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RADIOPACITY ANALYSIS OF SOME CHAIRSIDE COMPUTER-AIDED DESIGN-COMPUTER-AIDED MANUFACTURING MILLING MATERIALS

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ABSTRACT: In this study, the radiopacity of chairside Computer-Aided Design-Computer-Aided Manufacturing (CAD-CAM) milling materials was evaluated in comparison with dental structures. 105 specimens of 7 different thicknesses from 5 different types of chairside CAD-CAM milling materials: feldspar ceramic, hybrid ceramic, lithium disilicate glass-ceramic, zirconia-reinforced lithium silicate ceramic and a resin nano-ceramic were used for this in vitro study. Digital radiographs were obtained using an aluminum step wedge, a specimen of a tooth slice and 3 specimens from each material. Radiodensity was determined for each material using dedicated software. Lava Ultimate and Vita Suprinity were found as having higher radiopacity, whilst Vita Mark II and Vita Enamic were lower in radiopacity in comparison with dental structures. The radiodensity of Emax CAD was between enamel and dentine. Radiopacity of each CAD-CAM milling material was different and both material's type and thickness significantly affected the radiopacity.

Key words: *CAD-CAM, chairside, milling materials, radiopacity*

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INTRODUCTION

In the last three decades, exciting new developments in dental materials and computer science have led to the success of contemporary dental computer-aided design / computer-aided manufacturing (CAD-CAM) technology. The user friendly and easy manufacturing of very precise esthetic restorations, in a short period of time, made CAD-CAM technology an optimal option for prosthetic treatment in a large range of indications. Nowadays, several highly sophisticated chairside and laboratory CAD-CAM systems have been introduced and are continuously improving [1, 2, 3].

Milling materials designed for CAD-CAM techniques are also in evolution. If initially only glass ceramic was used, over time, new materials, based on different constituents were developed: zirconia in 2002, reinforced ceramics in 2005, composite resins in 2007 and hybrid ceramics in 2012. Each new material aims improved properties such as good mechanical, surface and optical characteristics, optimal quality of adhesion to adjacent structures and ease of usage [4].

One of the most important clinical characteristics of dental materials is radiopacity, which allows to identify the restoration under radiologic examination, to assess its relation with the adjacent dental structures and to diagnose the possible pathology of the respective tooth.

In most clinical cases, for a complete diagnosis, a complementary x-ray examination is necessary. It was suggested that less than 15% of inadequate restorations are detected clinically, while the rest are diagnosed only radiographically [5]; moreover, in 80-90% of the cases, secondary caries are located at the proximal gingival margin, where radiography is often the only way for their detection [6]. Therefore, all restorative materials should have intrinsic characteristics, to allow their detection and delimitation against enamel, dentin or cement. Therefore, radiopacity of restorative dental materials is of paramount importance because it helps the clinician to detect secondary caries, restorations' integrity and contours, missing interproximal contacts, marginal defects, voids, interfacial gaps, cement overhangs or misplaced fragments in case of trauma [7, 8, 9, 10, 11, 12]. However, excessive radiopacity would mask the dental structures and consequently may reduce the ability to diagnose recurrent caries [13, 14].

As in conventionally processed materials, radiopacity of restorative dental materials used in CAD-CAM technology is influenced by the structure and type of filler particles (heavy metals such as aluminum, barium, strontium, or zirconium [8]. Excessive incorporation of radiopaque fillers in the restorative dental materials results in reduced translucency, but affects also mechanical properties, increases thermal expansion and causes hydrolysis of silane bonding agents [8, 15, 16].

According to the International Organization for Standardization (ISO), the radiopacity of dental materials is expressed as an optical density value or in terms of equivalent aluminium (Al) thickness (in millimeters) by using a reference calibration curve under controlled radiographic conditions [17, 18]. Accordingly, restorative dental materials should have their radiopacity equal to or greater than that of Al [19], considering that there are studies which showed that the radiopacity of dentin was approximately equivalent to that of Al samples of the same thickness, whilst enamel had approximately twice the value of Al at the same thickness [20, 21].

