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Two-body wear of novel monolithic lithium-silicate ceramic materials and their corresponding different antagonists

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ABSTRACT

Objectives: Evaluation of the two-body wear of lithium-silicate ceramics against different antagonists compared to a direct resin composite and human teeth.
Methods: Initial LiSi Block [LISI], IPS e.max CAD [EMA], and CEREC Tessera [TESE] were investigated and compared with direct resin composite [FILL] and human teeth [tooth]. As antagonists were used: steatite, ceramic, and human enamel. The control group tooth was only tested with enamel antagonist. The combinations underwent thermomechanical aging using a chewing simulator. Material losses were calculated using GOM-analysis software. Kolmogorov-Smirnov test, Kruskal–Wallis H, Mann–Whitney-U-test with Bonferroni correction and Spearman-rho correlation were calculated. A fractographic analysis was performed.
Results: Within TESE, enamel antagonists led to lower restoration losses than steatite and ceramic antagonists. Within FILL, enamel and steatite antagonists caused lower material losses compared to ceramic antagonists. Against steatite antagonists, LISI showed lowest material losses. Against ceramic antagonists, the use of LISI led to lower material losses compared to FILL. Against tooth antagonists, TESE showed lower material losses than tooth and FILL and LISI lower than FILL. Within LISI, steatite antagonists showed lower material losses on the antagonist than ceramic. Within EMA, steatite antagonists showed higher material losses than ceramic ones. Within ceramic antagonists, LISI restoration material showed lower material losses than FILL and EMA.
Conclusions: Regardless of the antagonist material, the material losses of LISI and EMA were comparable. However, the abrasion resistance of LISI tended to be higher than EMA.
Clinical significance: LISI is a fully crystallized lithium-silicate ceramic and no longer needs to be processed after milling. In addition, the abrasion resistance is very good, regardless of the antagonist material chosen.

1. Introduction

Dental ceramics have become the material of choice for indirect restorations because they fulfill both the esthetic and functional requirements for anterior and posterior tooth restorations, while being considered one of the most biocompatible classes of material [1,2]. In general, the two main groups of dental ceramics that are still used today are zirconia and silicate ceramics. Depending on their type of reinforcement, the silicate ceramics can be categorized into slightly (feldspar/leucite) and highly reinforced ceramics (lithium silicate). These ceramics are typically employed for fabricating single unit restorations, such as partial and full crowns, inlays, onlays, and veneers. If the lithium silicate ceramics are pressed in the laboratory by dental technicians, they are referred to as lithium disilicate ceramics [3]. Ceramics that can be processed with subtractive manufacturing techniques are divided into lithium disilicate, lithium metasilicate, lithium alumina silicate and lithium di/alumina silicate ceramics [4]. The lithium disilicate ceramics have been on the market for the longest time and have been extensively studied. All these ceramics can be processed differently. They are available as pre-crystallized or fully crystallized CAD/CAM blocks [5]. After milling, the pre-crystallized blocks must be crystallized in special furnaces in order to obtain their final properties. The fully crystallized ones, on the other hand, must be well polished to ensure that there are no microcracks on the surface, which can cause the material to fracture prematurely. Another option is glazing, which can be done together with the individualization using stains [6]. This option can be used with both pre-crystallized and fully crystallized ceramics. The additional glaze theoretically closes the micro-cracks within the ceramic mass and thus

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primarily prevents sub-critical crack growth. Studies show that lithium silicate ceramics are not only processed differently, but also have different mechanical and optical properties depending on their manufacturing technique [4,7].

Lithium silicate ceramic restorations are mainly used monolithically without veneering. Particularly mechanical properties, such as hardness, wear resistance or fracture toughness, are supposed to influence the wear performance of such ceramics strongly [8–11]. Wear is defined as material loss from a restoration surface, caused by mechanical contact against a solid or liquid body, chemical reactions, or simultaneous effect of chemical and mechanical reactions (ISO/TS 14569-2: [12]). The hardness and thickness of enamel [10,13] as well as the chewing behavior in combination with parafunctional habits and neuromuscular forces [10,14,15] influence the clinical wear. The type of antagonist material is equally crucial, since antagonists with lower hardness show higher material losses than harder ones [16]. Therefore, the aim of this study is to evaluate the two-body wear of novel lithium silicate ceramic materials depending on different types of antagonist materials. The following null hypotheses were investigated: (1) all lithium silicate ceramic materials show similar two-body wear results, regardless of the antagonist materials (2) all antagonist materials show similar two-body wear results, regardless of the restoration materials (3) direct resin composites and extracted human teeth show similar material losses in the restoration and antagonist materials compared to the tested lithium silicate ceramics.

2. Materials and methods

2.1. Specimen preparation

Three lithium-silicate ceramic materials were examined in this study: i. Initial LiSi Block, GC Corporation, Tokyo, Japan; ii. IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein; iii. CEREC Tessera, Dentsply Sirona Inc., Charlotte NC, USA (Table 1, Fig. 1). Monolithic full crowns were milled (Ceramill motion 2, Amann Girrbach, Koblach, Austria) using a master standard tessellation language (STL) dataset of a mandibular first molar (Fig. 2A, B; [16]). The milled crowns were post-processed using a diamond flap polisher for pre-polishing (DIAPRO TWIST DT-H17DPmf, EVE Ernst Vetter, Keltern, Germany), then with a diamond flap polisher for high-gloss polishing (DIAPRO TWIST DT-H17DP, EVE Ernst Vetter) and finished with a diamond polishing paste (9300, Gebr. Brasseler, Lemgo, Germany) and a goat hair-brush (AR9464, Gebr. Brasseler).

Table 1
Restorative materials tested for two-body wear in this study.

