DENTAL MATERIALS 35 (2019) 534–542

Available online at www.sciencedirect.com

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Fatigue performance of adhesively cemented glass-, hybrid- and resin-ceramic materials for CAD/CAM monolithic restorations

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ARTICLE INFO

Article history:
Received 10 June 2018
Received in revised form
6 December 2018
Accepted 11 January 2019

Keywords:
CAD/CAM blocks
Mechanical cycling
Vita Mark II
IPS Empress CAD
IPS e.max CAD
Vita Suprinity
Vita Enamic
Lava Ultimate

ABSTRACT

Objective. To evaluate the fatigue failure load, number of cycles until failure, and survival probability of adhesively cemented materials with different microstructures (glass-, hybrid- and resin-ceramic) used to manufacture CAD/CAM monolithic restorations.

Methods. Disc-shaped specimens (n = 15; Ø = 10 mm; thickness = 1.0 mm) were produced from CAD/CAM blocks as follows: feldspathic (FEL); leucite (LEU); lithium disilicate (LD); zirconia-reinforced lithium silicate (ZRLS); polymer-infiltrated ceramic network (PICN); and resin nanoceramic (RNC). Adhesive cementation was performed onto epoxy discs (dentin analogue- Ø = 10 mm; thickness = 2.5 mm). The cemented assemblies were subjected to fatigue testing using a step–stress approach (400 N–2200 N; step-size of 200 N; 10,000 cycles per step; 1.4 Hz). Fatigue data were analyzed using Kaplan–Meier and Mantel–Cox (log-rank) tests ($p < 0.05$) and Weibull statistical analysis. Fractographic analysis was also performed.

Results. All RNC specimens survived the fatigue test (100% probability of survival at 2200 N; 100,000 cycles) and presented occlusal deformation in response to loading, while all other tested materials failed in distinct loading steps with radial cracks starting from the bonding surface. LD (1146.7 N; 47,333) and ZRLS (1013.3 N; 40,666) materials obtained the highest fatigue failure loads and cycles until failure, meanwhile all PICN specimens failed during the first step (0% probability of survival at 400 N; 10,000). FEL had similar Weibull modulus to LD and ZRLS and higher than LEU for both load and number of cycles outcomes.

Significance. The microstructure of adhesively cemented glass-, hybrid- and resin-ceramic CAD/CAM restorative materials influence their response during fatigue testing, which aids in suggesting the best clinical indications.

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https://doi.org/10.1016/j.dental.2019.01.013
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1. Introduction

The implementation of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology and improvements in the mechanical properties of machinable materials provide alternatives to conventional restorative systems, optimizing the use of ceramic materials and the reproduction of natural appearance of teeth [1–3]. Dental ceramics for CAD/CAM systems are highly promising and structurally reliable, as they can be milled from homogeneous industrially fabricated blocks, reducing the presence of processing flaws to a minimum [4].

In recent years, dental manufacturers have been focusing on developing ceramic materials with different microstructures which unify good mechanical properties and mimic the optical characteristics of natural teeth. Esthetic dental ceramics contain high volumes of glassy phase, which can be reinforced by embedding stronger particles, such as zirconia, or crystals in the composition as leucite, lithium disilicate and/or silicate. However, some studies have identified a high failure incidence of glass ceramic materials [5], not only due to the brittle nature of ceramics, but also to abrasive wear potential on opposing natural teeth [6–8]. In this sense, some new CAD/CAM materials have been developed as composite materials, known as ‘hybrid ceramic’ and ‘resin nanoceramic’, with the purpose of combining the advantageous properties of ceramics such as durability, biocompatibility and color stability with the properties of composite resins such as high flexural strength and low abrasiveness [9,10]. However, these new composite materials may have limitations in other aspects such as fatigue under intermittent cyclic loading, color instability, or the material itself and/or antagonist wear [11].

The long-term mechanical prediction of CAD/CAM materials in the oral environment should be based on fatigue experiments under intermittent loading, since they are more reliable predictors than inert strength data [12]. Also, more realistic scenarios are created using cyclic fatigue tests with adhesively cemented specimens considering the influence of resin cement penetration into the existing flaws of the ceramic surface, which improves the fracture resistance of ceramic restorations [13,14]. An approach of the accelerated fatigue test is the ‘step–stress test’, consisting of a time-varying load test in which the specimens are subjected to successively increased stress levels in a predetermined number of cycles [15], and the run-outs are incorporated in the analysis [16].

Nowadays, the increasing interest in monolithic restorations is guided by improvement in ceramic materials processed in industrial conditions and by the principles of conservative dentistry. This clinical alternative enables more conservative tooth preparations, significantly reducing the final ceramic thickness, and solving critical clinical situations lacking occlusal space among antagonist teeth [17]. Glass-, hybrid- and resin-ceramic materials appear as potential alternatives to monolithic restorations, as they show the highest mimicking ability to the optical characteristics of natural teeth for esthetic regions in comparison to polycrystalline ceramics, which present even better mechanical performance [18]. However, limited information is available on the fatigue behavior of glass-, hybrid- and resin-ceramic materials in monolayer assembly bonded to a substrate (for instance, dentin analoge material), which might result in adequate fatigue load bearing capacity to endure clinical intermittent mechanical stimuli. From this standpoint, better knowledge of the fatigue performance of these materials in monolayer assemblies is necessary to comprehend its behavior and guide clinical choices.