It was stated that the radiopacity of dental materials has to be equal or higher than the radiopacity of dentin [14, 22] or enamel [23]. Radiopacity of conventional and resin modified glass-ionomers [21, 24], conventional and flowable resin composites [21], dental ceramics [20, 25] has been studied; however, most literature address materials processed by conventional techniques [25]. There is little research focused on the radiopacity of CAD-CAM processed materials: Dicor MGC and Vita Blocks [26] or zirconia ceramics [25, 27, 28]. To the best of our knowledge there is no study of the radiopacity of newer materials such as hybrid ceramics or zirconia-reinforced lithium silicate ceramic. The purpose of this study was to evaluate the radiopacity of five frequently used chairside CAD-CAM milling materials at different thicknesses and to compare it with the radiopacity of hard dental structures.

The first null hypothesis was that radioopacity was not influenced by the type of material and the second null hypothesis was that the thickness of the slices can't influence the radiodensity.

RESULTS AND DISCUSSIONS

An in vitro study was conducted using 105 specimens of five different chairside CAD-CAM milling materials: feldspar ceramic (Vita Mark II -Vita), hybrid ceramic (Vita Enamic - Vita), lithium disilicate glass-ceramic (e.max CAD - Ivoclar), zirconia-reinforced lithium silicate ceramic (Vita Suprinity - Vita) and a resin nano ceramic (Lava Ultimate - 3M ESPE) (Table 1). For each material, specimens were cut and prepared at 7 different thicknesses. The three samples with the same thickness of each material, the tooth slice with the corresponding thickness and the aluminum step wedges were placed on an intraoral sensor and radiographed using a dental X-ray machine.

Table 1. CAD-CAM milling materials' characteristics

	Brand	Manufacturer	Structure	Composition
1	Vita Mark II	Vita Zahnfabrik, Bad Säckingen, Germany	feldspar ceramic	SiO_2: 56-64% Al_2O_3: 20-23% Na_2O: 6-9% K_2O: 6-8% CaO: 0,3-0,6% TiO_2: 0,0-0,1%
2	Vita Enamic	Vita Zahnfabrik, Bad Säckingen, Germany	hybrid ceramic	Ceramic part (86 wt% / 75 vol%): SiO_2: 58-63% Al_2O_3: 20-23% Na_2O: 9-11% K_2O: 4-6% B_2O_3: 0,5-2% ZrO_2 <1% CaO >1% Polymer part (14 wt% / 25 vol%):UDMA (urethane dimethacrylate), TEGDMA (triethylene glycol dimethacrylate)
3	E.max CAD	Ivoclar Vivadent Schaan, Liechtenstein	lithium disilicate glass-ceramic	SiO_2: 57-80% Li_2O: 11-19% K_2O: 0-13% P_2O_5: 0-11% ZrO_2: 0-8% ZnO: 0-8% Al_2O_3: 0-5% MgO: 0-5% Colouring oxides: 0-8%
4	Vita Suprinity	Vita Zahnfabrik, Bad Säckingen, Germany	zirconia-reinforced lithium silicate ceramic	ZrO_2: 8 – 12% SiO_2: 56 – 64% Li_2O:15 – 21% La_2O_3: 0.1% Pigments <10% Various > 10%
5	Lava Ultimate	3M ESPE, Seefeld, Germany	resin nano ceramic	Nanoceramic part (80 wt%): Silica particles Zirconia particles Resin matrix (20 wt%):

Both, material's type and thickness significantly affected the radiopacity (Figure 1 and Figure 2). The thickness of the material was significantly positively correlated with radioopacity (*r* ranged between 0.93 and 1, $p<0.001$) for all restorative materials, but also for enamel and dentin. The radiopacity of all samples (chairside CAD-CAM milling materials and tooth structures) increased with the thickness (Figure 1).