Material (Abbreviation)	LOT-Number	Type	Manufacturing and post-processing procedure
Initial LiSi Block (LISI)	2112021	Fully crystallized lithium disilicate ceramic	Subtractive manufacturing in milling machine, finishing with diamond flap polishers and goat hair-brush with diamond polishing paste
IPS e.max CAD (EMA)	626393	Partially crystallized lithium disilicate ceramic	Subtractive manufacturing in milling machine, crystallization firing parameters: 770 °C/840 °C, heat rates 60 °C/min and 30 °C/min and holding times 10 s/10 min, finishing with diamond flap polishers and goat hair-brush with diamond polishing paste
CEREC Tessera (TESE)	16012287	Partially crystallized lithium di/aluminasilicate ceramic	Subtractive manufacturing in milling machine, crystallization firing parameters: 760 °C, heat rate 60 °C/min and holding time 1:30 min, finishing with diamond flap polishers and goat hair-brush with diamond polishing paste

For the abutments a resin-based CAD/CAM-Blank (TRINIA, Bicon Europe Ltd., Büchenbeuren, Germany) with an elastic modulus of approximately 19 GPa was used. The abutments were milled (ceramill motion 2) using a master STL file (Fig. 2C, D) and air-abraded using 50 μm alumina powder with a pressure 0,1 MPa and a distance of 10 mm for the bonding process.

The intaglio surfaces of the lithium-silicate ceramic crowns were etched for 20 s using 5 % hydrofluoric acid (IPS Ceramic Etching gel, Ivoclar Vivadent) and cleaned with alcohol (Isopropyl alcohol, Otto Fischar, Saarbrücken, Germany) in an ultrasonic bath (Transistor Ultrasonic, T-14, L&R, New Jersey, USA) for 3 min. The crowns were conditioned for 5 s with a thin film of G-Multi PRIMER (GC Europe) and carefully dried with oil-free air. A self-adhesive resin composite luting material (G-CEM ONE, GC Europe, LotNo 2105261) was applied into the crowns, pressed manually onto the resin abutment and light-cured with a high-power LED polymerization lamp (D-Light Pro, GC Europe) with a light intensity of 1400 mW/cm^2 for 20 s at the distance of 5 mm occlusal and on three crown sides (Fig. 2E).

2.2. Preparation and restoration of human teeth

Ethical clearance for the use of human extracted teeth was obtained from the local ethics committee of the Ludwig-Maximilians-University of Munich. Human maxillary and mandibular extracted molars (N = 60) that were free of visible cracks, carious lesions or restorative materials were selected for the direct composite group and the control group. The teeth were cleaned and stored in a 0.5 % chloramine T solution (CAS: 499291232, chloramine T trihydrate, Carl Roth, Karlsruhe, Germany) at room temperature (23 °C) for a maximum of 7 days after extraction and then in distilled water at 5 °C for a maximum of six months. After preparation, all specimens were stored in distilled water at 37 °C for 24 h (Hera Cell 150, Heraeus, Hanau, Germany).

The teeth for the direct resin composite restorations (Fig. 2F) and the control group (Fig. 2G) were embedded up to the cemento-enamel junction (C.E.J.) with a self-curing acrylic resin (SCANDIQUCIK A/B, SCAN-DIA, Hagen, Germany) parallel to the tooth axis in a special holding mold with a cylindrical form. For the control group, unprepared and unrestored teeth were used. For the direct resin composite group, occlusal class I-cavities (vestibular-oral width of 3.0 mm, distal-mesial width of 6.5 mm, occlusal reduction of 4.0 mm, convergence angle of 6°) were prepared. The preparations were made under permanent water cooling at 40,000 min^{-1}/rpm with a conical diamond bur (6848.314.031, Gebr. Brasseler, Lemgo, Germany) in a high-speed handpiece (Perfecta 900, W&H, Laufen, Germany). Care was taken to always prepare cavities of the same size and depth, which was ensured with markings on the tooth and the bur. Prior to restoration, the prepared teeth were stored in distilled water at 37 °C for 24 h (Hera Cell 150, Heraeus, Hanau, Germany). For the direct restoration of the molars, the cavity was dried with oil-free air, conditioned with a bonding agent (G-Premio BOND, GC Europe) for 10 s, blown dry with air for 5 s and then light-cured at a distance to the light guide tip of 10 mm for 5 s (D-Light Pro). The resin composite (G-aenial A'CHORD, GC Europe) was applied to the cavity in two layers and light-cured for 20 s at distance of 1 mm (D-Light Pro).

2.3. Antagonist preparation

The following materials were used for fabricating the antagonists (N = 130): i. steatite (n = 40; steatite ball 1197, SD Mechatronik, Feldkirchen–Westerham, Germany) ii. ceramic (n = 40, Initial LiSi Block, GC

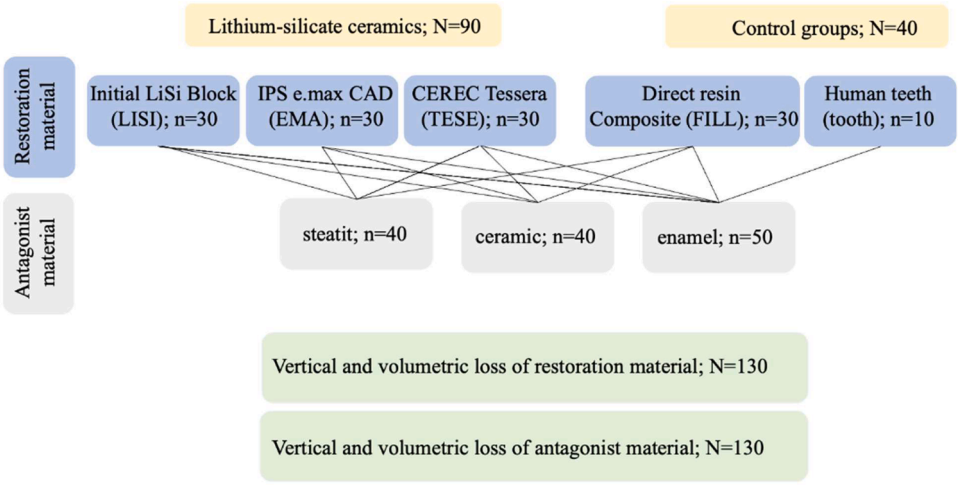

Fig. 1. Study design included all tested groups und specimen numbers.

