Comparative evaluation of surface roughness of posterior primary zirconia crowns

Abstract

Aims This study compared the surface roughness of four commercially available posterior zirconia crowns on the occlusal surface and occlusal edge (buccal cusps) of first and second primary molars crowns.

Methods Surface roughness of 40 posterior primary zirconia crowns was measured using a mechanical stylus profilometer. Ten mandibular right molar crowns, consisting of five first primary molar and five second primary molar crowns from four brands - Cheng, Sprig EZCrowns, NuSmile and Kinder Krowns were selected. Mean roughness, Ra and mean roughness depth, Rz was measured for all crowns on two selected surfaces, occlusal surface and buccal cusp tips. Data was evaluated by one way analysis of variance and Tukey's honestly significant difference test at 0.05 level of significance.

Results Statistically significant difference was found in the mean Ra and Rz values at both selected surfaces among four prefabricated paedodontic zirconia crowns. Kinder Krowns had higher Ra and Rz values compared to Cheng, Sprig EZCrowns and NuSmile. Roughness profile of Kinder Krowns also showed a higher vertical scale values co-relating with higher Ra and Rz scores, irrespective of the measurements taken on relatively flat surface (occlusal edge) or deeper surface (occlusal pits and fissures).

Conclusions Mechanically polished posterior primary zirconia crowns had a smoother surface profile than the combined polished-glazed primary zirconia crowns. Cheng Crowns had the lowest mean Ra and Rz value although not statistically significant from Sprig EZCrowns and Nu Smile. Kinder Krowns had the highest mean Ra and Rz scores than other crown groups.

Keywords Surface roughness · Zirconia crowns · Primary tooth wear · Paediatric dentistry

Introduction

A shift in parental expectation towards more aesthetic restorations has led to the increased use of tooth-coloured restorative materials in paediatric dentistry (Zimmerman et al. 2009). Primary zirconia crowns have become a popular treatment alternative as a full coverage extra-coronal restorations due to their superior clinical properties and higher aesthetic standards (Mundhe et al. 2015). These crowns are monolithic zirconia reconstructions enriched with alumina and yttria, to provide them high flexural strength and hardness during heavy masticatory loads (Hjerppe et al. 2016). A major drawback with this material is its strong abrasive property, that can lead to the wear of opposing natural enamel during occlusal contacts (Jung et al. 2010; Janyavula et al. 2013).The enamel and dentine of primary teeth are much thinner and has lower mineral content in comparison to the permanent dentition (Nelson et al. 1980; Wilson and Beynon, 1989). Consequently, a question of special interest will be the wear behaviour of the primary tooth enamel when opposed to the extremely hard zirconia crowns, particularly in molar region with higher masticatory force.

Tooth wear by dental ceramics is closely related to the topographical features of a material especially surface roughness apart from ceramic microstructure and intra oral environment (Oh et al. 2002; Johnson-Harris et al. 2016).

Roughness can be defined as a complex role of irregularities or little indentations that characterises a surface and have influence on wetting, quality of adhesion, and brightness (Cerci et al. 2012). Different parameters such as mean roughness, Ra and mean roughness depth, Rz are used to evaluate the surface roughness. Ra parameter describes the overall roughness and is now considered as the main reported measurement method in studies conducted on surface roughness. Ra allows the quantification of the surface roughness and the value is higher for rough surfaces. Rz, also known as ten points mean roughness measures sum of the mean height of five highest peaks and the mean depth of five deepest profile valleys within the evaluation length (Zinelis et al. 2005; Field et al. 2010).

Devices used for characterising surface roughness can be categorized into three groups: optical profilometer, scanning probe microscopes and mechanical contact. Optical method uses a laser beam to illuminate the surface and measures the 3D profile of the material using contactless method (Yilbas and Hasmi, 1999; Sandoval et al. 2015). Atomic force microscope is an example for scanning probes which provides a three dimensional image and quantitative values allowing comparisons among different materials (Schaefer et al. 1995). The mechanical contact method shows roughness caused by polishing and mostly uses a stylus profilometer consisting of a stylus and its diamond pin. The radius of the diamond pin, the pressure applied and material hardness influences the measurement (Sandoval et al. 2015).