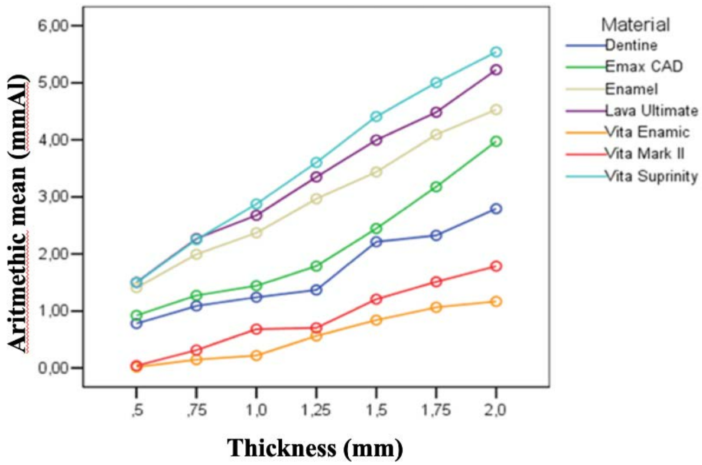

Figure 1. Radiopacity mean value of studied materials as well as of natural teeth structures versus sample thickness

The ascending sequence of the radiopacity for the evaluated materials' samples was Vita Enamic, Vita Mark II, dentine, Emax CAD, enamel, Lava Ultimate and Vita Suprinity. The mean radiopacity of chairside CAD-CAM milling materials ranged between 0.57±0.44 mm Al (Vita Enamic) and 3.60±1.41 mmAl (Vita Suprinity). The mean values for the radiopacity of dental structures were 2.97±1.07 mmAl for the enamel and 1.69±0.71 mmAl for the dentine (Figure 2).

Vita Enamic had statistically significant lower radiopacity values than dentine, enamel and all the others CAD-CAM materials ($p\leq0.007$) except Vita Mark II (p=0,945). Lava Ultimate and Vita Suprinity had statistically significant higher radiopacity values than dentine and all the other CAD-CAM materials ($p\leq0.002$, $p\leq0.001$) but not significantly different than the enamel (p=0.870, p=0.398). The mean radiopacity values for EmaxCAD was statistically significant different from Vita Mark II, Vita Suprinity, Lava Ultimate and Vita Enamic ($p\leq0.002$), but not from hard dental tissues (p=0.110 for enamel and p=0.750 for dentine). The mean radiopacity values for Vita Mark II were statistically significant different from emax CAD, enamel, Lava Ultimate and Vita Suprinity (*p*≤0.001), but nor for dentine (*p*=0.138) and Vita Enamic (*p*=0.945). The mean radiopacity values for enamel were statistically significant different from Vita Enamic, Vita Mark II and dentine (*p*≤0.001) (Figure 2).

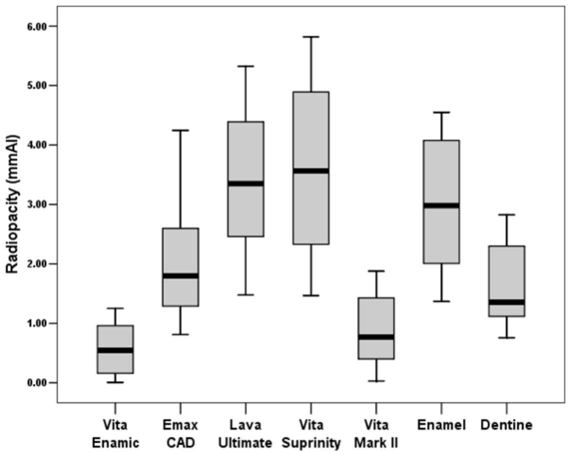

Figure 2. Radiopacity values (p<0.001) (Median, 25th-75th Percentile, Minimum - Maximum)

The analysis of thickness influence on radiopacity for the chairside CAD-CAM milling materials is revealed in Table 2. The radiopacity of CAD - CAM milling materials ranged from 0.02±0.01mmAl (Vita Enamic at 0.5mm) to 5.54±0.26mmAl – (Vita Suprinity at 2 mm).

Multivariate analysis revealed that at all evaluated materials, including dentin and enamel, size and material type had a combined effect on the radiopacity (p<0,001). We found that if the thickness increases, the difference between radiopacity of the materials increases (Figure 3).