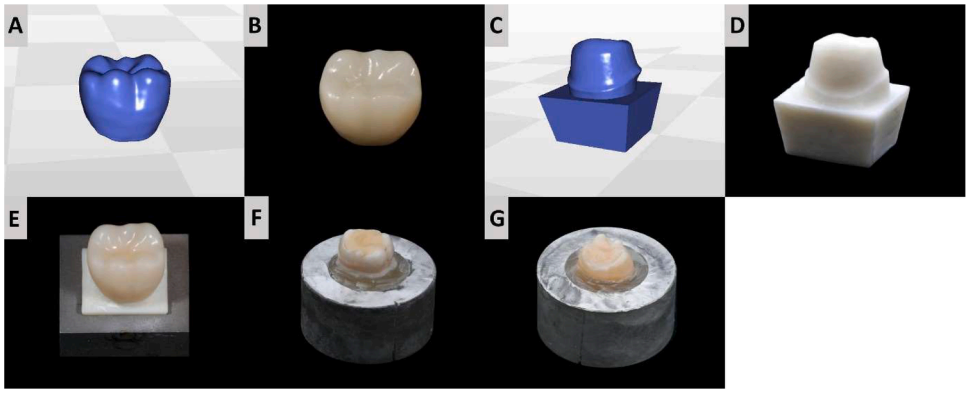

Fig. 2. A. Master crown STL file. B. milled and finished master crown. C. Master abutment STL-file. D. milled master abutment.

Europe), iii. Enamel from extracted human teeth (n = 50). For the ceramic antagonists, cylinders with a 4 mm diameter hemisphere at one end were digitally constructed (Fig. 3A) and milled (Ceramill Motion 2) from Initial LiSi blocks (Fig. 3B).

To fabricate the enamel antagonists, mesiobuccal cusps were cut from mandibular first molars with a cutting disc under water cooling (Fig. 4A). The cusps were embedded in a cylindrical steel holder with amalgam (Dispersalloy, Dentsply Sirona, Bensheim, Germany) (Fig. 4B). The cusps were shaped into a hemisphere using a stationary drill (BT-BD 1020, Einhell ISC GmbH, Landau/Isar, Germany) with a hemispherical diamond abrasive body (d = 4 mm) (Fig. 4C).

The steatite antagonists were defined by the supplier as d = 6 mm. The spherical antagonists were embedded with resin (SCANDIQUCIK A/B) (Figs. 3C, 5C) in a metallic specimen holder (Fig. 5B).

2.4. Thermomechanical artificial aging

The restorations and the antagonists were mounted in a chewing simulator (CS-4.10, SD Mechatronics) and exposed to 1.2 million masticatory cycles with a frequency of 1.5 Hz and force of 50 N (Fig. 1e). The chambers were filled alternately for 60 s each with 5 and 55 °C distilled water (6000×), so that in addition to mechanical loading, thermal cycling also took place simultaneously. The antagonists were positioned in the central fossa of the restoration, exhibiting three-point occlusal contact, and opposed to antagonists moving with a vertical stroke of 2 mm and a lateral movement of 0.7 mm (Fig. 6 AB).

2.5. Determination of the material losses

Before (pre-scan) and after thermomechanical aging (post-scan), all restorations and antagonists were scanned with a triagonal laser scanner

Fig. 3. A. Master ceramic antagonist STL file. B. milled and separated ceramic antagonist. C. embedded ceramic antagonist. D. milled master abutment.

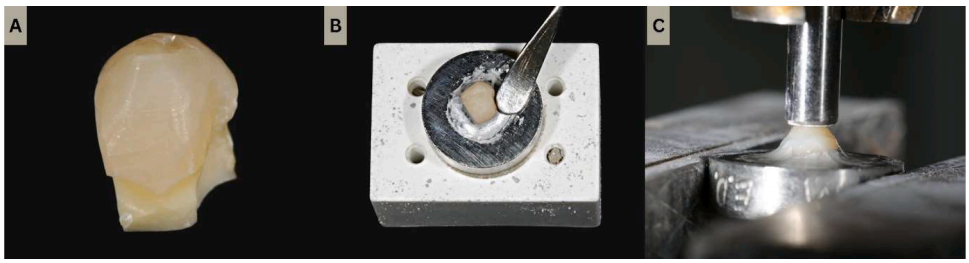

Fig. 4. A. Mesiobuccal cusps from mandibular first molars. B. Embedding the enamel antagonist. C. Shaping of the cusp into a hemisphere using a stationary drill.

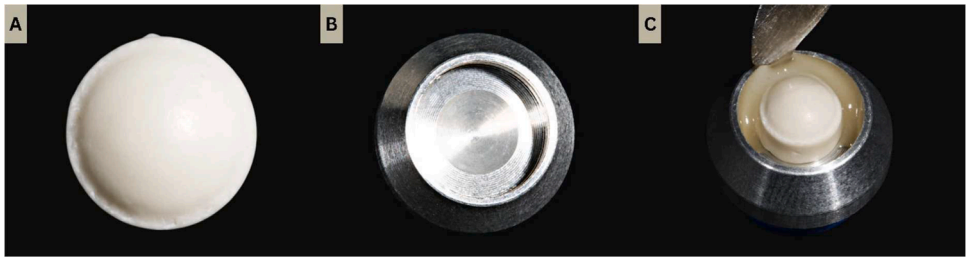

Fig. 5. A. Steatite antagonist. B. Metallic specimen holder for the embedding the antagonists and fixation in the chewing machine. C. Embedded steatite antagonist.