The roughness of primary zirconia crowns also has a major impact on the retention of oral micro-organisms. Studies done by Bollen et al. (1997) and Song et al. (2015) have demonstrated that a critical roughness threshold Ra value of 0.2µm or lower is required for intraoral hard surfaces, beyond which will leads to plaque accumulation on the restoration surface, resulting in an increased risk for caries and gingival inflammation.

Commercially, there are four different manufactures of primary zirconia crowns namely: NuSmile, Sprig EZCrowns, Cheng Crowns and Kinder Krowns. Each brand has a different process of manufacturing and finishing the crowns. Both laboratory and clinical studies have investigated the role of surface treatments of zirconia on antagonist tooth wear and showed that polished zirconia seems to have the lowest wear in contrast with the glazed surfaces (Mitov et al. 2012; Janyavula et al. 2013; Lawson et al. 2014). Consequently, it's imperative to check the surface profile of these crowns as their surface finishing methods greatly influence the antagonistic tooth wear. The aim of this study is (1) to evaluate the surface roughness of prefabricated primary zirconia molar crowns using mechanical stylus profilometer (2) to compare the occlusal surface and occlusal edge (buccal cusp tips) surface profile of these crowns.

Materials and Methods

No ethical approval was required from the institutional research ethical committee as the study neither involved human subjects/animals nor teeth.

Samples

A total of 40 unaltered primary posterior zirconia crowns were selected from four different manufacturers - NuSmile Crowns (Huston, Texas, USA), Sprig EZCrowns, formely EZ-Pedo crowns (Loomis, Calif., USA), Cheng Crowns (Exton, PA, USA) and Kinder Krowns (St. Louis Park, Minn., USA). These included five crowns of primary mandibular right first molar (no#84) and five crowns of primary mandibular right second molar (no#85) from each brand. All the crowns were stored in containers according to the manufacturer's instructions.

Experimental machine set up

The surface roughness of the selected primary zirconia crowns was evaluated using a mechanical surface roughness tester (Portable Surface Roughness Measurement Surftest SJ-400, Mitutoyo Corp, Kanagawa, Japan). The surface roughness tester machine was calibrated as per manufacturer's instructions prior to the experiment in order to yield the correct measurements. The method used for calibration was a simple procedure called "Ra calibration" using a precision roughness specimen of known Ra value of 2.94µm. The calibration was performed by measuring the precision roughness specimen and adjusting the difference, if any between the measured and reference value.

Measuring surface roughness

Initially a training session was given to the researcher to ensure the repeatability and reproducibility of the experiment. Subsequently the machine was calibrated and two trial specimens were tested by the same researcher to avoid any inter-observer error. To measure the roughness profile, a diamond stylus of tip radius 2µm/80µin and tip angle 60º was used. The stylus moved across the selected surface under a constant load of 5 N with a measuring speed of 0.5mm/s, returning speed of 1mm/s and a measuring range of 800 µm. All the 40 posterior primary prefabricated zirconia crowns were tested at two different surfaces, occlusal surface and occlusal edge (buccal cusps). Polyvinyl siloxane impression material was used to hold and stabilize the crown samples on a firm base, sufficiently isolated from all the sources of vibration (Fig. 1). The stylus of the machine was adjusted so that it would properly contact the measured surface of the crown. Additionally, the detector was checked to ensure that the stylus was parallel to the measured surface while it traversed performing the measurement. An effort was made to repeat the procedure at the same location thrice on the selected surfaces for all samples. After completing the measurement of each surface, the stylus was readjusted to the new position to start evaluating the next surface. The surface roughness tester recorded the roughness parameters - Ra, Rz and the roughness profile at the selected two surfaces for each crown.

The value of Ra was calculated from the graph by taking the arithmetic average of the absolute values of the profile heights over an evaluation length (Pan et al. 2017). Ra averages all peaks and valleys of the roughness profile and then neutralizes the few outlying points so that the extreme points have no significant impact on the final results. While, Rz was calculated by taking the sum of mean height of the five highest profile peak and mean depth of five deepest profile valley for each sampling length measured, from a line parallel to the mean line (Teicher et al. 2017). Since Rz averages the five highest peaks and five deepest valleys, the extremes have an impact on the final value.