Clinicians are faced with everyday situations in which they need to evaluate the characteristics presented by each individual patient and decide which ceramic material better fulfills the desired requirements, as many materials have similar clinical indications. Hence, comparative data that characterize the fatigue properties of CAD/CAM materials are necessary for making the right decision regarding long-term clinical performance. Thus, this study aims to compare and characterize the mechanical behavior under intermittent loading (fatigue failure load, number of cycles until failure, and survival probability) of different adhesively cemented glass-, hybrid- and resin- ceramic materials recommended for monolithic restorations. The hypothesis tested was that CAD/CAM materials with different microstructures present distinct fatigue behavior.

2. Materials and methods

The materials used in this study, their chemical composition, manufacturers and batch numbers are described in Table 1.

2.1. *Specimens preparation and cementation procedure*

CAD/CAM blocks were shaped into cylinders using a diamond drill (internal diameter = 10 mm; Diamant Boart, Brussels, Belgium) coupled to a bench drill (SBE 1010 Plus, Metabo; Nürtingen, Germany) under refrigeration. The cylinders were cut under water-cooling (Isomet 1000; Buehler, Lake Bluff, United States), resulting in 90 discs with an initial thickness of 1.1 mm and diameter of 10 mm, simulating the average occlusal table of a first molar [19]. The ‘occlusal’ surface of the discs was polished with 600- and 1200-grit SiC polish papers (Ecomet Polisher, CarbiMet SiC Abrasive Paper, Buehler) until reaching 1.0 ± 0.1 mm in thickness. The cementation surface was kept ‘as-cutting’. Following the manufacturer’s instructions, zirconia-reinforced lithium silicate discs (Vita Suprinity) and lithium disilicate (IPS e.max CAD) underwent a crystallization firing (Programat P100, Ivoclar AG, Schaan, Liechtenstein) for 8 min at 840 °C (heating rate 55 °C/min) or 10 min at 850 °C (heating rate 30 °C/min), respectively.

The epoxy resin plates with 2.5 mm thickness (Epoxy Plate, $150 \times 350 \times 2.5$ mm; Carbotec GmbH & Co. KG, Königs Wusterhausen, Germany) were also shaped into cylinders to produce epoxy discs (Ø = 10 mm) in the same aforementioned way for the CAD/CAM blocks. A simplified tri-layer setup [20] was used to simulate the restoration of a posterior tooth with a final thickness of 3.5 mm after bonding the two-layer discs, in which the ceramic/resin disc (simplified restoration) represented an occlusal restoration and the epoxy resin disc simulated dentin. According to Sulieman et al. [21], a final thickness of 3.5 mm is equivalent to the average thickness from pulp wall to occlusal surface.

Table 1 – Chemical composition, manufacturers and surface treatments of CAD/CAM materials.

Group	CAD/CAM material	Manufacturer (Batch Number)	Chemical composition[a]	Surface treatment[a]
FEL	Vita Mark II (Fine- particle feldspar ceramic)	VITA Zahnfabrik (56731)	SiO_2 56–64 wt%, Al_2O_3 20–23 wt%, K_2O 6–8 wt%, Na_2O 6–9 wt%, other and coloring oxide 0–0.6 wt%	60 s 5% HF[b]
LEU	IPS Empress CAD (Leucite-based glass ceramic)	Ivoclar Vivadent (V12349)	SiO_2 60–65 wt%, Al_2O_3 16–20 wt%, K_2O 10–14 wt%, Na_2O 3.5–6.5 wt%, other oxides 0.5–7 wt%, pigments 0.2–1 wt%	60 s 5% HF[b]
ZRLS	Vita Suprinity (Zirconia-reinforced lithium silicate ceramic)	VITA Zahnfabrik (42991)	SiO_2 62–65 wt%, Al_2O_3 8.5–12 wt%, K_2O 9–12 wt%, Na_2O 5–7.5 wt%, CaO 1–2 wt%, ZrO_2 < 1 wt%, B_2O_3 4–6 wt%,	20 s 5% HF[b]
LD	IPS e.max CAD (Lithium disilicate-based glass ceramic)	Ivoclar Vivadent (W93126)	SiO_2 57–80 wt%, Li_2O 11–19 wt%, K_2O 0–13 wt%, P_2O_5 0–11 wt%, ZrO_2 0–8 wt%, ZnO 0–8 wt%, other and coloring oxides 0–12 wt%	20 s 5% HF[b]
PICN	Vita Enamic (Fine-structure feldspar ceramic network reinforced by a polymer network)	VITA Zahnfabrik (49620)	SiO_2 58–63 wt%, Al_2O_3 20–23 wt%, Na_2O 6–11 wt%, K_2O 4–6 wt%, B_2O_3 0.5–2 wt%, other and coloring oxides 0–1 wt%	60 s 5% HF[b]
RNC	Lava Ultimate (Resin nanoceramic)	3 M ESPE (N429998)	20% composite resin, 80% ceramic SiO_2 69%, ZrO_2 31%	50 μm Al_2O_3, 2.0 bar

[a] The chemical compositions and surface treatments are described according to the manufacturers' information.
[b] HF: hydrofluoric acid.