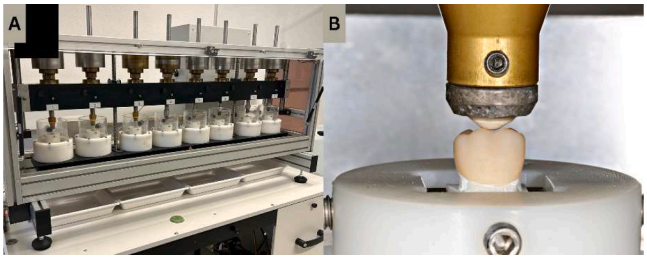

Fig. 6. A. Chewing simulator used in this study B. Positioning the antagonist in the central fossa of the restoration.

(LAS 20, SD Mechatronik). Therefore, the specimens were cleaned with a soft toothbrush and sputted with an occlusion spray (ARTI-SPRAY, Dr. Jean Bausch, Cologne, Germany) of a distance of 20 cm for 2–3 s. The scan field was defined via the commands ``set starting point'' and ``set end point''. The Z-level for the measurement was set in the center of the specimen. All scans were performed with the setting ``ceramic glossy'' and revolution XY of 0.04 mm. To determine the material loss (GOM Inspect, Carl Zeiss GOM Metrology, Oberkochen, Germany), the point cloud of the initial scans was converted as a CAD model and the scan after aging was converted as a mesh. The data overlay was performed based on the pre-direction of the CAD model and the mesh. The abraded area was selected and defined based on the ``local-best-fit'' orientation. The inspection was performed by comparing the areas on the CAD model. The material losses in the post-scans generated a measuring area, which was defined by the visual edge of the abrasion field. This abrasion area in the post-scans served as a reference for the measurement of the maximum height of the application (vertical gain) and ablation (vertical loss) as well as the volume of the substance application (volumetric gain) and ablation (volumetric loss) as a sum integral. The vertical loss was defined in the direction of the surface normal and thus indicated the maximum distance between the surfaces within the selected area. Further, the abraded surfaces were examined using a digital light microscope (VHX-S600E, Keyence, Osaka, Japan) at 50x magnification.

2.6. Statistical analyses

The normal distribution was tested using Kolmogorov-Smirnov-test. 12 of 56 groups (23.08 %) showed deviation from the normal distribution; therefore, for data analyzed non-parametric test were used. Spearman rho correlation was calculated between the vertical and volumetric material losses. The differences between the groups were evaluated using Kruskal–Wallis-H- and Mann–Whitney-U test with Bonferroni correction (IBM Statistics SPSS V27.0, IBM, Chicago III, USA). For all tests, the level of significance was set to $p < 0.05$.

3. Results

3.1. Relationship between vertical and volumetric material loss

A positive correlation between the vertical and the volumetric losses was observed for all groups (restoration side: $r = 0.843$, $p < 0.001$; antagonist side: $r = 0.674$, $p < 0.001$) (Fig. 7). Therefore, vertical losses were valuated and described in the following as material losses.

3.2. Material losses on restoration material

3.2.1. Impact of the antagonist material

Within LISI ($p = 0.718$) and EMA ($p = 0.874$) no impact of the antagonist material on the material loss was found. Within TESE, enamel antagonists led to lower material losses compared to steatite ($p = 0.019$) and ceramic ($p = 0.036$) antagonists. Within FILL, enamel ($p = 0.002$) and steatite ($p = 0.006$) antagonists caused lower material losses compared to ceramic antagonists (Table 2).

3.2.2. Impact of the restoration material

Against steatite antagonists, the restoration material LISI ($p < 0.023$) showed lower material losses compared to the remaining restoration materials. Ceramic antagonists led to lower material loss in LISI restorations compared to FILL ($p < 0.001$). With enamel antagonists, TESE restorations showed lower material losses than tooth ($p = 0.039$) and FILL ($p = 0.004$), and material loss in LISI restorations were lower than in the FILL group ($p = 0.007$) (Table 2).

3.3. Material losses on antagonist material side

3.3.1. Impact of the antagonist material

LISI led to lower material losses in steatite antagonists compared to ceramic antagonists ($p = 0.003$). Within EMA, steatite antagonists

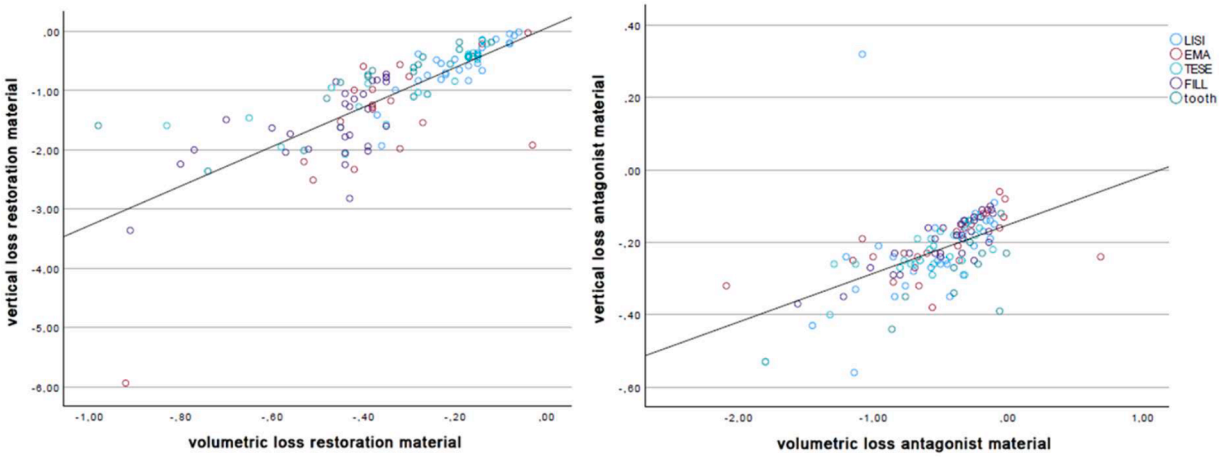

Fig. 7. Associations between vertical and volumetric loss for restorations (link) and for antagonists (right).

