

Shade Stability of Polymer Infiltrated and Resin Nano Ceramic Crowns after Dynamic Chewing Simulation

ABSTRACT

Objective: Investigation of the shade stability of polymer-infiltrated and resin nano ceramic crowns before and after artificial aging. *Method:* 40 identical crowns of each of the materials VITA Enamic (VE) and Lava Ultimate (LU) were manufactured. Half of the crowns went through a dynamic chewing simulation (CS) with thermocycling. *Material subgroups:* 1. VE, 2. VE/CS, 3. LU, 4. LU/CS (each n=20). These were divided into 4 groups (n=5) and distributed in usual stain solutions. The shade of each crown was measured occlusally and vestibularly before and after insertion using a spectrophotometer (n=5). The data were analyzed using ANOVA and Tukey's test ($p \leq 0.05$). *Results:* Sum scores (SSC) of the occlusal ΔE values: LU/CS: 7.99, VE: 5.75 VE/CS: 5.44, LU: 5.17. The total sum of the SSC yielded, for the materials: SSCtotal(VE): 20.0 and SSCtotal(LU): 24.0. *Significance:* Occlusally, there were significant shade differences for VE/CS ($p=0.025$) and LU/CS ($p=0.014$) between red wine and distilled water. LU/CS is significantly more clearly stained occlusally by coffee in comparison to the other three material subgroups (VE: $p=0.007$, LU: $p=0.026$, VE/CS: $p=0.013$). *Conclusions:* The shade stability of VITA Enamic crowns is superior to that of Lava Ultimate crowns. Only Lava Ultimate is affected by chewing simulation.

INTRODUCTION

Esthetics plays an important role in today's dentistry. From the materials point of view, there are various denture and restoration materials. Tooth-colored ceramics and composites have been used for years. Recently, compound materials of composite and ceramic have also been used as dental restoration materials.

The polymer-infiltrated ceramic VITA Enamic (VE) and the resin nano ceramic Lava Ultimate (LU), both available on the dental market since 2012, are worth highlighting among the composite materials.

These new materials combine positive characteristics like fracture and flexural strength.^{1,2} Altogether this leads to a high elasticity, which provides a decisive advantage on one-piece zirconia implants as fixed connection and for implementation of the dynamic chewing processes.^{3,4}

The polymer-infiltrated ceramic VE features an intertwined network of polymer and ceramic parts as its structure and combines the mechanical properties of both ceramic and resin-based composites.⁵ This polymer network inhibits the formation of crack,⁶ thus making the material hardwearing. LU is a resin nano ceramic consisting of about 79% nano-ceramic

Keywords

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particles and 21% polymer. There are already a few studies available in the literature on the mechanical properties of these materials.⁷⁻¹⁰ Since the bending strength and E-module of these composites are similar to that of teeth and they feature less hardness than ceramics, they are used as restoration materials.⁷ As early as 2013, Coldea *et al.* (2013) wrote that these composite materials imitate the properties of a natural tooth more than the previous materials.⁸ Therefore, patients have an increasing comfort. They have a softer occlusal contact using one of these composite restorations compared to full ceramic restorations. The fracture susceptibility of LU and VE crowns following accelerated artificial aging by chewing simulation is lower in comparison to the fracture susceptibility of glass and zirconia ceramic crowns.⁹ Al-Harbi *et al.* (2015) published that LU had both a greater bending strength and a greater surface roughness than feldspar ceramic after artificial aging.¹⁰

Using these composite materials as a clinician, it is easier to fit, repair and adjust these dental restorations and it might also lower dental laboratory bills. The dental laboratories come up with lower costs and shorter milling and finishing times.

Some of the latest studies in the literature about color behavior of these new composite materials from last year until now were carried out by Soygun *et al.* (2017),¹¹ Karakaya *et al.* (2017),¹² Alharbi *et al.* (2017),¹³ Acar B. *et al.* (2018),¹⁴ Sarikaya *et al.* (2018)¹⁵ and Quek *et al.* (2018).¹⁶ The important facts of these studies are reviewed afterwards in the discussion.

There are not yet any *in-vitro* studies in the literature on the shade stability of crowns made of the materials VE and LU after accelerated artificial aging by a dynamic chewing simulation with thermocycling.

This *in-vitro* study investigated, for the first time, the shade stability of polymer-infiltrated ceramic and resin nano ceramic crowns before and after dynamic chewing simulation with thermocycling.

The following two null hypotheses were formulated for this *in-vitro* study. Both materials demonstrate the same shade differences after dynamic chewing simulation with thermocycling. A dynamic chewing simulation with thermocycling has a significant impact on the occlusal shade stability of the crowns.

MATERIALS AND METHODS

40 crowns each (tooth 14) were manufactured from both of the materials, VITA Enamic (VE) and Lava Ultimate (LU) (Table 1), using CAD/CAM processes (Biogeneric: 0.48), and the sur-

faces were polished in a standard manner according to the manufacturer's instructions.