Prior to surface treatment, the ceramic/resin specimens were cleaned in an ultrasonic bath with isopropyl alcohol (5 min), while the dentin analogue discs were cleaned with distilled water (5 min). The bonding surface of CAD/CAM disc was treated as recommended by each manufacturer (Table 1), rinsed with an air–water spray for 30 s, dried, and ultrasonically cleaned in distilled water for 5 min. A primer containing multiple bond promoters (Monobond Plus, Ivoclar Vivadent) was subsequently scrubbed on the bonding surfaces of all CAD/CAM discs for 15 s and then kept reacting for 45 s (1 min for the entire procedure).

The cementation surface of the epoxy resin discs was etched with hydrofluoric acid (9%, Ultradent Porcelain Etch, Ultradent Producs Inc, South Jordan, United States) for 60 s, washed for 30 s, and ultrasonically cleaned (5 min) with distilled water [22]. Then, Multilink Primers A and B (Ivoclar Vivadent) were mixed in a 1:1 ratio, scrubbed on the treated surfaces (30 s), and air-dried until a thin layer was obtained.

Afterward, each CAD/CAM disc was adhesively cemented to the corresponding epoxy disc with resin cement (Multilink Automix, Ivoclar Vivadent). The bonded discs were placed under constant load of 50 N followed by removing the cement excesses and light-activation (Elipar S10, 3 M ESPE, St. Paul, United States) for five exposures of 20 s each (one in each direction — 4 positions at 0°, 90°, 180°, 270°, and on top). All the specimens were stored in distilled water (37 °C) for at least 24 h and a maximum period of 5 days before conducting the step–stress fatigue tests.

2.2. *Step–stress fatigue tests*

The cemented assemblies of each material (n = 15) were tested until failure using the step–stress test method in an adapted fatigue tester (Fatigue Tester, ACTA, The Netherlands). Cyclic loading was applied at a frequency of 1.4 Hz for 10,000 cycles at each load step, with amplitudes ranging from a minimum load of 5 N to the maximum initial load of 400 N using a 40 mm diameter stainless-steel piston ball [23] under distilled water. The specimens were checked for cracks every 10,000 cycles by light oblique transillumination [24]. If the specimen survived after 10,000 cycles, the load level was increased by a fixed load increment of 200 N in the same specimen (until the maximum load of 2200 N), but if failure occurred, the load level and the number of cycles were recorded for statistical analysis. The radial crack was considered as the main outcome.

2.3. *Fractographic analysis*

After the cyclic fatigue tests, all failed specimens were analyzed under stereomicroscopy (Olympus, Shinjuku, Tokyo, Japan) for contact damage and by light oblique transillumination to identify the crack direction. Then, these specimens were longitudinally sectioned into two halves, perpendicularly to the radial crack direction with a diamond blade under water-cooling (Isomet 1000, Buehler). The one-sided radial crack was cut as close as possible to the center of the specimen (where the stress is higher for being the region where the load was applied). Representative specimens from each group were ultrasonically cleaned in distilled water (5 min), gold sput-

Table 2 – Mean fatigue failure loads (N) and number of cycles until failure with respective standard error and 95% confidence interval (CI) for the experimental groups.

Group	Fatigue failure load (N)				Number of cycles			
	Mean	SE	CI (95%)		Mean	SE	CI (95%)	
			Lower bound	Upper bound			Lower bound	Upper bound
FEL	746.67^{C}	36.34	675.44	817.89	27,333.33^{C}	1817.03	23,771.96	30,894.71
LEU	680.00^{BC}	86.85	509.77	850.22	24,000.00^{BC}	4342.48	15,488.74	32,511.26
ZRLS	1013.33^{BA}	98.50	820.28	1206.39	40,666.67^{BA}	4924.83	31,014.00	50,319.34
LD	1146.67^{A}	63.14	1022.90	1270.43	47,333.33^{A}	3157.25	41,145.11	53,521.55
PICN	Statistical analysis was not possible because all samples failed at the first step (400 N/10,000 cycles).							
RNC	Statistical analysis was not possible because all samples survived until the final step (2200 N/10,000 cycles).							

The same uppercase letters indicate no statistically significant difference.

tered, and analyzed under scanning electron microscopy (SEM; Evo LS15, Oberkochen, Carl Zeiss, Germany) to identify the size and origin of the critical defect.

2.4. Data analysis

Statistical analysis was performed using Kaplan–Meier and Mantel–Cox (Log Rank) tests followed by a pairwise comparison ($p < 0.05$; SPSS version 21, IBM, Chicago, United States). The failure steps and total number of cycles until failure were submitted to Weibull statistical analysis to describe the Weibull modulus (shape m — mechanical reliability of the material) and the characteristic measurement (scale η — load at which the probability of failure is 63.2%) using the Super SMITH Weibull 4.0k-32 software (Wes Fulton, Torrance, United States).