Table 2
Descriptive statistics of the vertical losses for the different restoration and antagonist materials [mm].

Restoration material	Antagonist	Restoration side		Antagonist side	
		mean ± SD	min/ median/ max	mean ± SD	min/ median/ max
LISI	steatite	−0.172 ± 0.09^{aA}	−0.36/ −0.18/ −0.06	−0.138 ± 0.18*^{aA}	−0.35/ −0.16/ 0.32
	ceramic	−0.193 ± 0.09^{aA}	−0.33/ −0.16/ −0.08	−0.335 ± 0.11^{bA}	−0.56/ −0.31/ −0.19
	enamel	−0.200 ± 0.09^{aAB}	−0.37/ −0.2/ −0.08	−0.219 ± 0.06^{abA}	−0.33/ −0.23/ −0.14
EMA	steatite	−0.367 ± 0.17*^{aB}	−0.74/ −0.29/ −0.19	−0.279 ± 0.12^{bA}	−0.53/ −0.26/ −0.15
	ceramic	−0.348 ± 0.16^{aAB}	−0.53/ −0.39/ −0.03	−0.154 ± 0.06^{aB}	−0.24/ −0.15/ −0.06
	enamel	−0.331 ± 0.08*^{aABC}	0.42/ −0.36/ −0.16	−0.201 ± 0.07^{abA}	−0.32/ −0.20/ −0.12
TESE	steatite	−0.367 ± 0.17*^{bB}	−0.74/ −0.29/ −0.19	−0.251 ± 0.11*^{aA}	−0.53/ −0.25/ −0.14
	ceramic	−0.407 ± 0.23^{bAB}	−0.83/ −0.40/ −0.14	−0.226 ± 0.05^{aAB}	−0.29/ −0.23/ −0.13
	enamel	−0.163 ± 0.02*^{aA}	−0.20/ −0.17/ −0.13	−0.221 ± 0.85^{aA}	−0.40/ −0.21/ −0.14
FILL	steatite	−0.423 ± 0.05*^{aB}	−0.56/ −0.43/ −0.35	−0.202 ± 0.09^{aA}	−0.37/ −0.17/ −0.10
	ceramic	−0.649 ± 0.17^{aAB}	−0.91/ −0.65/ −0.44	−0.188 ± 0.06^{aB}	−0.29/ −0.19/ −0.11
	enamel	−0.406 ± 0.07^{bC}	−0.57/ −0.38/ −0.35	−0.202 ± 0.05^{aA}	−0.29/ −0.20/ −0.13
tooth	enamel	−0.395 ± 0.23^{BC}	−0.98/ −0.39/ −0.12	−0.283 ± 0.09^{A}	−0.44/ −0.27/ −0.12

*not normally distributed, ^{abc}lower letters indicated significant differences between antagonist martials within one restoration material, ^{ABC}capital letters indicated significant differences between restoration materials within one antagonist material.

showed higher material losses than ceramic ones ($p = 0.011$). There were no differences in antagonistic material loss between the three antagonist materials when placed against TESE ($p = 0.716$) and FILL ($p = 0.753$) restorations (Table 2).

3.3.2. *Impact of the restoration material*

There were no differences in material loss of steatite ($p = 0.061$) and enamel antagonists ($p = 0.225$) with any type of restoration material. Within ceramic antagonists, LISI restoration material caused lower material losses than FILL ($p = 0.023$) and EMA ($p = 0.001$) (Table 2).

Fig. 8 presents the material losses of the restoration materials with different antagonists (Fig. 9).

No fractures of the crowns/specimens were observed during or after the chewing simulation.

4. Discussion

The research interest of properties of CAD/CAM lithium silicate ceramics is increasing, especially concerning newly introduced materials. Therefore, this investigation analyzed the two-body wear of one fully crystallized and one partially crystallized lithium disilicate ceramic as well as a partially crystallized lithium di/aluminasilicate ceramic and compared them with a direct resin composite material and human teeth. In addition, different antagonist materials were used, namely steatite, ceramic, and human enamel. All tested null hypotheses: (1) all lithium silicate ceramic materials show similar two-body wear results, regardless of the antagonist materials (2) all antagonist materials show similar two-body wear results, regardless of the restoration materials (3) direct resin composites and extracted human teeth show similar material losses in the restoration and antagonist materials compared to the tested lithium silicate ceramics are rejected.