However, for Vita Enamic and Vita Mark II (effect size 0.32), Vita Mark II and Dentine (effect size 0.8), Dentine and Emax CAD (effect size 0.46), Emax CAD and Enamel (effect size 0.82), and for Enamel, Lava Ultimate and Vita Suprinity (effect size 0.39 respectively 0.24) no significant difference was found between radiopacities (*p*>0.05). The post hoc power analyses conducted showed that the achieved power for the difference between the radioopacities in our tested materials where p was not significant was between 0.07 for an effect size of 0.24 and 0.60 for an effect size of 0.82, where p was significant was between 0.85 for an effect size of 1.12 and 0.95 for an effect size of 1.28.

Table 2. Radioopacity of tested materials, for the considered thicknesses (Means ± standard deviations).

	Radiopacity (mmAl)						
Thickness	**0.5mm**	**0.75mm**	**1mm**	**1.25mm**	**1.5mm**	**1.75mm**	**2mm**
Vita Enamic	0.02 ± 0.01^{1}	0.15 ± 0.07^{1}	0.22 ± 0.10^{1}	0.56 ± 0.06^{2}	0.84 ± 0.11^{3}	$1.06\pm0.11^{3,4}$	1.17 ± 0.07^{4}
Emax CAD	0.92 ± 0.11^{1}	1.27 ± 0.02^{1}	1.44 ± 0.01^{1}	$1.79\pm0.02^{1,2}$	$2.45\pm0.21^{2,3}$	$3.18\pm0.75^{3,4}$	3.97 ± 0.47^{4}
Lava Ultimate	1.50 ± 0.02^{1}	2.27 ± 0.17^{2}	2.68 ± 0.20^{3}	3.35 ± 0.06^{4}	4.00 ± 0.10^{5}	4.49 ± 0.10^{6}	5.23 ± 0.08^{7}
Vita Suprinity	1.50 ± 0.03^{1}	2.25 ± 0.08^{2}	2.88 ± 0.14^{3}	3.60 ± 0.10^{4}	4.41 ± 0.07^{5}	5.00 ± 0.15^{6}	5.54 ± 0.26^{7}
Vita Mark II	0.04 ± 0.01^{1}	0.31 ± 0.07^{1}	0.68 ± 0.08^{2}	0.70 ± 0.18^{2}	1.21 ± 0.15^{3}	$1.51\pm0.14^{3,4}$	1.79 ± 0.11^{4}
Enamel	1.41 ± 0.04^{1}	1.99 ± 0.02^{2}	2.37 ± 0.01^{3}	2.97 ± 0.03^{4}	3.44 ± 0.02^{5}	4.09 ± 0.02^{6}	4.53 ± 0.02^{7}
Dentine	0.78 ± 0.03^{1}	1.09 ± 0.04^{2}	1.24 ± 0.04^{3}	1.37 ± 0.03^{4}	2.21 ± 0.02^{5}	2.32 ± 0.02^{6}	2.79 ± 0.03^{7}
Analysis was performed for each material (row in the table) separately. Different superscript (in the same row) indicates statistically significant difference ($p<0.05$) between radiopacities from the same material (same row).							

Sample size calculations using the minimum above mentioned effect sizes, $\alpha=0.05$, and power of 0.90 showed that the minimum number of observations per group needed to find an effect is 315.

This study evaluated the radiopacity of some of the newest most used chairside CAD-CAM milling materials, using digital radiography and pixel gray-scale measurement (ex: Emax CAD used from 2006, Lava Ultimate from 2012, Vita Enamic and Vita Suprinity from 2013).

Both null hypotheses were rejected, since we found that the radiopacity depends on the material's type and thickness.

The influence of the material type upon the radiodensity may be related to the composition.

Materials with low atomic numbers elements in their composition (such as silicone and alumina) appear radiolucent, whereas materials having elements with high atomic numbers (such as zinc, strontium, zirconia, barium glass or sulfate, lanthanum, and ytterbium) appear radiopaque [8, 12, 13, 29, 30].