3. Results

Significant differences among the different materials were detected for the fatigue failure loads and number of cycles (Table 2). The RNC group presented the best fatigue performance since the cemented discs survived until the last loading step (2200 N) and cycles (100,000) without radial cracking, even though noteworthy surface deformation took place, while all the PICN discs failed by radial crack detection in the first step (400 N; 10,000). Regarding the glass-ceramic materials, a direct relation between crystalline content, fatigue failure load and number of cycles could be observed (LD ≥ ZRLS ≥ LEU ≥ FEL) (Table 2).

Table 3 summarizes the survival rates of the restorations for loading steps and number of cycles until failure, while Fig. 1 shows the survival curves for the two aforementioned parameters.

Fig. 2 shows the Weibull curves for the groups. The Weibull parameter results are described in Table 4. There was a statistical difference in Weibull modulus between FEL and LEU groups for the fatigue failure load and number of cycles. On the other hand, there was no difference in the scale η values between FEL and LEU groups, or for the LD and ZRLS groups.

With the exception of RNC specimens in which surface deformation occurred, the failure analysis under a light microscope showed that radial cracks starting from the cemented surface took place in all failed specimens, and there were

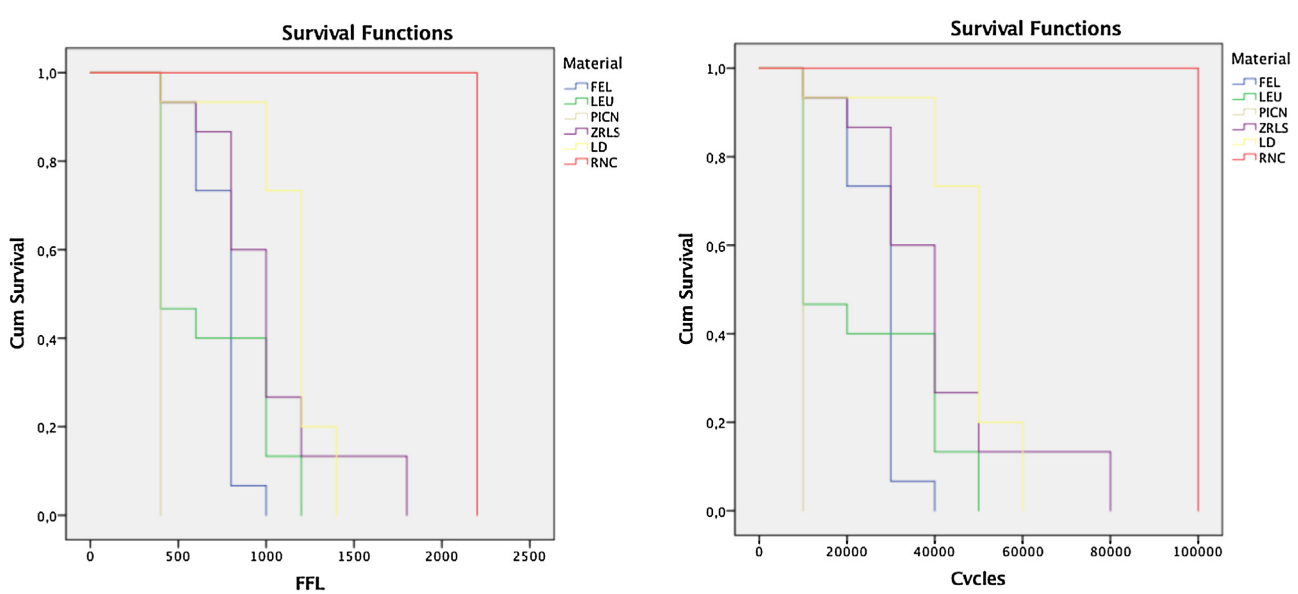

Fig. 1 – Survival curves according to the steps of fatigue failure load (FFL; left) and number of cycles (right) in which each disc failed, obtained by Kaplan–Meier and Log-rank tests.

Table 3 – Survival rates (probability that the specimens have to exceed the respective load or number of cycles without failure and the respective standard error) for the different materials.

Group	Load steps (N)									
	400	600	800	1000	1200	1400	1600	1800	2000	2200
FEL	0.93 (0.1)	0.73 (0.1)	0.07 (0.1)	0.00 (0.0)	–	–	–	–	–	–
LEU	0.47 (0.1)	0.40 (0.2)	0.40 (0.2)	0.13 (0.1)	0.00 (0.0)	–	–	–	–	–
ZRLS	0.93 (0.1)	0.87 (0.1)	0.60 (0.1)	0.27 (0.1)	0.13 (0.1)	0.13 (0.1)	0.13 (0.1)	0.00 (0.0)	–	–
LD	0.93 (0.1)	0.93 (0.1)	0.93 (0.1)	0.73 (0.1)	0.20 (0.1)	0.00 (0.0)	–	–	–	–
PICN	0.00 (0.0)	–	–	–	–	–	–	–	–	–
RNC	1	1	1	1	1	1	1	1	1	1