Based on our results, LISI restorations showed the lowest in vitro two-body wear among the three lithium silicate materials after a simulated mastication for five years. Interestingly, the abrasion of the LISI restorations did not depend on the type of antagonist material, as the material loss registered with all three antagonists were in a similar range (Fig. 10). One of the main differences between LISI and the other two lithium silicate materials is their crystallization state during milling. In general, lithium silicate ceramics consist of $Li_2Si_2O_5$ crystals that are embedded in a glassy matrix [17]. EMA, which was the first lithium disilicate ceramic block introduced for subtractive manufacturing, is processed in an intermediate crystalline state ("blue state"), where lithium metasilicate (Li_2SiO_3) makes up a certain proportion of the lithium silicate crystals [18]. Milling ceramics in their pre-crystallized state is an elegant method for enhancing the cutting efficiency, while reducing wear of the milling tools. The final mechanical and aesthetic

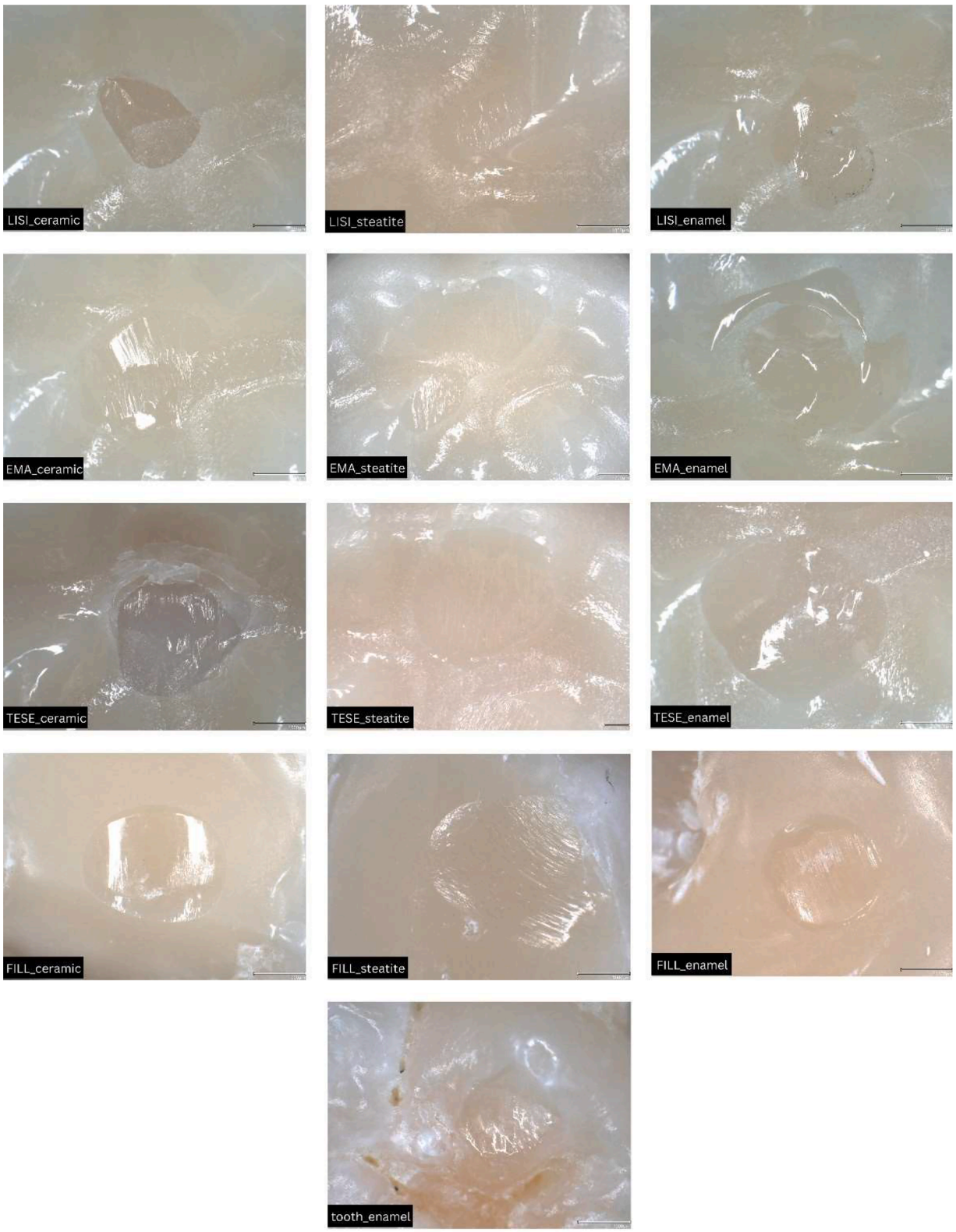

Fig. 8. Selection of abrasion surfaces on the restoration side representing the specific materials and antagonist at 50x magnification. The individual abrasion surfaces were first labelled with the restoration material and then with the antagonist material. (e.g. restoration material: LISI, antagonist material: ceramic; LISI_ceramic).

properties of the restoration are achieved after a heating cycle in special furnaces, where lithium metasilicate is turned into lithium disilicate crystals [19]. In this study, the restorations manufactured from EMA and TESE blocks were produced in a two-stage process involving heat treatment for crystallization, whereas the LISI restorations did not undergo any additional firing procedure after milling. The material LISI is a novel type of lithium disilicate ceramic block that can be processed in a fully crystallized state. This feature may be attributed to the smaller crystal size in the LISI matrix, which is also one of the key structural differences compared to older CAD/CAM lithium disilicate ceramics