The study was conducted by stating the null hypothesis that there was no significant difference in surface roughness of four brands of primary molar zirconia crowns on the occlusal surface and occlusal edge (buccal cusps). The data was evaluated using one way ANOVA and Tukey's HSD test and the statistical significance was accepted at $p < 0.05$.

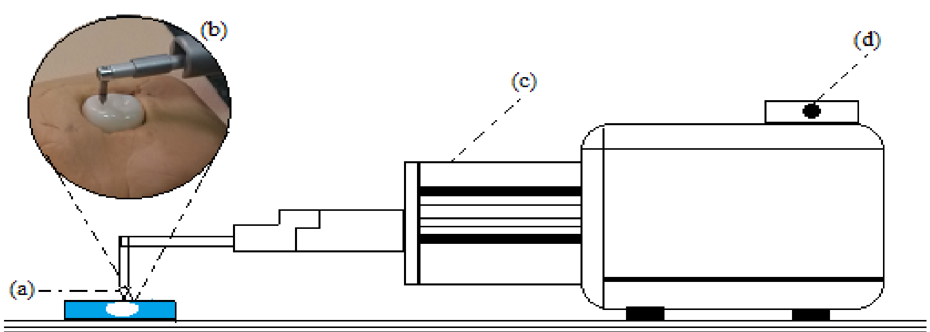

Fig. 1 Mechanical stylus profilometer and position of zirconia crown during surface roughness measurements (a) profilometer stylus (b) Zirconia crown held and stabilized using polyvinyl siloxone during measurements (c) detector of profilometer (d) Height of the detector adjusted by turning the up/down knob

Results

The mean Ra and Rz scores with the standard deviations for both the selected surfaces of primary mandibular right first and second molar zirconia crowns are included in Table 1 and Table 2 respectively.

The mean Ra on the occlusal surface and occlusal edge (buccal cusps)

There was a statistically significant difference in mean Ra values on the four different groups at $p<0.05$ level for the occlusal surface of first molar (F [3, 56] = 87.3, p = 0 .013) and second molar (F [3, 56] = 140.3, p = 0.013) crowns. On Tukey's HSD test the mean score for Kinder Krowns first molar (M = 0.70, SD = 0. 03) and second molar (M = 0.91, SD = 0.09) crowns presented a significantly different Ra scores compared to Cheng, Sprig EZCrowns and NuSmile crowns for the occlusal surface. A similar observation was also seen for the occlusal edges at $p<0.05$ level of first molar (F [3, 56] = 81.8, p = 0.013) and second molar (F [3, 56] = 65.1, p = 0.013) crowns. Tukey's HSD test revealed mean Ra scores of Kinder Krowns first molar (M = 1.04, SD = 0.26) and second molar (M = 0.60, SD = 0.12) to be significantly different from other three brands at occlusal edge.

Table 1 Ra value on the occlusal surface and occlusal edge (buccal cusps) for primary mandibular first and second molar zirconia crowns

Type of Zirconia Crowns	Occlusal Surface		Occlusal Edge (Buccal Cusps)	
	First molar Ra µm (SD)	**Second molar Ra µm (SD)**	**First molar Ra µm (SD)**	**Second molar Ra µm (SD)**
Cheng	0.34 (0.07)	0.36 (0.04)	0.30 (0.04)	0.28 (0.02)
Sprig EZCrowns	0.39 (0.09)	0.45 (0.07)	0.41 (0.08)	0.36 (0.03)
NuSmile	0.37 (0.06)	0.40 (0.06)	0.36 (0.06)	0.35 (0.05)
Kinder Krowns*	**0.70 (0.03)**	**0.91 (0.09)**	**1.04 (0.26)**	**0.60 (0.12)**

*(*Ra values showed a statistically significant difference on the four groups of primary zirconia crowns and Kinder Krowns had a significantly higher Ra value compared to Cheng, Sprig EZCrowns and NuSmile crowns at p <0 .05)*

The mean Rz on the occlusal surface and occlusal edge (buccal cusps)