Table 1. Used materials

Material	Classification	Composition	Manufacturer
VITA Enamic (VE) 1M2	polymer-infiltrated ceramic	feldspathic ceramic (86%), acrylic polymer (14%)	VITA Zahnfabrik, Bad Säckingen, Germany
Lava Ultimate (LU) A3-HT	resin nano ceramic	resin nano ceramic (79%), polymer matrix (21%)	3M Espe, Neuss, Germany

All crowns were fixed adhesively according to the manufacturer's instructions on standardized abutments (ZrO₂). Half of the crowns of each material (subgroups n=20) were subjected to a chewing simulator to implement an accelerated artificial aging. In this process a chewing simulation (CS), with simultaneous thermocycling (TC) of 5500 cycles with changing temperatures from 4 °C to 56 °C for 60 s each, was executed. Hereby a hydroxyapatite steatite pellet (6.35 mm diameter) performed repeatedly (1.2 million times) a vertical force of 50 N at a speed of 60 mm/s on the occlusal surface (1.5 mm down the inner cliff of the vestibular cusp and 0.5 mm horizontally toward the central fossa) of the crowns to generate an occlusal wear.

Thus, a clinical wear period of about five years was simulated. This resulted in four subgroups: 1. VE, 2. LU, 3. VE/CS, 4. LU/CS, which, in turn, were each divided again into four equal subgroups (n=5) (Figure 1).

This was followed by a standardized initial shade measurement (n=5) of each crown, vestibularly and occlusally, with the VITA Easyshade Advance 4.0 spectrophotometer. At the occlusal measurement site, an abrasion had been created by the chewing simulation. To guarantee a comparable shade measurement of each crown both occlusally and vestibularly, the following measurement device was made:

Tooth 14 was milled from a plaster relined maxillary phantom model. A brass pin was stuck in region 14 in putty material, surrounded by Luxatemp. Vacuum-formed templates (Erkodur, 1.0 x 120 mm) were stretched over this measurement device and a large, 5 mm hole drilled, one occlusal and one vestibular, in region 14. Around each of these holes, a 5 mm long plastic tube was glued with superglue (Figures 2 - 4).

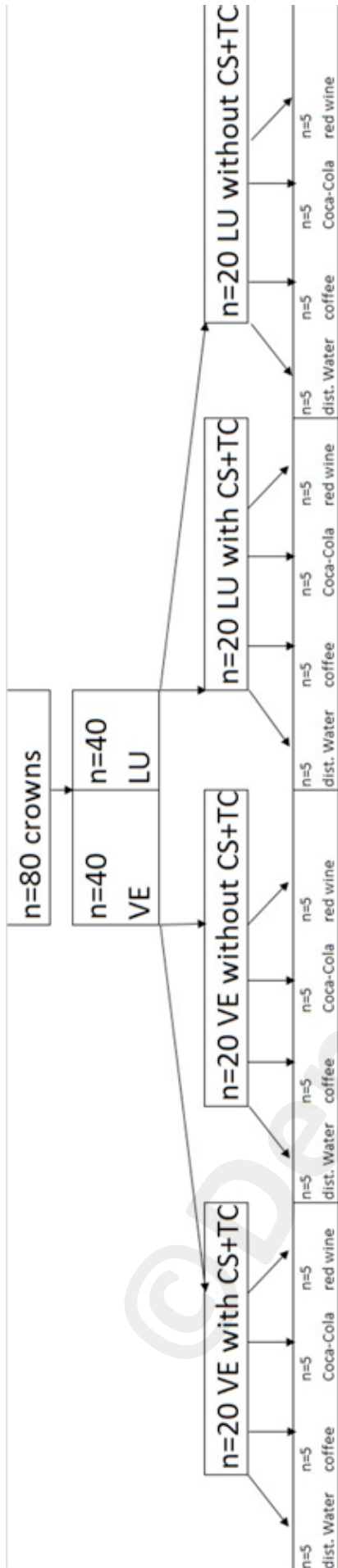


Figure 1: Distribution of the crowns. VE VITA Enamic, LU Lava Ultimate, CS chewing simulation, TC thermocycling



Figure 2: Color measuring templates of regio 14 vestibular and occlusal



Figure 3: Color measuring occlusal

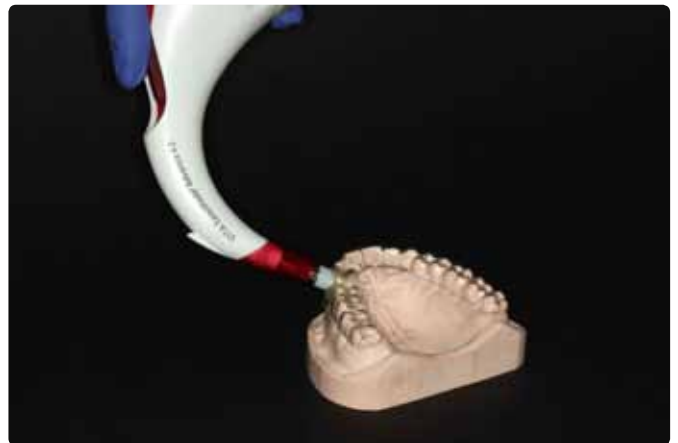


Figure 4: Color measuring vestibular

This guaranteed that the measuring head of the spectrophotometer could be placed, with each shade measurement, on the same place on each crown. The spectrophotometer was recalibrated after each measurement. Then these groups were systematized immersed into the beverages coffee (NES-CAFE powder 2.5g/ 100 ml distilled water), Coca-Cola, red wine (Blauer Zweigelt, year 2015) and a control group in distilled water over an investigation period of 14 days under standard conditions (darkness, room temperature, closed containers). The liquids were renewed every two days. After 14 days, the specimens were rinsed with distilled water and dried carefully with cellulose. After this, another standardized shade measurement (n=5) was conducted occlusally and vestibularly.