Our study is in accordance with the existing research. Vita Mark II and Vita Enamic have an important percentage of silicon oxide (56-64% respectively 58-63%) and aluminum oxide (20-23%) in their composition, resulting a lower radiopacity of these materials, while Vita Suprinity and Lava Ultimate were the materials that showed the highest radiopacity of all evaluated materials. The high radiopacity level could be attributed to zirconia added in their composition (ex: Vita Suprinity has 8-12% zirconia in the composition) or lanthanum oxide (0,1% in Vita Suprinity). Even if the tested materials had approximately the same level of silicon oxide (between 56% and 80%), the level of zirconia oxide was different: lower than 1% for Vita Mark II and Vita Enamic, between 0% and 8% for Emax CAD and higher than 8% for Vita Suprinity and Lava Ultimate (Table 1). As a practical consequence, it could be assumed that the radiopaque restoration is evident, the limit between the restorations and the adjacent dental structures (enamel or dentine) is visible and the lack of continuity between the two surfaces is detectable.

However, due to the Mach effect, excessively radiopaque restorations may hinder a clinician’s ability to spot marginal defects [31]. The latter phenomenon is a visual illusion which enhances the contrast between two areas of different radiopacities, making the dark border area darker. This effect might be misinterpreted as pathology in certain situations [9].

Emax CAD was the only material that had radiopacity values within values of hard dental tissues, enamel and dentine. The values of radiopacity for Emax CAD were higher than those of dentine and lower than that of enamel, for all seven thicknesses. This may need a particular attention to distinguish the restoration in comparison with the adjacent structures.

However, diagnostic challenges arise in clinical situations when radiographic images present barely discernible radiopacity differences between dental tissues and restorative materials [32, 33]. This is even more challenging when treating patients with multiple pathologies and a high caries risk. Vita Mark II and Vita Enamic had radiopacity values lower that the dentine, in our study. This might involve that the use of radiopaque luting cement is essential to permit detection of possible pathology around CAD-CAM restorations when using these classes of materials.

The samples from the previous studies have greater thicknesses (1mm or 2mm) [20, 25, 26]. In a time when minimally invasive dentistry gains more and more terrain, there is a need for the assessments of smaller thicknesses as well (0.5mm). In our study, the effect of the thickness upon the radiopacity varies differently, according to the material considered. In the case of Vita Suprinity and Lava Ultimate, statistically significant differences between the radiopacity values appear among all thickness of the samples. The same outcome is noticed for the dental structures (enamel and dentine).

On the other hand, Vita Mark II, Emax CAD and Vita Enamic have no statistically significant differences between the radiopacity values at low thicknesses (1mm±0.25); instead differences between the radiopacity values were significant only from this dimension upwards. It is very often that the restorations have lower thicknesses.

Moreover, previous studies focused on 1, 2 or maximum 3 types of thicknesses [12, 20, 28]. Our results offer data regarding the radiopacity of an extended range of thicknesses and materials that cover a wide area of the treatment indications via CAD-CAM restorations.

When choosing the right chairside CAD-CAM milling material for prosthetic restorations, the radiopacity has to be taken into consideration, in correlation with the thickness of the future restoration, in order to prevent difficulties in detection of adjacent pathology.

With increasingly recommendations of minimally invasive restorations that involve chairside CAD-CAM, our results of radiopacity for different materials in seven different thicknesses, have considerable clinical significance. The importance of radiographic characteristics is indispensable in the clinical diagnosis of secondary lesions, restoration integrity control, marginal adaptation or misplaced fragments.

The clinical value of this study is enhanced by the objectivity of the radiographic examinations. All the data from one thickness of the same material were analyzed on the same radiography. The sample size of 3, chosen for this study, is the maximum number of samples that can be radiographed using one examination.

CONCLUSIONS

In the limitations of this study, it can be concluded that both material's type and thickness significantly affected the radiopacity. The chemical composition of the materials has its role in these radiographic characteristics and the amount of elements with high atomic numbers seems to be an important factor in the radiopacity of the materials.

Additionally, the radiodensity of CAD-CAM milling materials was different from that of the human dentin and enamel and the radiopacity of the tested materials increased as follows: Vita Enamic, Vita Mark II, dentine, Emax CAD, enamel, Lava Ultimate and Vita Suprinity.

Further studies should be conducted for other relevant thicknesses and new materials.