There was a statistically significant difference in mean Rz values on the four different groups at $p<0.05$ level for the occlusal surface of first molar (F [3, 56] = 74.4, p = 0.013) and second molar (F [3, 56] = 104.1, p = 0.013). On Tukey's HSD test, mean score for Kinder Krowns first molar (M = 2.23, SD = 0.28) and second molar (M = 4.97, SD = 1.29) crowns presented a significantly different Rz scores compared to Cheng, Sprig EZCrowns and NuSmile crowns for the occlusal surface. A similar observation was seen for the occlusal edges at $p<0.05$ level of first molar (F [3, 56] = 76.7, p = 0.013) and second molar (F [3, 56] = 151.3, p = 0.013) crowns. Tukey's HSD test revealed mean Rz scores of Kinder Krowns first molar (M = 3.5, SD = 0.99) and second molar (M = 2.66, SD = 0.36) to be significantly different from other three brands at occlusal edge.

Table 2 Rz value on the occlusal surface and occlusal edge (buccal cusps) for primary mandibular first and second molar zirconia crowns

Type of Zirconia Crowns	Occlusal Surface		Occlusal Edge (Buccal Cusps)	
	First molar Rz µm (SD)	**Second molar Rz µm (SD)**	**First molar Rz µm (SD)**	**Second molar Rz µm (SD)**
Cheng	1.10 (0.08)	0.86 (0.12)	1.03 (0.09)	0.98 (0.14)
Sprig EZCrowns	1.20 (0.28)	1.30 (0.63)	1.30 (0.16)	1.56 (0.44)
NuSmile	1.53 (0.16)	0.90 (0.08)	1.10 (0.01)	1.16 (0.12)
Kinder Krowns*	**2.23 (0.28)**	**4.97 (1.29)**	**3.5 (0.99)**	**2.66 (0.36)**

(Rz values showed a statistically significant difference on the four groups of primary zirconia crowns and Kinder Krowns had a significantly higher Rz value compared to Cheng, Sprig EZCrowns and NuSmile crowns at p <0 .05)*

Roughness profiles of occlusal surface and occlusal edge (buccal cusps) of four different posteriors primary zirconia crowns

Figures 2 and 3 represents the graphs of occlusal surface roughness profiles of first and second primary molar zirconia crown of each brand while surface profiles at buccal cusp edges for both molar crowns of each manufacturer are shown in figures 4 and 5. The evaluation length used to measure roughness profile was 1.25mm (1250µm) having a sampling length of 0.25mm x 5. The central line in graph representing a value of 0 is called the mean line. The profiles above the mean line are called peaks and below the mean line are called valleys. All four categories of graphs demonstrated a roughness profile below the mean line. The occlusal surface and occlusal edge of first and second molar primary zirconia crown showed a variation in the vertical scale and not in the horizontal scale in all four roughness profile graphs. The variation in vertical scale has occurred as surface roughness parameters are measured from the peaks and valleys on the graph. Consequently a change in Ra and Rz values will be automatically adjusted by the profilometer on vertical scale of graph to show a higher or lower scores according to surface roughness of the zirconia crown. The horizontal scale remained unaltered as it is determined by the evaluation length.