The data from the shade measurement were expressed by the spectrophotometer in values of the CIEL*a*b system (Commission Internationale de l'Éclairage). Here, the parameters L, a and b stand for the following: L: lightness, 0-100, a: -a* = green + a* = red, b: -b* = blue + b* = yellow. The ΔL , Δa , Δb and ΔE values between the final (day 14) and initial (day 0) shade measurements were calculated. The formula for the calculation of ΔE (shade difference) is: $\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}$ ^{17,18}

The statistical evaluation of the data was done with IBM SPSS Statistics Version 21 (SPSS Inc., Chicago, IL, USA). The descriptive statistics (max. ΔE mean, standard deviation, sum scores) of the individual ΔL , Δa , Δb and ΔE values were collected and the data analyzed with one-way ANOVA and Tukey's *post hoc* test ($p \leq 0.05$).

RESULTS

The largest occlusal ΔE mean values were for VE/CS (2.1±1.1) and for VE (2.1±0.9) caused by red wine and for LU/CS (3.6±0.8) and LU (2.0±0.8) caused by coffee. The largest vestibular ΔE mean values were for VE/CS (1.6±0.4) caused by coffee, for VE (1.6±0.8) caused by red wine, and for LU/CS (2.4±0.8) and LU (2.3±0.5) caused by coffee.

Figure 5 shows the result for the crowns occlusally after 14 days of dwell time (one each per group).

The shade differences caused by coffee and red wine are more significant for LU/CS in relation to LU than for VE/CS in relation to VE. The greatest shade differences for LU/CS can be seen with coffee and red wine.

Figures 6-8 show boxplot diagrams of the ΔE values of the material subgroups and the different stain solutions.

In Figure 6 "open circle 57" is the maximum value 3.50 of VE, and "open circle 137" is the maximum value 3.28 of LU.

In Figure 7 "closed star 82" is the minimum value 1.20 and "closed star 88" is the maximum value 1.66 of LU/CS.

The sum score (SSC) of the ΔE mean values of the four subgroups of the four liquids is showed in Table 2.

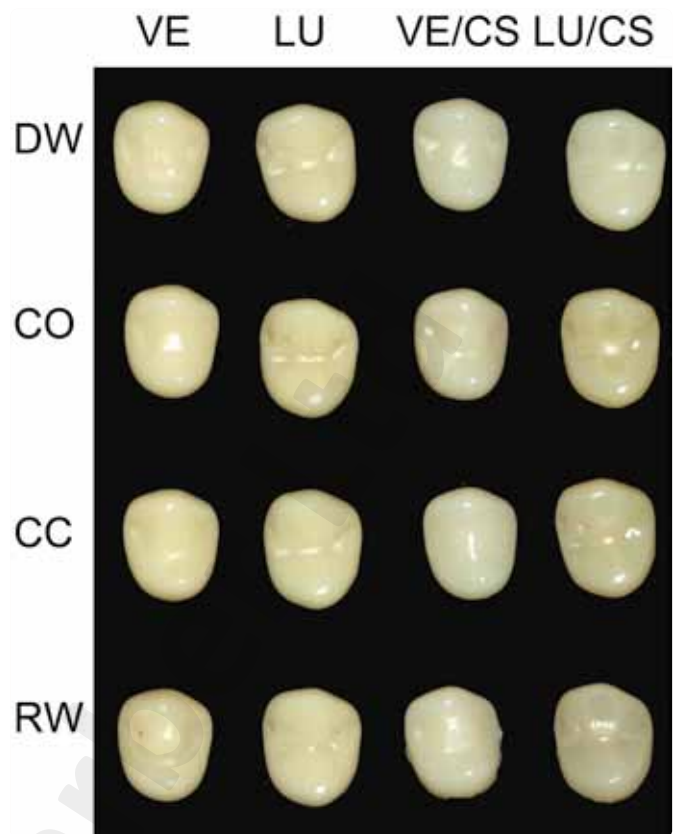


Figure 5: Result of the crowns occlusal after immersion. VE VITA Enamic, LU Lava Ultimate, CS chewing simulation, DW distilled water, CO coffee, CC Coca-Cola

The total of the SSC yielded the following values for the respective material, combined with and without CS: $SSC_{total}(VE)$: 20.0 and $SSC_{total}(LU)$: 24.0.

