer and occlusal veneer and material selection for occlusal veneers. These elements should be carefully evaluated when restoring worn tooth especially in the posterior region. However, it is important to consider that this *in vitro* study was performed under laboratory conditions, which may not necessarily be the same in clinical situations. Also, slight variation in selected tooth and restoration size might have created variation in the results. Microfractures and quality of collected teeth could have also affected the results. The quasi-static loading test chosen for this study represents important information about mechanical stability and fracture behavior of materials [54,55]. However, cycling loading might provide more relevant data in terms of clinical conditions [54,56]. Despite the promising performance of the HC veneers from the present *in vitro* study, further *in vitro* and long-term *in vivo* studies are needed to better understand the mechanisms and critical material and operator-related factors which confirm clinical success of thin occlusal veneers. Also, effect of cement layer needs more clarification which could be studied using different cement layer thicknesses and testing setups including cycling loading and shear and tensile strength tests.

5. Conclusions

Within the limitations of this *in vitro* study, it can be concluded that tooth restored with thin HC occlusal veneers provide higher load-bearing capacity compared with LDGC veneers of the same thickness. Tooth restored with HC veneers are also less sensitive to the effect of veneer and cement layer thickness.

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Declaration of Competing Interest

Authors Topias Yli-Urpo, Timo Närhi and Lippo Lassila declare no conflict of interest.

Author Vallittu PK declares that he consults Stick Tech—Member of GC in training and RD.

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