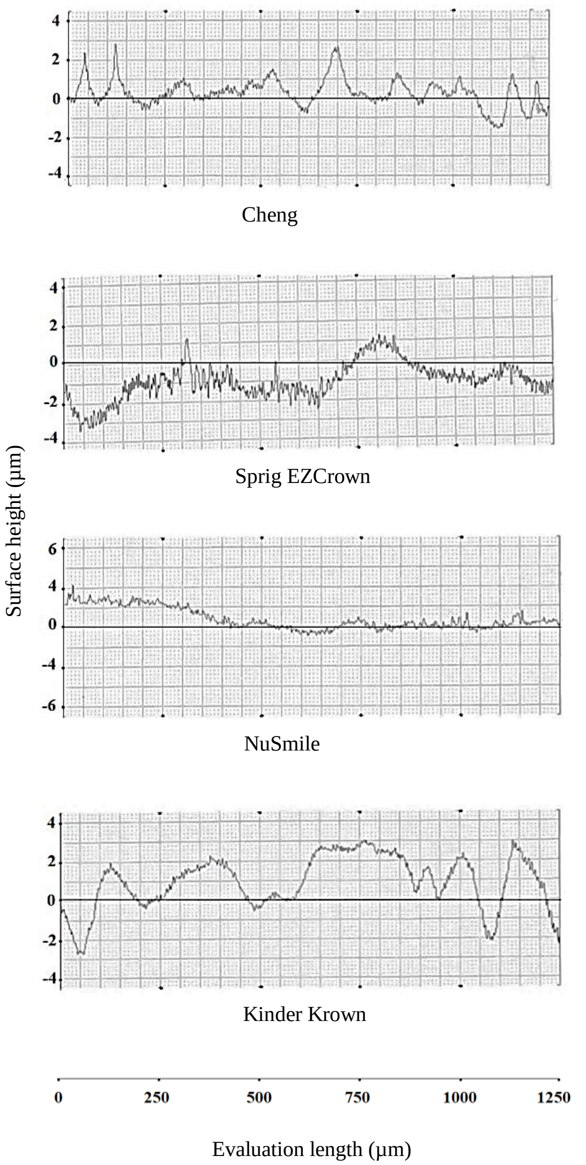

Fig. 2 Occlusal surface roughness profile of primary mandibular first molar zirconia crown

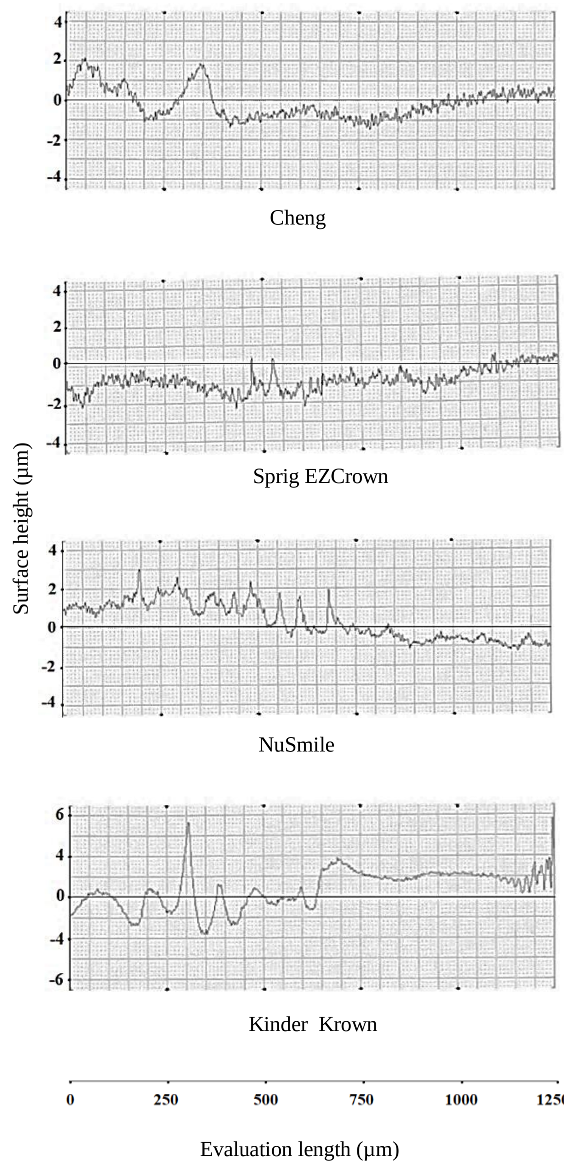

Fig. 3 Occlusal surface roughness profile of primary mandibular second molar zirconia crown