Occlusally, there were significant shade differences for VE/CS ($p=0.025$) and LU/CS ($p=0.014$) between red wine and distilled water. Also, coffee stained LU/CS the most and significantly in comparison to distilled water and the other two stain solutions (with distilled water: $p<0.0001$, with Coca-Cola: $p<0.0001$, with red wine: $p=0.032$). Red wine also stained LU/CS occlusally ($p<0.0001$) significantly greater than Coca-Cola. LU/CS is also stained significantly more by coffee in comparison to the other three material subgroups (VE/CS: $p=0.013$, VE: $p=0.007$, LU: $p=0.026$). For both materials without the chewing simulation,

Table 2. Sum scores of the mean ΔE -values

Material	Sum score occlusal	Sum score vestibular
VE	5.75	4.16
LU	5.17	5.09
VE/CS	5.44	4.68
LU/CS	7.99	5.74

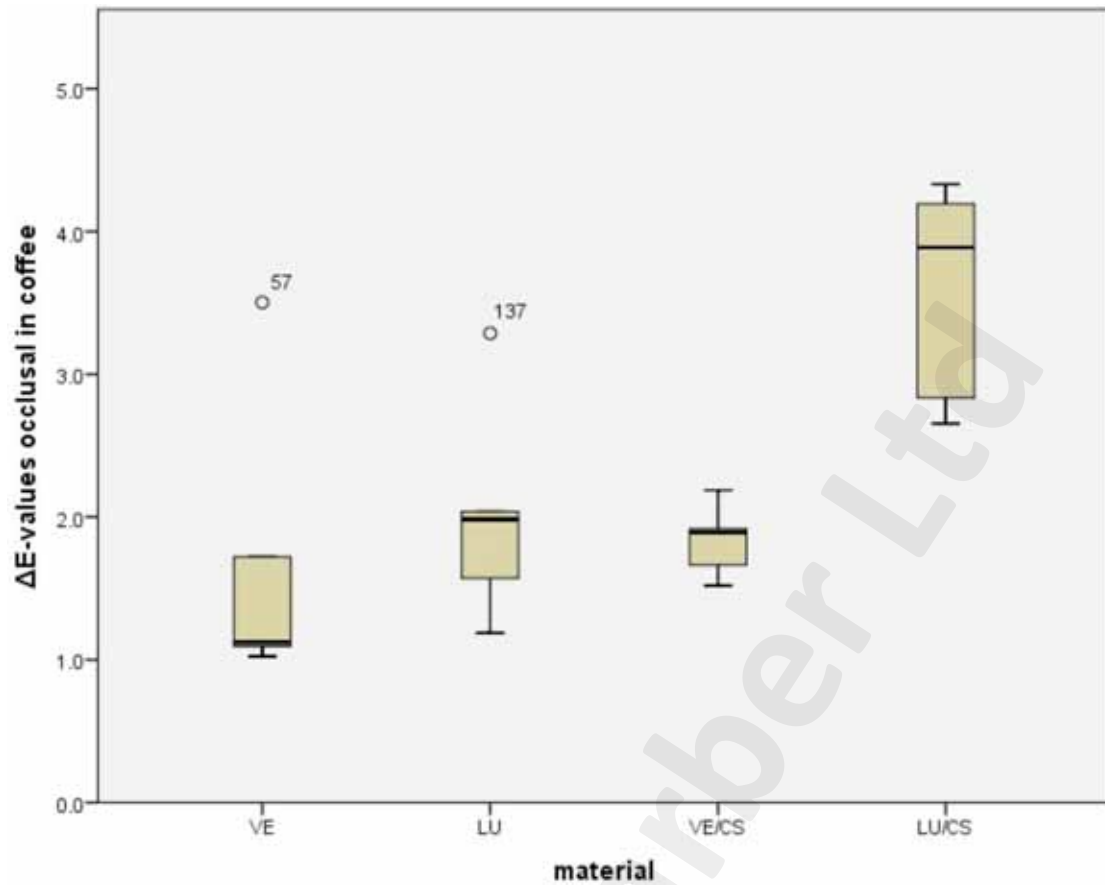


Figure 6: Boxplots, ΔE-values occlusal in coffee. VE VITA Enamic, LU Lava Ultimate, CS chewing simulation