Group	Number of cycles									
	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	100,000
FEL	0.93 (0.1)	0.73 (0.1)	0.07 (0.1)	0.00 (0.0)	–	–	–	–	–	–
LEU	0.47 (0.1)	0.40 (0.1)	0.40 (0.1)	0.13 (0.1)	0.00 (0.0)	–	–	–	–	–
ZRLS	0.93 (0.1)	0.87 (0.1)	0.60 (0.1)	0.27 (0.1)	0.13 (0.1)	0.13 (0.1)	0.13 (0.1)	0.00 (0.0)	–	–
LD	0.93 (0.1)	0.93 (0.1)	0.93 (0.1)	0.73 (0.1)	0.20 (0.1)	0.00 (0.0)	–	–	–	–
PICN	0.00 (0.0)	–	–	–	–	–	–	–	–	–
RNC	1	1	1	1	1	1	1	1	1	1

no Hertzian cone cracks. Representative SEM micrographs of the fracture surfaces are presented in Fig. 3. Since all RNC specimens survived the fatigue tests, their occlusal surface (in contact with the piston) was also analyzed under SEM to search for signs of deformation/wear in the restorative material. The SEM images of RNC group (Fig. 4) revealed surface wear promoted by the piston for all survived discs until the 2200 N load step.

4. Discussion

The present study demonstrated that the distinct microstructures influenced the fatigue behavior of adhesively cemented glass-, hybrid- and resin-ceramic materials recommended for monolithic restorations. Thus, the tested hypothesis was accepted, since RNC specimens survived until the last loading step (2200 N) and number of cycles (100,000) without radial cracking, presenting the highest fatigue performance, while all PICN specimens failed in the first step (400 N; 10,000).

Ceramics are considered brittle materials with increased susceptibility to fracture under tensile stresses. This brittleness results in developing cracks with subsequent crack propagation and finally catastrophic failure [25]. Moreover, ceramic restorations are subject to thermal, chemical and mechanical influence in the oral cavity. Differences in size, nature and distribution of the crystalline phases in ceramic materials are known to influence their fracture behavior [26].

With regards to microstructure, particle-filled glass ceramics can incorporate crystalline structures to improve the mechanical properties, such as lithium disilicate-based glass ceramic (LD) and zirconia-reinforced lithium silicate ceramic (ZRLS). The presence of lithium disilicate crystals promotes crack deflection, which improves its fracture strength [27]. However, the newly formed lithium disilicate phase in crystallized ZRLS is somewhat low intensity when compared to the $Li_2Si_2O_5$ intensity in LD [28]. Our data show that LD obtained the best performance among ceramic materials, only being statistically similar to ZRLS. Despite the fatigue behavior of ZRLS being statistically similar to LD in the present study, the mean fatigue failure load and number of cycles was also similar to LEU; while LD showed statistically higher values for scale η, mean fatigue failure load and number of cycles compared to FEL and LEU ceramics.

CAD/CAM-generated all-ceramic crowns have clinically superior success rates (81.2%) than composite resin crowns (55.6%) in relation to esthetics, restoration loosening and wear resistance [29]. Despite this, the resin nanoceramic material (RNC) behaved better under fatigue testing than all the ceramic materials tested due to the difference in elastic properties (resin component), even though notable surface deformation could be detected placed at the region under piston loading, meaning that other experiments (for instance, wear tests) should be run to assess distinct outcomes. This material tends to be less brittle and more flexible, withstanding the cyclic loading by undergoing more elastic deformation before failure [11], as observed in Fig. 4. A previous investigation reported that the flexural strength and resilience modulus of RNC was significantly higher than the other evaluated glass-ceramics