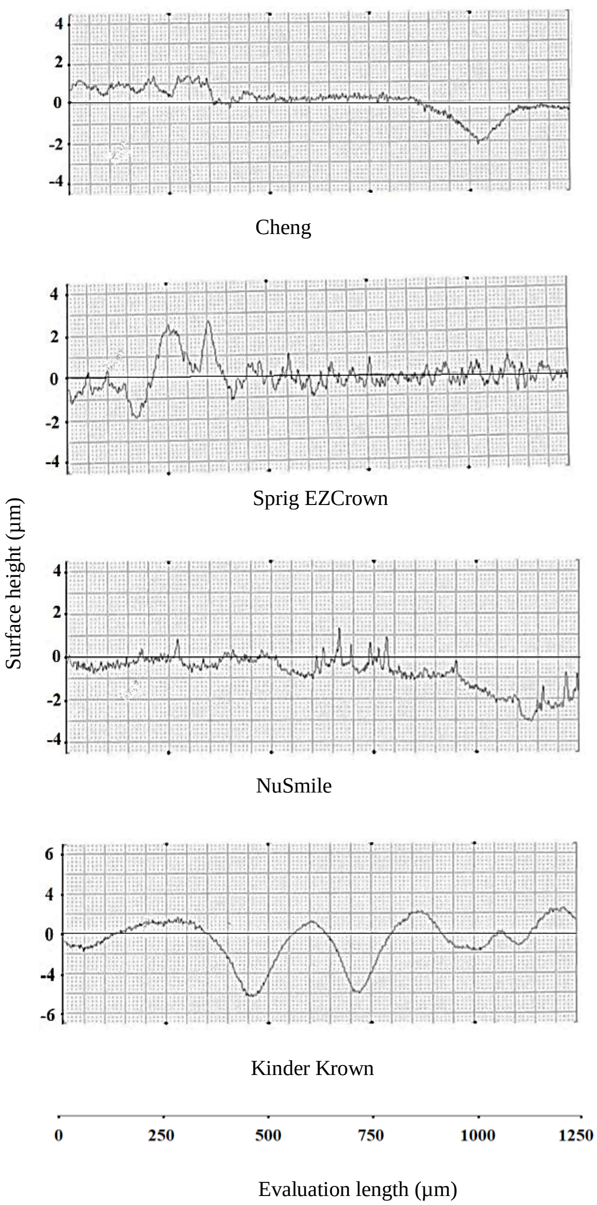

Fig. 4 Occlusal edge surface roughness profile of primary mandibular first molar zirconia crown

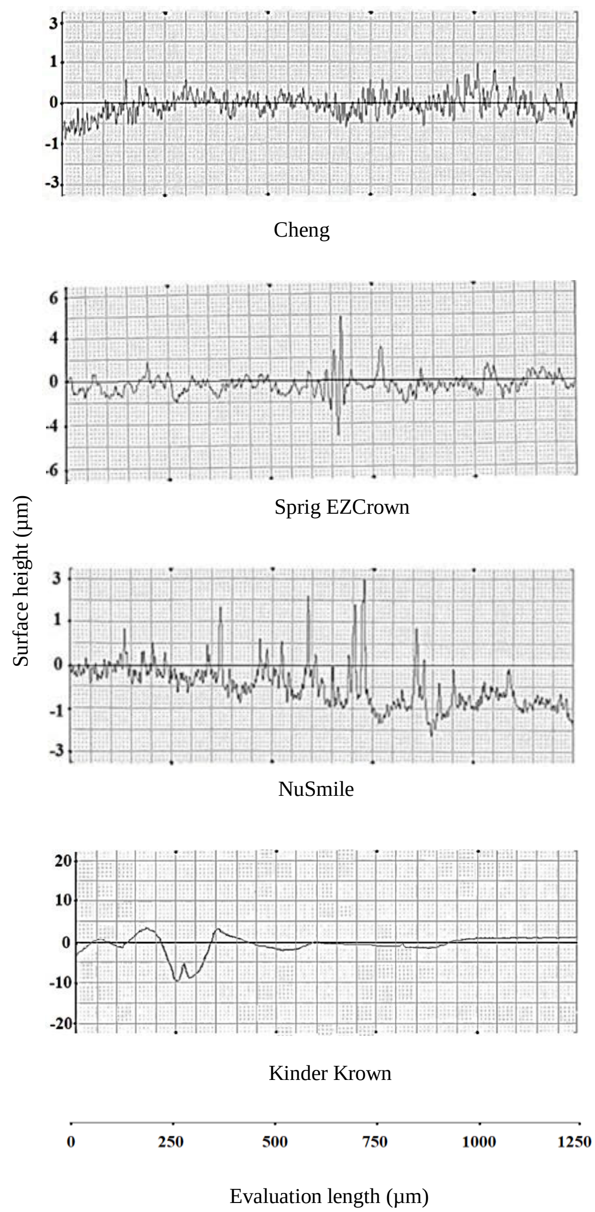

Fig. 5 Occlusal edge surface roughness profile of primary mandibular second molar zirconia crown