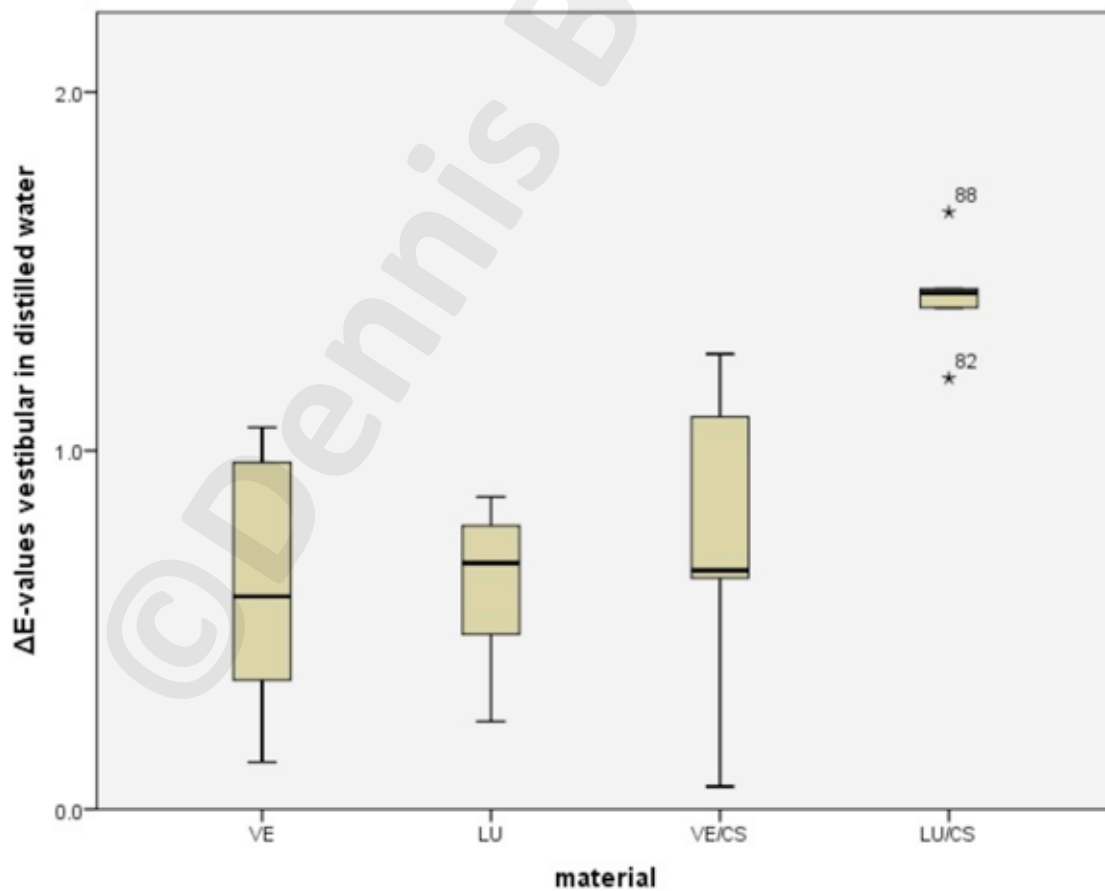


Figure 7: Boxplots, ΔE-values vestibular in distilled water. VE VITA Enamic, LU Lava Ultimate, CS chewing simulation

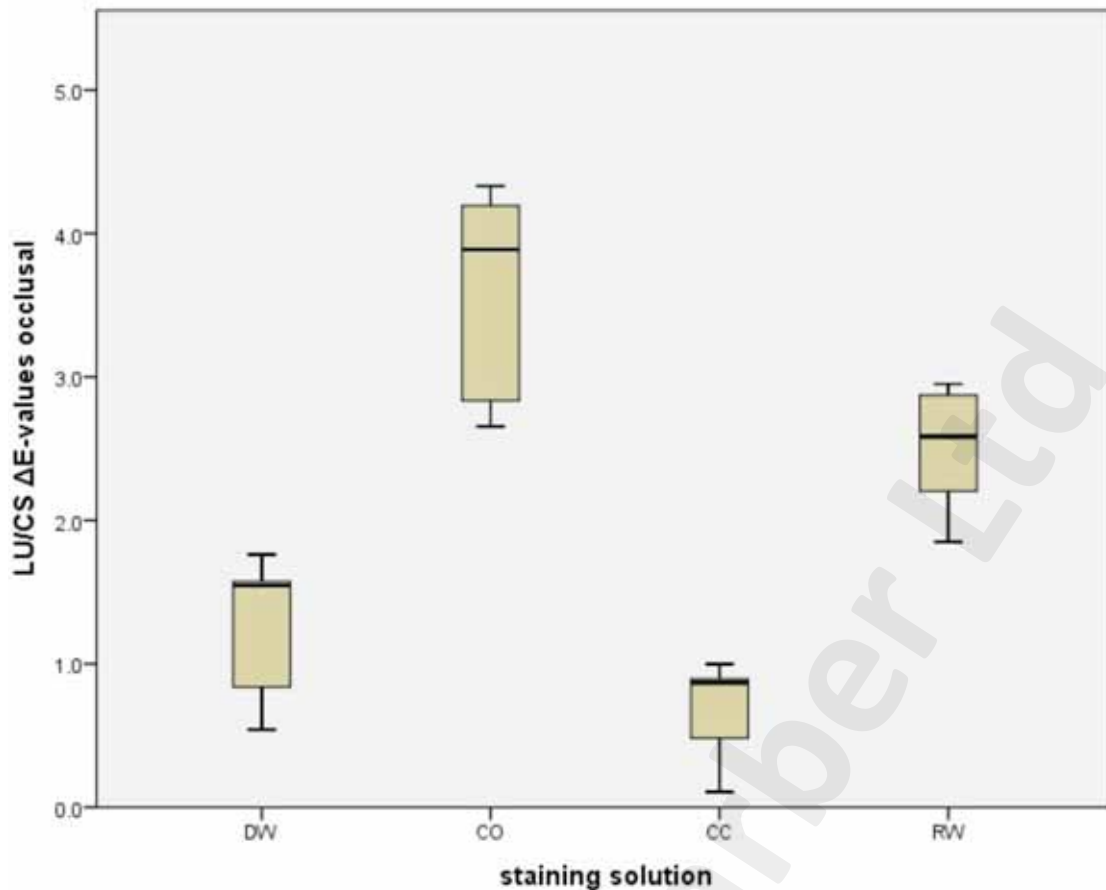


Figure 8: Boxplots, LU/CS ΔE-values occlusal. DW distilled water, CO coffee, CC Coca-Cola, RW red wine

there were no significant occlusal shade differences caused by immersion in the stain solutions in comparison to distilled water or each other (Table 3).