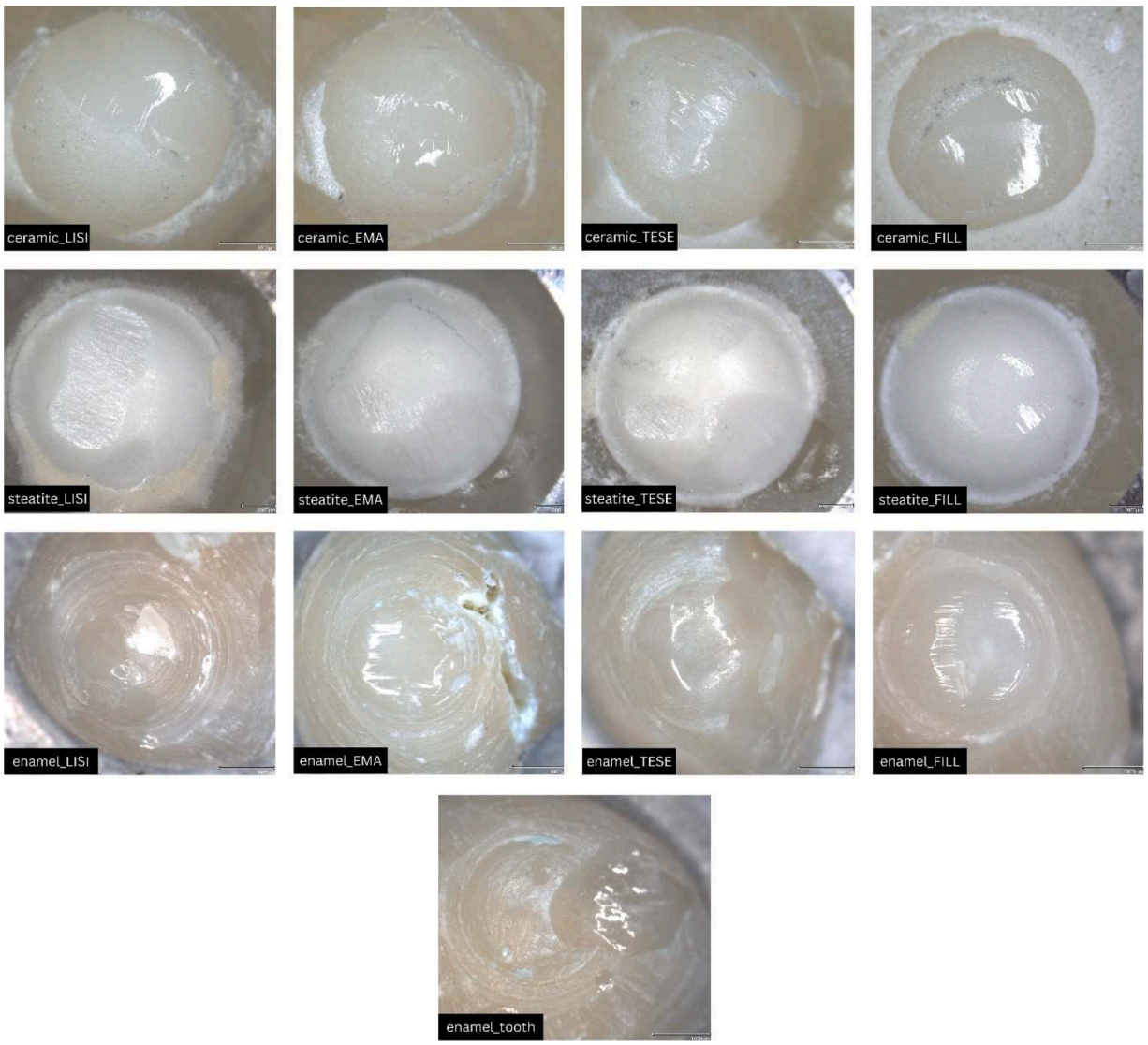

Fig. 9. Selection of abrasion surfaces on the antagonist side representing the antagonists 50x magnification.

such as EMA. While LISI and TESE have been reported to have similar crystal sizes of approximately 0.3 μm, the crystals incorporated in EMA are significantly larger (1–1.5 μm) [20]. Perhaps the smaller crystals in LISI were also responsible for the lower wear compared to EMA restorations, assuming that the material loss caused by crystals breaking out from the matrix due to the masticatory forces is proportional to the average crystal size of the material. However, the crystal size may not be the only parameter affecting the wear of the lithium disilicate ceramics, otherwise TESE restorations, having a similar crystal size as LISI, would have also shown a similar wear behavior as the LISI specimens. One may assume that the presence or absence of additional firing after milling the restoration affects the arrangement of the crystals within the ceramic matrix. According to the manufacturer, a technology unique to LISI called "High Density Micronization" (HDM) is responsible for tightly filling the spaces in the glass matrix with $Li_2Si_2O_5$ crystals. Although the firing procedure of TESE restorations leads to a dramatic increase in flexural strength (>700 MPa) and high flexural strength has been traditionally associated with lower wear, the $Li_2Si_2O_5$ crystals after firing may not be arranged as densely as in fully crystallized materials, thus being more susceptible to wear [6]. Naturally, this is an assumption which must be confirmed with microstructural analyses in future studies.

When examining the wear of dental materials, it is important to consider how both the material of the restoration and the antagonist are affected over time. The choice of the three antagonist materials used in this study is justified by their clinical relevance. Enamel, being the natural antagonist in the oral cavity, is subjected to wear by a natural process known as attrition. However, it is desirable that enamel wear caused by artificial antagonists does not exceed the normal level of attrition. Our study provided favorable results regarding enamel wear, since the vertical loss registered in enamel antagonists was in a similar range with all agonist groups, including TOOTH, FILL, and all three lithium disilicate ceramic restoration materials. Within the LISI group, no influence of the antagonist material on the material losses in the ceramic was observed, while TESA showed the lowest material losses with enamel antagonists. In contrast, in the FILL group, the material losses in combination with enamel antagonists were in the same range of values as the combination with steatite spheres. Steatite showed Marten's hardness values of 3310 N/mm^2 and enamel of 2144 N/mm^2 [16]. A previous study concluded that higher material losses of the restoration materials are caused by a higher Martens hardness of the antagonist material compared to the substrate material. To decrease substrate wear, an antagonist with a lower Marten's hardness may thus be preferrable [16]. In this study, this can be confirmed with ceramic TESA. Here, higher material losses were observed with enamel antagonists than with steatite. Based on the lower Martens hardness and flexural strength of