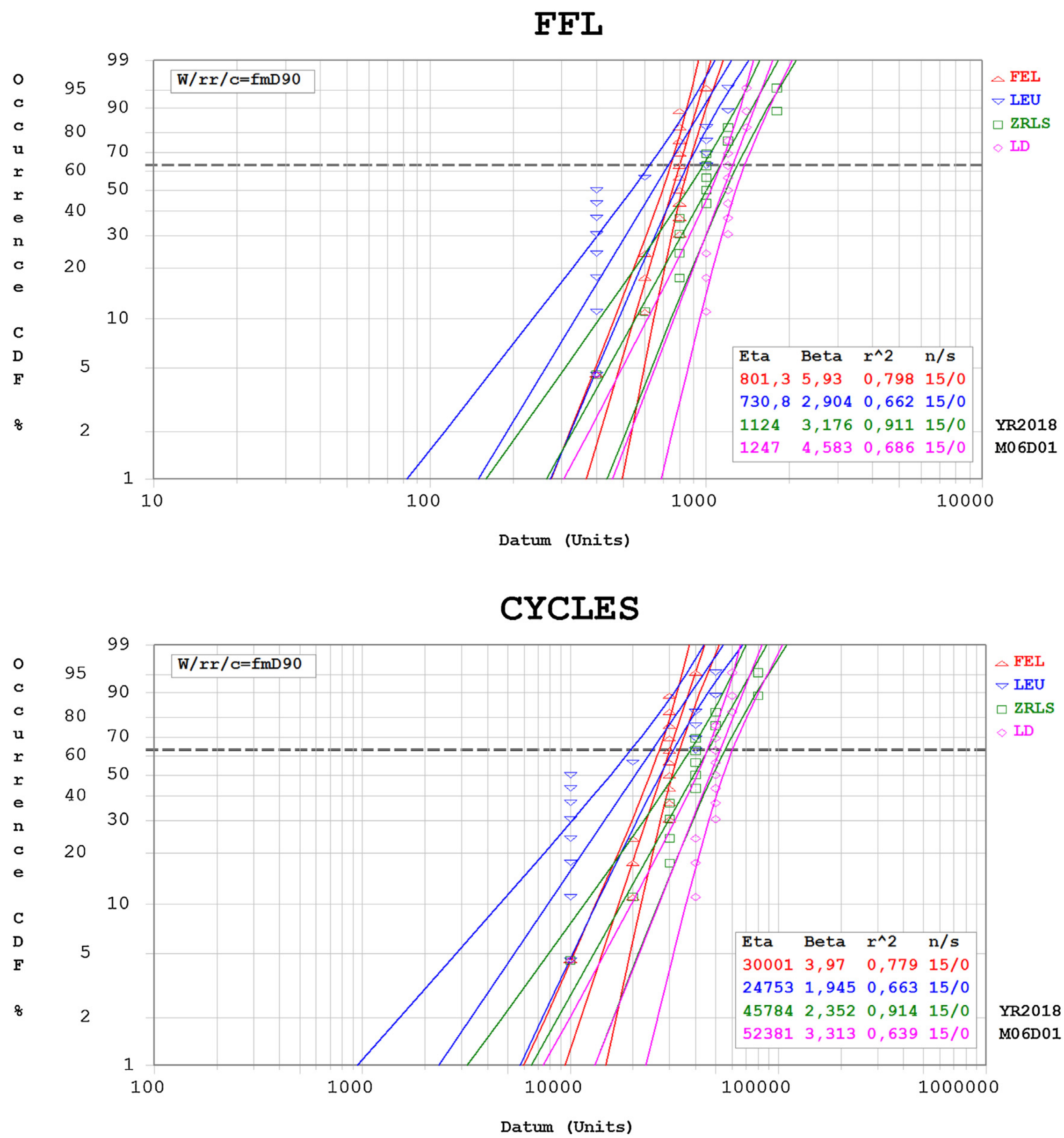

Fig. 2 – Weibull plots according to the steps of fatigue failure load and number of cycles.

Table 4 – Weibull parameters with the 95% confidence intervals (maximum likelihood estimation).

Group	Fatigue failure load		Number of cycles	
	Shape *m* (95% CI)	Scale η (95% CI)	Shape *m* (95% CI)	Scale η (95% CI)
FEL	5.93 (4.18–8.40)^{A}	801 (743–864)^{A}	3.97 (2.76–5.71)^{A}	30,001 (26,953–33,593)^{A}
LEU	2.90 (2.13–3.95)^{B}	731 (624–856)^{A}	1.94 (1.42–2.66)^{B}	24,753 (19,558–31,328)^{A}
ZRLS	3.18 (2.36–4.27)^{AB}	1124 (976–1295)^{B}	2.35 (2.76–5.71)^{AB}	45,784 (37,836–55,402)^{B}
LD	4.58 (3.11–6.76)^{AB}	1247 (1128–1378)^{B}	3.31 (2.23–4.93)^{AB}	52,381 (45,592–60,182)^{B}
PICN	Statistical analysis was not possible because all samples failed at the first step (400 N/10,000 cycles).			
RNC	Statistical analysis was not possible because all samples survived until the final step (2200 N/100,000 cycles).			

Different letters in each column (outcome) indicate statistical differences among conditions; analyses based on overlapping of confidence intervals.

(FEL and LEU) and polymer-based (PICN) CAD/CAM restorative materials [11].

Even when presenting superficial damage, monolithic RNC crowns endured fatigue loads 3–4 times higher than those causing catastrophic failure in leucite-based glass-ceramic crowns [30], corroborating our results. Thus, even though RNC materials presented the best performance withstanding all fatigue testing steps (2200 N and 100,000 cycles), we highlight that this behavior should be interpreted as a good indication of high resistance (low susceptibility) to fracture only for this material. It is additionally expected that the failure of this material could probably be caused by wear over time and deformation of the surface, whose outcomes were not considered by our investigation. Thus, our findings for RNC material (strong fatigue performance) must be interpreted with caution.