EXPERIMENTAL SECTION

Specimen Preparation

For each material, specimens were cut and prepared at 7 different thicknesses (0.5mm, 0.75mm, 1mm, 1.25mm, 1.5mm, 1.75mm, and 2mm) (3 specimens for each thickness) with a precision saw (IsoMet 1000 -

Buehler) using a diamond cutting blade for hard brittle materials and structured ceramics (IsoMet Diamond Wafering Blade, 5in, 15LC - Buehler) at a speed of 100 rotations per minute.

To reach the desired thickness (±0.01mm) the samples were measured with an electronic micrometer and polished using sandpaper (Klingspor) with increasing grits (P240, followed by P400, P800, P1000 and P1200).

In addition, four freshly extracted intact premolars were cut in slices, preparing sections of teeth in the same seven thicknesses (0.5mm, 0.75mm, 1mm, 1.25mm, 1.5mm, 1.75mm, and 2mm. A 1–10 mm thick aluminum step wedge with the purity of 99.52% Al with 0.22% Fe and 0.001% Cu was used as reference for the evaluation of the radiodensity of the materials under controlled radiographic conditions.

Radiograph images

The three samples with the same thickness of each material, the tooth slice with the corresponding thickness and the aluminum step wedges were placed on an intraoral sensor and radiographed using a dental X-ray machine (Intraoral X-Ray Soredex, Minray) at 70kV, 7mA, 0.04s with the target sensor at the distance of 30 cm. (Fig. 3)

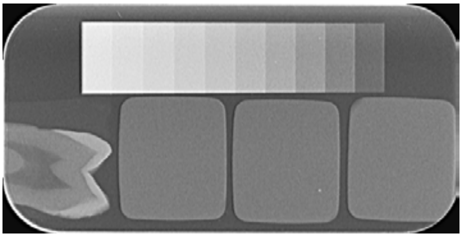

Figure 3. Radiography with 3 specimens of chairside CAD-CAM milling material (Lava Ultimate at 1mm thickness), 1 specimen of tooth structures and an aluminum step wedge

The mean gray value of each aluminum step wedge and selected materials were measured by outlining a region of interest using the equal-density area tool of the Image J software. For the 148 x 180 pixels’ area in each image type, the mean gray-scale value and standard deviation were calculated. The gray value of each specimen was recorded from the mean of the three readings. In a same procedure the enamel and the dentin slices were also measured in three different regions. The radiopacity values of the samples were expressed in terms of the equivalent thickness of aluminum per 1 mm unit thickness of material.

Statistical analysis

The processed data varied according to two parameters: slice thickness and type of material. Both univariate and multivariate analysis were performed.

In the univariate analysis the data were compared with the Anova test followed by Tukey HSD post-hoc analysis. Correlation analysis was determined by calculating the *r* Pearson correlation coefficients between radiopacity and slice thickness.

Multivariate analysis was performed by applying Anova two-way test. Each material was tested against enamel and dentine separately. The data were assessed for the influence of the slice thickness. The combined effect of the slice thickness and the difference between the material and the enamel or dentin was also reported.

The statistical significance was considered if $\alpha<0.05$. Statistical analysis was conducted in software package SPSS 25.0. Post hoc power analyses and sample size calculations were conducted using the software package GPower (Gpower v.3.1.9.2., Kiel, Germany), for each studied material.

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REFERENCES

1. P.R. Liu, *Compendium of Continuing Education in Dentistry,* **2005**, *26*, 507.
2. B. Culic, C. Gasparik, M. Varvara, C. Culic, C. Dragos, L. Silaghi-Dumitrescu, D. Dudea, *Studia UBB Chemia*, 2017, *62(1)*, 61.
3. T. Miyazaki, Y. Hotta, J. Kunii, S. Kuriyama, Y. Tamaki, *Dental Materials Journal*, **2009**, *28*, 44.
4. L.H.D. Silva, E. Lima, RBP. Miranda, S.S. Favero, U. Lohbauer, P.F. Cesar, *Brazilian Oral Research*, **2017**, *31*, 58.
5. J.H. Poorterman, I.H. Aartman, H. Kalsbeek, *Community Dentistry and Oral Epidemiology,* **1999**, *27*, 331.
6. I. Mjör, *Quintessence International,* **1998**, *29*, 313.
7. L.M.P. Salzedas, M.J.Q. Louzada, AB. Oliveira Filho, *Journal of Applied Oral Science*, **2006**, *14*, 147.