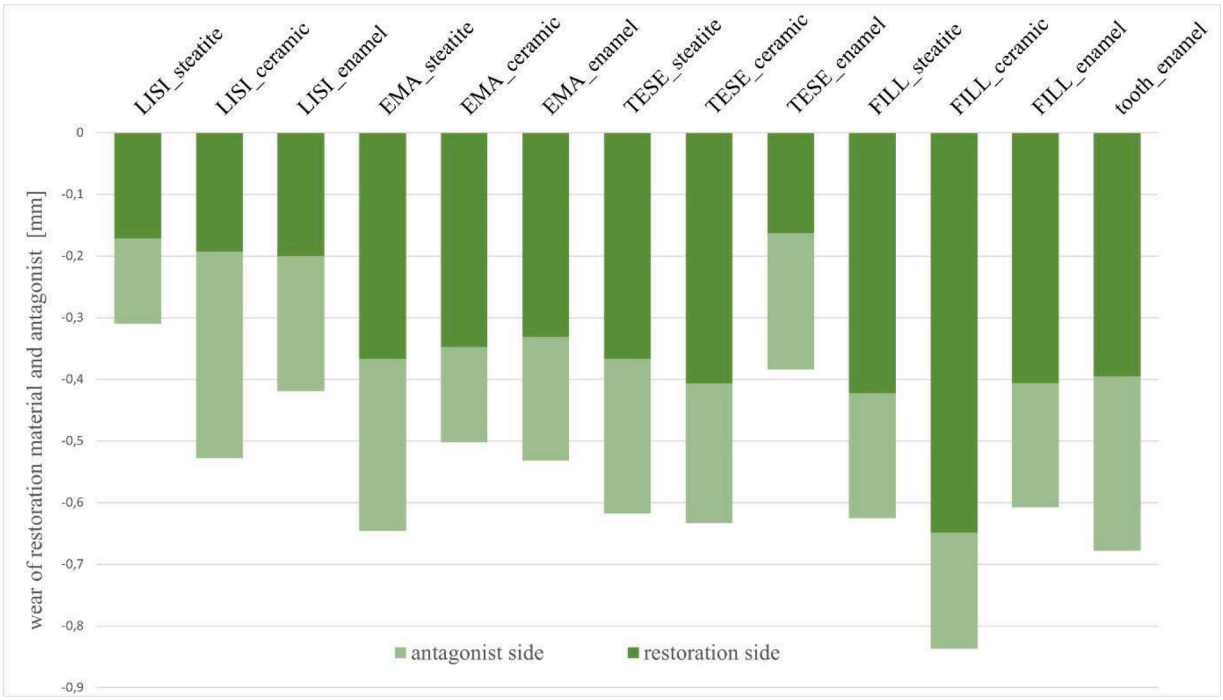

Fig. 10. Mean values for two-body wear of materials and antagonists respectively.

composite, it is not surprising that the teeth in the FILL group showed the highest material loss against ceramic antagonists [21].

It should be mentioned that glazing is frequently performed in clinical practice, mainly for enhancing the esthetics of both anterior and posterior restorations. However, for the sake of comparison, none of the ceramic restorations were glazed in this study. Recent in vitro studies suggest that glazed restorations made of LISI are more resistant to wear compared to solely polished restorations [6]. On the other hand, glazing has been reported to increase abrasion in the enamel antagonists, especially when the glaze is worn off due to mastication [9]. Since the underlying ceramic structure is not polished before glazing, the antagonist is exposed to a more porous ceramic structure compared to unglazed ceramics that have been polished. The higher surface roughness is thought to be responsible for higher abrasion of the enamel antagonist.

Upon examination of the experimental setup, it can be inferred that the trajectories of the chewing simulator accurately replicate the bidirectional movements inherent in human mastication, encompassing both vertical and eccentric movements. Furthermore, the abutments utilized for crown mounting were fabricated from a resin material. A resin composite abutment closely emulates the properties of natural tooth structure (elastic modulus resin composite: 19 GPa, elastic modulus dentin: 18–20 GPa) and effectively replicates a resin composite core build-up, thereby establishing an in vitro test configuration conducive to more precise clinical extrapolations.

The present investigation is limited by the varying antagonist geometry, with steatite antagonists possessing a diameter of 6 mm, while the other antagonists showed a diameter of 4 mm. Further studies are necessary to verify the presently observed correlations with other dental restorative materials.

In addition, all crown materials survived the in-vitro chewing simulation (the equivalent of 5 years in-vivo). It can be concluded that the survival data are promising and all tested lithium silicate crowns can be recommended for permanent use.

A comparative analysis was conducted to assess the wear simulation devices ACTA, Zurich, Alabama, MTS and OHSU for direct resin composites [22]. The wear behavior of 10 direct resin composites subjected to the five wear simulation methods exhibited non-congruent outcomes, attributable to the distinct wear testing principles employed by each method. To comprehensively characterize the intricate oral wear environment, clinical studies are indispensable. Nonetheless, in vitro wear measurement studies demonstrate limited correlation with clinical data [22] yet offer a standardized assessment of diverse materials [10]. Given the absence of clinical investigations on the wear rate of various antagonists against lithium silicate ceramics, the findings of this study involving different ceramics and their respective antagonists necessitate clinical validation. Patients with bruxism should also be included in future research endeavors.

5. Conclusion

After clinical simulated five years in-vivo using a chewing simulation, the LISI ceramic revealed the lowest abrasion losses with all antagonist materials. Also, no impact of antagonist material was observed. Therefore, it can be stated that the LISI restoration material has a constant material loss regardless of the antagonist. The measured EMA ceramic material losses showed higher values than LISI ones. The highest impact of the antagonist material was noticed within TESE and FILL ceramic groups.

CRediT authorship contribution statement

Bogna Stawarczyk: Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **John Meinen:** Investigation. **Sabina Noreen Wuersching:** Writing – original draft, Visualization.

Declaration of competing interest

The authors declare that they have no conflict of interest.

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