Discussion

The major concern with use of monolithic zirconia crown as a restorative material is the abrasive nature of material and surface roughness that can cause wear of the opposing natural enamel (Esquivel-Upshaw et al. 2017). Industrial polishing and finishing of zirconia crowns is done to create a smooth restoration by removing surface irregularities and excess material (Kontos et al. 2013). The type of surface finish of prefabricated primary zirconia crowns can be an influencing factor in tooth wear. NuSmile uses a proprietary injection-molded, sintered system with hand smoothing followed by mechanical polishing, Kinder Krowns are polished on the lingual surface and glazed on all other surfaces, while Sprig EZCrowns crowns are polished on the occlusal, lingual and glazed on the facial surfaces (Theriot et al. 2017). Cheng crown uses a proprietary six step polishing technique and hand-finishing of each crown after the milling process with mirror like smart satin polishing on all surfaces. (B.Cheng, [info@chengcrowns.com] email, June 6, 2018).

Several in vitro studies have shown that polished zirconia leads to less opposing enamel wear than glazed and these results were also confirmed by a recent systematic review (Passos et al. 2014). Esquivel-Upshaw et al. (2017) reported that polished zirconia showed less enamel wear in comparison to glazing. The initial roughness of glazed zirconia is higher than polished zirconia due a higher coefficient of friction. This phenomenon occurs due to the loss of 20 to 50µm thick glaze layer after cementation of crown leading to the exposure of underlying surface of ceramics which is most critical for producing wear. Additionally, particles from the glaze may also act as third-body abrasives in enamel wear process (Janyavula et al. 2013).

In present study, polished occlusal surfaces of Cheng, NuSmile and Sprig EZCrowns had a lower Ra and Rz values as compared to glazed Kinder Krowns. Although Cheng crowns showed the least Ra and Rz values among the three brands with polished occlusal surfaces (Cheng, NuSmile and Sprig EZCrowns), the difference was not statistically significant. Kinder Krowns with their glazed occlusal surface showed the highest Ra and Rz values which were statistically significant as compared to all other crowns. Manufacturing and finishing techniques of commercially available primary zirconia crowns can affect the surface topography. A previous study conducted by Theriot et al. (2017) evaluated a relationship between gloss and surface roughness of three paediatric zirconia crowns – NuSmile, Kinder Krowns and Sprig EZCrowns. They concluded that higher the mean gloss, lower is the mean surface roughness of a crown and vice versa. However, they compared only anterior zirconia crowns and excluded Cheng crowns which in the present study displayed the lowest mean Ra and Rz values. Furthermore, posterior crowns were selected in this study due to the greater compressive forces applied by them to the antagonist teeth.

Majority of studies have been performed on permanent dentition to observe the wear behaviour of monolithic zirconia restorations. Their results have concluded that zirconia crowns are associated with greater wear of opposed enamel than natural teeth (Jung et al. 2010; Stober et al. 2014; Passos et al. 2016). Reviews of past dental literature have also revealed that there are very limited clinical studies on posterior primary zirconia crowns where chance of tooth wear is higher. Walia et al. 2014 and Holsinger et al. 2016 found no tooth wear on opposing dentition with Zirkiz anterior paediatric crowns (Zirkiz, HASS Corporation, Gangwon-do, Korea) and anterior EZ-Pedo crowns respectively. All crowns in present study had the Ra value greater than the critical threshold of 0.2 µm, below which plaque microorganisms can adhere to tooth and restorative materials. It implies that all commercially available posterior primary zirconia crowns have highly smooth surfaces that resulted in reduced gingival inflammation. This is also reflected in few clinical studies conducted on primary zirconia crowns. Abdulhadi et al. (2017) carried out a randomized clinical split mouth trial comparing NuSmile ZR crowns and stainless steel crowns in primary molars. However they did not evaluate the opposing tooth wear but their results showed that NuSmile crowns had better gingival response and reduced plaque retention. Similar results were also obtained in another split mouth study conducted by Walia et al. (2015) where gingival response was found to be better and reduced plaque biofilm formation on NuSmile ZR molar crowns in comparison to stainless steel crowns. NuSmile fabricates their zirconia crowns by a proprietary injection molding and hand polishing technique that results in a smooth surface with lower Ra values.