8. A.T. Hara, MC. Serra, F. Haiter-Neto, AL. Jr. Rodrigues, *American Journal of Dentistry,* **2001**, *14*, 383.
9. I. Espelid, A.B. Tveit, R.L. Erickson, S.C. Keck, E.A. Glasspoole*, Dental Materials,* **1991**, *7,* 114.
10. S. Nandini, *Journal of Conservative Dentistry,* **2010**, *13*, 184.
11. K.S. Oikarinen, T.M. Nieminen, H. Mäkäräinen, J. Pyhtinen, *International Journal of Oral and Maxillofacial Surgery,* **1993**, *22*, 119.
12. S. Saridag, D. Helvacioglu-Yigit, G. Alniacik, M. Özcan, *Dental Materials Journal,* **2015**, *34*,13.
13. J. Sabbagh, J. Vreven, G. Leloup, *Operative Dentistry,* **2004**, *29*, 677.
14. M.D. Turgut, N. Attar N., A. Onen, *Operative Dentistry,* **2003***, 28*, 508.
15. A. Amirouche-Korichi, M. Mouzali, DC Watts, *Dental Materials,* **2009**, *25*, 1411.
16. M. Taira, H, Toyooka, H. Miyawaki, M. Yamaki, *Dental Materials,* **1993**, *9*, 167.
17. International Standards Organization, “Test method for determining radio-opacity of materials”, ISO 13116:2014,1st ed, **2014**.
18. International Standards Organization, “Polymer-based restorative materials“, ISO 4049:2009, 4th ed, **2009**.
19. D.C. Watts, J.F. McCabe*. Journal of Dentistry,* **1999**, *27*, 73.
20. S. Hosney, M. Kandil, O. El-Mowafy, *International Journal of Prosthodontics*, **2016**, *29*, 271.
21. T. Hitij, A. Fidler, *Clinical Oral Investigations,* **2013**,*17*, 1167.
22. O.M. El-Mowafy, C. Benmergui, *Operative Dentistry,* **1994**, *19*, 11.
23. G. Pekkan, S. Saridag, N.C. Beriat, *Avicenna Journal of Dental Research,* **2011**, *35*, 2.
24. R.B. Fonseca, C.A. Branco, PV Soares, L. Correr-Sobrinho, F. Haiter-Neto, AJ. Fernandes-Neto, *et al*., *Clinical Oral Investigations,* **2006**, *10*, 114.
25. G. Pekkan, K. Pekkan, M.G. Hatipoglu, S.H. Tuna, *Journal of Prosthetic Dentistry,* **2011**, *106*, 109.
26. O.M. El-Mowafy, J.W. Brown, D. McComb, *Journal of Dentistry.,* **1991**, 19, 366.
27. F. Martinez-Rus, A.M. Garcia, A.H. de Aza, G. Pradies, *International Journal of Prosthodontics*. **2011**, *24*,144.
28. G. Pekkan, S. Saridag, K. Pekkan, D.Y. Helvacioglu, *Dental Materials Journal*., **2016**, *35*, 257.
29. Z. Ergücü, LS. Türkün, E. Önem, P. Güner, *Operative Dentistry*, **2010**, *35*, 436.
30. K.D. Jandt, AMO. Al-Jasser, K. Al-Ateeq, RW. Vowles, GC. Allen, *Dental Materials* **2002**,*18*, 429.
31. H.M. Berry Jr., *The Journal of the American Dental Association,* **1983**, *106*, 622.
32. H.B. Akerboom, C.M. Kreulen W.E van Amerongen, A. Mol, *Journal of Prosthetic Dentistry* **1993**, *70*, 351.
33. A.D. Cruz, R.G. Esteves, IAVP Poiate, P.P. Portero, S.M. Almeida, *Operative Dentistry* **2014**, *39*, 90.