Vestibularly, red wine stained VE significantly more ($p=0.031$) than distilled water. LU/CS is stained by coffee significantly more ($p=0.001$) than by Coca-Cola vestibularly. Coffee also stains LU vestibularly significantly more than distilled water and Coca-Cola (each $p=0.004$). Furthermore, distilled water showed significantly more shade differences in LU/CS vestibularly than in VE/CS ($p=0.028$), VE ($p=0.009$) and LU ($p=0.008$). Coffee stained LU/CS ($p=0.006$) and LU ($p=0.011$) vestibularly significantly more than VE (Table 4).

Coca-Cola caused the lowest shade differences in both materials. Within the four material subgroups, no significant shade differences were detected on either surface. Likewise, red wine did not cause any significant shade differences either occlusally or vestibularly within the four material subgroups.

In both materials without chewing simulation (VE and LU), no significant shade differences occurred occlusally between the stain solutions and distilled water. Likewise, no significant shade differences occurred between VE and LU occlusally in all stain solutions.

Table 3. Statistical analysis occlusal. Mean (standard deviation) of the color change (ΔE) occlusal of the crowns. Same superscript letters in the same column and same subscript numbers in the same row indicate a significant difference ($p \leq 0.05$).

Occlusal	Distilled water ΔE mean value(SD)	Coffee ΔE mean value(SD)	Coca-Cola ΔE mean value(SD)	Red wine ΔE mean value(SD)
VE	0.81(0.25)	1.69(1.05) ^b	1.13(0.76)	2.10(0.87)
LU	0.74(0.53)	2.01(0.79) ^c	0.78(0.16)	1.64(1.53)
VE/CS	0.69(0.26) ₁	1.83(0.25) ^a	0.85(0.61)	2.05(1.13) ₁
LU/CS	1.25(0.53) ₁	3.58(0.78) _{1,2,3} ^{a,b,c}	0.66(0.37) ₂	2.49(0.46) _{1,2,3}

Table 4. Statistical analysis vestibular. Mean (standard deviation) of the color change (ΔE) vestibular of the crowns. Same superscript letters in in the same column and same subscript numbers in the same row indicate a significant difference ($p \leq 0.05$).

Vestibular	Distilled water ΔE mean value(SD)	Coffee ΔE mean value(SD)	Coca-Cola ΔE mean value(SD)	Red wine ΔE mean value(SD)
VE	0.74(0.46) ^a	1.55(0.37)	0.88(0.73)	1.49(1.52)
LU	0.62(0.39) ¹ _b	1.05(0.47) ^{a,b}	0.86(0.53)	1.62(0.80) ₁
VE/CS	1.43(0.16) ^{a,b,c}	2.41(0.79) ₁ ^a	0.47(0.36) ₁	1.42(0.96)
LU/CS	0.61(0.25) ₁ ^c	2.31(0.46) _{1,2} ^b	0.59(0.21) ₂	1.56(1.18)

DISCUSSION

In order to maintain an optimal esthetic appearance, shade has a decisive role. Increased patient demand for improved esthetics led to the further development and innovation of restoration materials.¹⁹ Many different factors can have an effect on the discoloration of dental materials.

The objective of the present study was to investigate the shade stability of polymer-infiltrated ceramics (VE) and resin nano ceramic (LU) crowns in comparison to each other, both before and after dynamic chewing simulation with thermal cycling with regard to significant ($p \leq 0.05$) shade differences.

The first null hypothesis, that both materials exhibit the same shade differences after dynamic chewing simulation with thermocycling, is to be rejected since LU/CS showed significantly greater shade differences occlusally caused by coffee than VE/CS ($p=0.013$) (Figure 6). With no chewing simulation, there is no significant shade difference in any of the stain solutions between the materials VE and LU occlusally.

The second null hypothesis, that a dynamic chewing simulation with thermocycling has a significant influence on the occlusal shade stability of the crowns, is to be accepted for the resin nano ceramic LU. Occlusally, LU/CS showed a shade difference of $\Delta E=3.58 \pm 0.78$ and LU $\Delta E=2.01 \pm 0.79$. This shade difference is significant ($p=0.026$) (Figure 6).

Furthermore, there were significant shade differences for LU/CS with coffee in comparison to red wine ($p=0.32$), Coca-Cola ($p<0.0001$) and distilled water ($p<0.0001$) and with red wine in comparison to Coca-Cola ($p<0.0001$) and distilled water ($p=0.014$) (Figure 13). Vestibularly, there were also significant shade differences between the different stain solutions for VE, LU/CS and LU. In VE between red wine and distilled water ($p=0.031$), in LU/CS between coffee and Coca-Cola ($p=0.001$). In LU between coffee and distilled water ($p=0.004$) and between coffee and Coca-Cola ($p=0.004$).

First, some aspects of the materials and methods used will be discussed.

According to the manufacturer's information, there has been an indication restriction for the LU material as crown material since 2015.

In the present study LU was used representatively of other resin-nano ceramics with highly crosslinked resins or rather similar high polymer content.