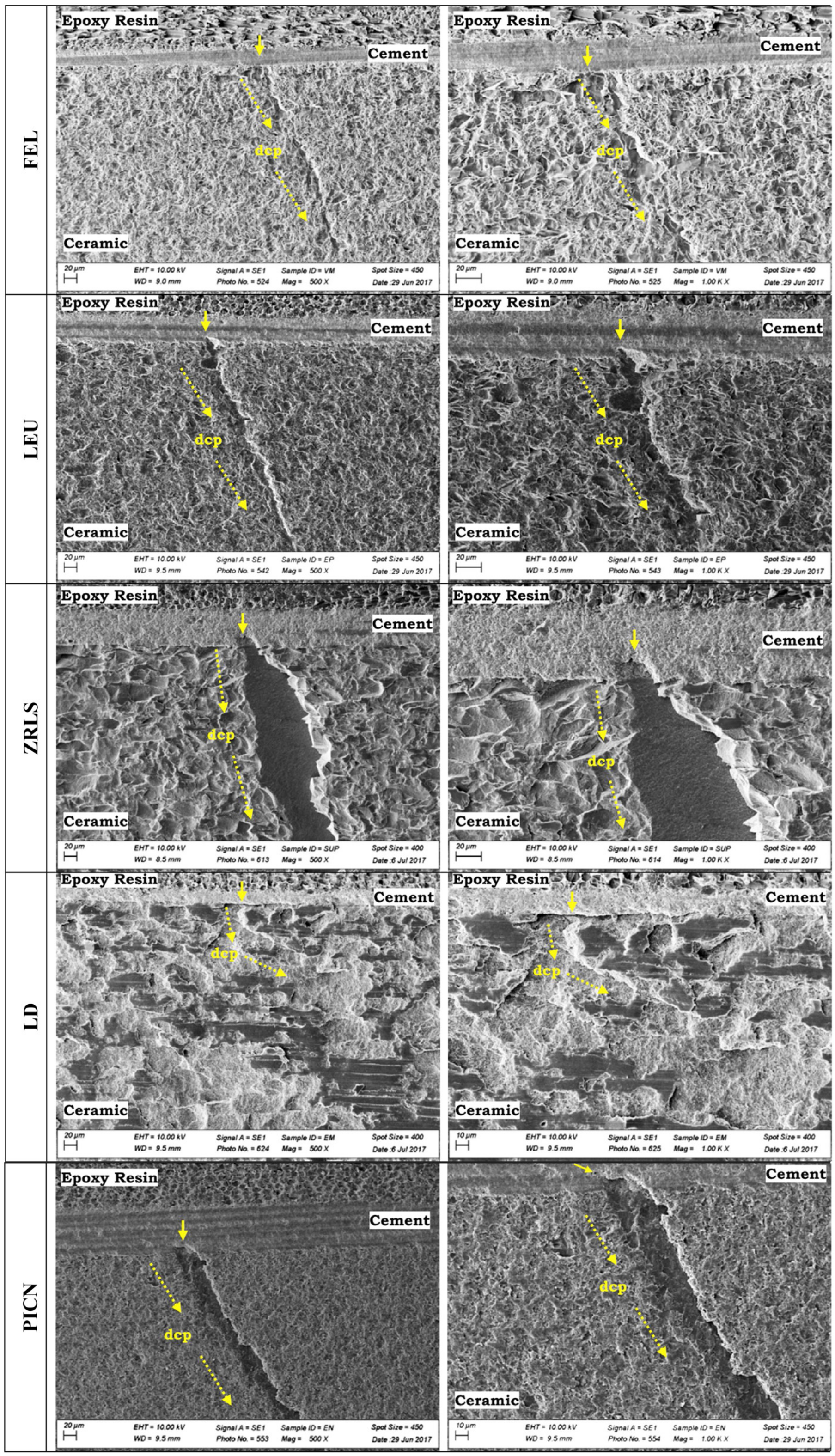

Fig. 3 – Fractographic analysis in Scanning Electron Microscopy (500 × and 1000 × magnifications, left and right respectively) where it is noticed the origin of fracture in the cementation surface (filled arrow) under tensile stresses and the crack propagation towards the load application (crack location pointed by dashed arrows).