Glazing produces a smooth and esthetic crown surface however, adjustment on occlusal and proximal areas of primary zirconia crown is sometime required for better fit. This procedure can remove the glaze layer, thereby increasing the surface roughness which can abrade upon attrition resulting in excessive wear on natural primary teeth enamel. Numerous studies have concluded that opposing tooth enamel showed lower mechanical wear if clinical adjustment of zirconia crowns by dental burs was followed by proper re-polishing procedures (Mitov et al. 2012; Lawson et al. 2014; Bandeira et al. 2017). Therefore to have a lower surface roughness, clinicians should always re-polish the adjusted prefabricated primary zirconia crowns in order to cement the crown on the prepared tooth surface.

In present study, the surfaces of posterior primary zirconia crowns to be assessed were selected on basis of their function during occlusion. The occlusal surface of primary mandibular molars zirconia crowns were selected as the central fossa in mandibular molars represented the contact points of upper maxillary molar tooth. The occlusal edges of buccal surface were also evaluated as buccal cusps constituted the functional cusp in mandibular molars (Khera et al. 1990). Since the selected surfaces of zirconia crown is not flat, the same location was measured repeatedly in order to have most probable values for uniformity when comparing different crowns brands. Stylus profilometer was selected to measure surface roughness profile of the crowns based on its feasibility and advantages: accuracy, ease of use and faster to save time. Optical profilometer has better speed, sensitivity characteristics and additionally it can measure the surface roughness from sub-micrometer range up to several tens of micrometers. However, the major drawbacks of optical method is the higher cost of the machine, complex algorithm and more meticulous setups involved during measurements (Arecchi et al. 1979).

It was observed that all selected crowns represented a roughness profile graph below the mean line. This might have occurred due to the presence of occlusal fossa, pits and fissures present on occlusal surface of primary zircona crowns. On the occlusal surface of primary first molar zirconia crown a higher vertical scale was seen for NuSmile crown irrespective of the fact that Ra and Rz value is significantly lower compared to Kinder krown. This has occurred due to a relatively flat graph with minimal peaks and valleys compared to the rest of the group. While on occlusal edge of first molar and second molar, and occlusal surface of second molar, a higher vertical scale is observed for Kinder krown, co-relating with higher Ra and Rz value. The value of vertical scale of graphs also co-relates better to Rz value than Ra, as Rz value increases either the corresponding peaks increases or the vertical scale of the graph increases. The greater co-relation of vertical scale of graphs to Rz value might have occurred due to the fact that Rz averages the five highest peak and five deepest valley. The same reason can be associated with the fact that Rz scores will be higher compared to Ra scores.

Manufacturers should aim to fabricate primary zirconia crowns with minimal possible Ra and Rz values as to reduce the opposing tooth wear and buildup of plaque biofilm. Results of present in vitro laboratory study may not co-relate exactly with the clinical situation. Therefore further clinical studies are required to support results of the in vitro study to know exact wear process of primary enamel when antagonized with primary zirconia crowns during occlusion.

Conclusion

All four commercially available posterior primary zirconia crowns have different surface profiles at two recorded surfaces. Cheng crowns had the smoothest occlusal surface and occlusal edges for both primary first and second molars. However, the values need to co-relate with clinical performance of these tooth coloured zirconia crowns in the oral cavity.

Compliance with ethical standards

Disclosure of potential conflicts of interest Author 1 declares that he has no conflict of interest. Author 2 declares that she has no conflict of interest. Author 3 declares that he has no conflict of interest.

Research involving Human Participants and/or Animals This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was not required as the study neither involved human subjects or teeth.

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