Both internal and external factors influence the shade stability of each material. The internal factors include the matrix, the percentage and distribution of the filler in the composition and the adhesive materials used. External factors include exposure to the environment, UV radiation, heat and pigments such as those that occur in beverages and food. These pigments may cause discoloration through adsorption and absorption.²⁰ The pH value of the environment can also have an influence on shade stability.²¹ Some surface discolorations can be removed from restoration materials by polishing.²²

Currently, there are some studies in the literature on the shade stability of these modern composite materials.^{11-16, 23-26} The compound materials VE and LU showed good shade stability in different stain solutions over a period of 120 days in comparison to the feldspar ceramic Mark II and other materials (VITA Hybrid-Ceramic (exp), Paradigm MZ 100, Kerr (exp), Filtek Supreme XTE, Venus Diamond, Filtek Siloranes).²³ Arocha *et al.* (2014) wrote that CAD/CAM manufactured composites LU and Paradigm MZ 100 feature a greater shade stability than laboratory manufactured composites (SR Adoro, Premise Indirect).²⁴ In a study by Acar O. *et al.* (2016), the shade stability of various materials (IPS e.max CAD, Filtek Supreme Plus) after placement in coffee with 5000 thermocycling cycles was investigated. In this case, the nano-hybrid composite Filtek Supreme Plus was more strongly discolored than the resin nano ceramic LU, and this in turn was more strongly discolored than the polymer-infiltrated ceramic VE. Both composite materials showed greater shade differences than the lithium disilicate ceramic IPS e.max CAD.²⁵ The study by Karaokutan *et al.* (2016) studied the influence of artificial aging by a weathering machine and a one-week dwell time in distilled water on the shade stability of three ceramics using inlays. In this study, the resin nano-ceramic LU showed greater shade differences than a feldspar ceramic (CEREC Blocs) or a leucite glass ceramic (IPS Empress CAD).²⁶ In the study of Soygun *et al.* (2017) was the color stability of LU not as good as the color stability of a lithium-disilicate and a leucite-ceramic after the exposition in three different mouthrinses.¹¹ In the study of Karakaya and Cengiz (2017) was the color stability of VE specimens better than the one of LU specimens after the immersion in coffee

and red wine.¹² The study of Alharbi *et al.* (2017) showed that VE specimens had less ΔE values than LU after the immersion in coffee, tea and red wine. Also the residual discoloration values of VE were smaller than the ones of LU after a bleaching procedure of these stained specimens.¹³ Acar B. *et al.* (2018), showed that there is a moderate positive correlation between the surface wear and colour stability of LU in their study with surface treatment.¹⁴ In the study of Sarikaya *et al.* (2018), coffee caused the highest ΔE -values by VE and LU in comparison to distilled water, Cola and tea after different polishing techniques. Also, the transparent parameter, which was generally higher by LU than by VE, decreased in coffee, tea and cola.¹⁵ Quek *et al.* (2018) stated, that CAD/CAM composites including VE and LU are more colour stable than direct and indirect materials. But all types had clinical perceptibly colour changes after one week immersion in red wine.¹⁶

The crowns were manufactured in the standard manner from blocks for the CEREC CAD/CAM system (Biogeneric: 0.48) and therefore each crown has the same mass, since the thickness of specimens in stain experiments can have an influence on shade stability.²⁵ The accelerated artificial aging through the dynamic chewing simulation caused an occlusal abrasion surface on the crowns, which is not as pronounced in the VE crowns as in the LU crowns.³⁴ This difference can also be seen on the crowns (Figure 6). In some cases, the minimum layer thickness of the LU crowns could have been undercut. Whether this influence led to altered shade differences must be investigated in further studies.

Coffee, Coca-Cola and red wine are everyday beverages, which have frequently been used in studies investigating the shade stability of dental materials. The control group is usually placed in distilled water or artificial saliva.^{17,23,27,28}

The containers were sealed and darkened since the study by de Oliveira *et al.* (2015) showed that a shade difference may occur in resin-based composites due to exposure to UV light and UVB radiation over a period of five days.²⁹

The investigation period of 14 days shows clearer shade differences than after only seven days. Studies show that discoloration can also increase over time after 14 days.^{20,23}

The spectrophotometer VITA Easyshade Advance 4.0 is excellently suited for the shade measurement of dental materials due to its ease of use, reproducibility and high precision with extra-oral specimens and intra-orally in patients.³⁰⁻³³

The shade measurement of the crowns was carried out in a special measuring device specifically produced for this *in-vitro* study in order to guarantee a standardized shade measurement. The exact positioning of the spectrophotometer, always at the same locations on the crowns, was implemented in the best possible manner with the help of measuring templates made from vacuum-formed templates. However, small positioning errors also cannot be ruled out in this method.³⁴ Likewise, measurement errors cannot be 100% excluded by a variance in the spectrophotometer itself.

There are different thresholds for the perceptibility and acceptance of tooth shade differences in the literature. Here "PT", "50:50 PT" or "PT (50:50%)" means the perceptibility threshold at which 50% of the test subjects perceive a shade difference, and "AT," "50:50 AT" or "AT (50:50)" means the acceptability threshold at which 50% of the test subjects accept a shade difference and would, for example, exchange or match a neighboring tooth with this shade difference.

Paravina *et al.* (2015) defined PT: $\Delta E = 1.2$ and AT: $\Delta E = 2.7$, where a total of 175 test subjects participated in this multi-center study.³⁵

The retrospective study by Khashayar *et al.* (2014), which included and compared a total of 48 studies from different databases, indicates that more than 50% of these studies defined PT as $\Delta E = 1.0$ and 35% of these studies defined AT as $\Delta E = 3.7$.³⁶

There are still some more studies in the literature determining the values for PT and AT.