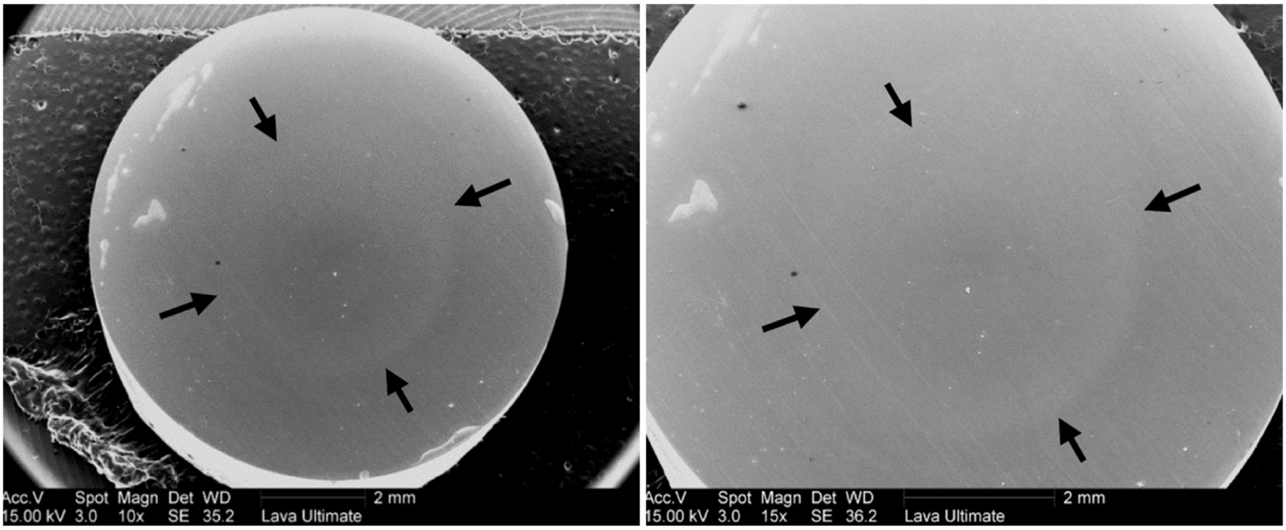

Fig. 4 – Representative SEM images (10 × and 15 × magnifications) from resin nanoceramic group (RNC), which all specimens survived the step–stress fatigue tests. The black arrows indicate the wear surface by the piston since this material has composite resin in its composition and by that, a greater resilience.

Albeit RNC and PICN materials contain an organic network that allegedly reduces brittleness, they presented completely distinct behaviors wherein PICN depicted the worst fatigue performance. A possible explanation for the differences in the fatigue performance may be the higher flexural strength of RNC compared to PICN observed in previous studies [31,32]. The differences in inorganic content and composition of the resin matrix, dimension, and dispersion of the filler particles might be factors contributing to the differences in flexural strength of these two materials [32]. Thus, contrary to what might be expected, it is noted that PICN still presents high brittleness characteristics, as has been observed with classical glass-ceramic materials [33].

Weibull modulus is a measure of data scatter (a material's mechanical reliability), where a high value may reflect reduced flaws (structural reliability) due to advanced technology in the fabrication of ceramic blocks for dental restorations [33]. In the present study, feldspathic ceramic material has shown the highest Weibull modulus for fatigue failure load and number of cycles data compared to leucite-based glass ceramic. The high reliability of feldspathic ceramic has been demonstrated in previous studies [4,33]. However, feldspathic and leucite-based ceramic materials showed statistically similar values for scale η, mean fatigue failure load, and number of cycles until failure.

In a clinical situation, mean chewing forces range between 285.01 ± 149.17 N and 462.3 ± 199.3 N (for men), and 253.99 ± 131.00 N up to 445.8 ± 174.7 (for women), independent of age group [34,35]. Despite this, maximum chewing force can approach 800 N during sleeping and bruxism [36]. In this sense, LD and ZRLS had 0.93 and 0.60 survival rates at 800 N (93% and 60% probability of LD and ZRLS samples exceeding 800 N without occurring failure, respectively), while FEL and LEU presented 0.07 and 0.40 rates (7% and 40% probability of FEL and LEU samples exceeding 800 N without failure). A similar survival behavior could be depicted for number of cycles until failure in comparing these ceramic materials in this current study. Assuming the inherent limitations of an in vitro study and extrapolating our results, only two CAD/CAM glass ceramic materials (LD and ZRLS) seem to be clinically predictable for a monolithic restoration with 1.0 mm thickness.

Regarding the accelerated fatigue methodology employed, the step–stress approach incorporates run-outs (survivals) in the analysis taking into account the cumulative damage, as well as estimating longer lifetimes, thus optimizing testing time [16]. In spite of using an aggressive fatigue profile, the step–stress method enabled clear differentiation among the different materials tested, making the test feasible considering the low frequency applied (1.4 Hz) and the time consumed. Even so, if a mild fatigue profile (lower initial load and step size) had been run, it might induce more accumulated damage (slow crack growth mechanisms) and reduce the average loads for the observed fatigue failure. However, the authors believe that the fatigue performance observed among all materials tested herein would not change. Furthermore, the simplified tri-layer assembly and the test configuration enabled observing all radial cracks initiating in the cementation surface in the fractographic analysis, underneath the load application point.

Factors including only applying axial loads (without sliding and lateral forces), the absence of CAD/CAM milling surface topography, and the use of an analogue dentin material (presenting hygroscopic expansion in water) should be considered as limitations of the present study. The relative low number of cycles (up to 100,000) employed during fatigue tests could be pointed out as another limitation. Indeed, further clinical studies evaluating the long-term performance of the tested materials are necessary to confirm these current in vitro findings.

5. Conclusions

– The microstructure of adhesively cemented glass-, hybrid- and resin-ceramic materials directly affects their performance under fatigue. Thus, the inherent limitations of the materials and the importance of in-vitro fatigue experiments should be considered to guide the optimal clinical indication.

- The fatigue performance of evaluated ceramic restorative materials appear to have been strongly influenced by the crystalline content immerged in the glassy matrix.
- Resin nanoceramic material presented the best fatigue performance due to greater resilience, which enabled more stress absorption through deformation as the main outcome; while glass- and hybrid-ceramic materials showed brittleness and radial cracking as the main outcome.

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