From the diversity on this subject in the literature, it can be concluded that the threshold values PT and AT have not been precisely defined and presumably will not be in the future. The clinically relevant threshold AT differs in the citations here by a value of 1, which is actually not perceivable as a shade difference by the human eye.³⁰ Thus, a variation of the thresholds by this value is not significantly critical.

The meta-analysis by Khashayar *et al.* (2014) compared several studies and, therefore, the most test subjects participated in this publication on the thresholds of PT and AT.³⁶ Based on this study, no material, with or without chewing simulation, have clinically relevant ($\Delta E > 3.7$) shade differences after 14 days of dwell time in the study conducted here. Based on the stricter values of Paravina *et al.* (2015), only LU/CS showed clinically relevant shade differences ($\Delta E > 2.7$).³⁵

With regard to these more modern composite materials, the following can be found in the literature. The study of Alharbi *et al.* (2017) showed that the polymer-infiltrated ceramic VE and the resin nano ceramic LU have a very good shade stability in relation to seven other tested ceramic and composite materials which are also partially suitable for the CAD/CAM system.²³ VE also has fewer shade differences than LU. The color stability of polymer-infiltrated ceramics is superior to that of resin nano ceramics in the study by Acar *et al.* (2016).²⁵ In this study as well, the resin nano-ceramic LU had an overall lower shade stability in comparison to the polymer-infiltrated ceramic VE. Clinical or *in-vitro* studies which have investigated the shade stability of crowns of these materials before and after dynamic chewing simulation with thermocycling are not currently available in the literature. Both materials showed shade differences in distilled water with and without chewing simulation. In all studies on shade experiments, the materials also showed shade differences in distilled water.

The finding that VE, VE/CS and LU showed no clinically relevant ($\Delta E > 2.7$) shade differences is likely due to the polishing and the investigation period of 14 days. To verify this, further studies must be carried out.

Only LU/CS had clinically relevant ($\Delta E > 2.7$) occlusal shade differences in coffee. Due to a different material composition, internal matrix, and a better resistance to the dynamic chewing simulation with thermocycling, the polymer-infiltrated ceramic VE showed no clinically relevant shade differences.

Nevertheless there are some limitations of this *in-vitro* study compared to *in-vivo* studies or conditions about shade stability of dental materials. The first limitation is the performed chewing force. In this *in-vitro* study there was a static vertical chewing force of 50 N. The average human chewing force is between 50 and 80 N, but the maximum bite force (MBF) is more than this value and up to approximately 350 N.³⁷ Humans can also exercise chewing forces in all three dimensions. Thus, this fact can affect the surface wear including the shade stability of dental restorations in a different way than a chewing simulation can do. The second limitation is the temperature. In the oral cavity, the temperature is usually constant between 36 °C and 37.5 °C. The temperature can vary, for example by drinking hot and cold beverages, but not as fast as it was performed in the thermocycling from 4 °C to 56 °C in 1 minute for 5500 times. As a third limitation is the following aspect listed. Humans consume a lot more of different staining solutions and particles with their daily food and beverages, also possibly at the same time, than there were tested in this *in-vitro* study. The last two limitations might also lead to a different shade stability of dental materials than in this *in-vitro* study.

CONCLUSION

Considering the limits of this *in-vitro* study, the following conclusions can be formulated. The color stability of the polymer-infiltrated ceramic VITA Enamic is superior to that of the resin nano ceramic Lava Ultimate in the statistical comparison.

A dynamic chewing simulation with thermocycling has no significant influence on the shade stability of VITA Enamic or Lava Ultimate, but causes clinically relevant ($\Delta E > 2.7$) shade differences in Lava Ultimate.

Both composite materials are particularly vulnerable to coffee and red wine with regard to shade stability. Coffee stained the crowns of both composite materials occlusally, to different extents, after dynamic chewing simulation with thermocycling. Overall, however, all color differences were small in relationship to the published perception thresholds of the human eye.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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MANUFACTURER'S DETAILS

- VITA Zahnfabrik, Spitalgasse 3, 79713 Bad Säckingen, Germany: VITA Enamic, VITA Easyshade Advance 4.0
- 3M Espe, Carl-Schurz-Straße 1, 41460 Neuss, Germany: Lava Ultimate, Bonding Crowns to abutments RelyX™ Ultimate
- Sirona Connect, Fabrikstraße 31, 64625 Bensheim, Germany: CEREC CAD/CAM machine
- Picodent® Dental-Produktions- und Vertriebs-GmbH, Lüdenscheider Str. 24-26, 51688 Wipperfürth, Germany: Brass pin
- Kaniedenta GmbH & Co. KG. Dentalmedizinische Erzeugnisse, Zum Haberland 36, 32051 Herford, Germany: Putty material
- DMG Chemisch-Pharmazeutische Fabrik GmbH, Elbgaustraße 248, 22547 Hamburg, Germany: Luxatemp
- ERKODENT® Erich Kopp GmbH, Siemensstr. 3, 72285 Pfalzgrafenweiler, Germany: Vacuum-formed templates
- ACCU DENT, Dental-Depot, Kreuzstrasse 10, 97490 Poppenhausen, Germany: Superglue

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