Quantitative and Qualitative Assessment of the Wear of Primary Enamel Against Three Types of Full Coronal Coverage

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Abstract

Aims: the objective of the study was to assess the wear of primary teeth against three types of crown coverage, both quantitavely and qualitatively. **Methods:** specimens of 30 extracted primary molars, were mounted against 10 specimens of zirconia crowns (group A), 10 specimens of preveneered stainless steel crowns (group B), and 10 extracted primary molars and 10 specimens of stainless steel crowns (group C) and were undergone in vitro wear testing using an abrasive machine. Measurement of the amount of weight loss was performed, in addition to a scanning electron microscopic examination of the worn enamel surfaces. **Results:** the greatest wear was recorded in zirconium specimens, and the lowest was in preveneered stainless steel crowns with a significant difference noted between the three groups ($p<0.001$).The micro-morphological wear characteristics revealed the most aggressive wear with complete loss of enamel structure in zirconium specimens. **Conclusions:** the zirconium crowns induced the most severe wear in primary molars, followed by stainless steel crowns, and the least wear was induced by preveneered stainless steel crowns.

Introduction

In primary dentition, large, multisurface carious lesions often advocate the use of a full-coverage restoration. Full coverage is likewise indicated in deep approximal cavities, circumferential caries, bilateral approximal cavities and history of root canal treatment [1-3]. The American Academy of Pediatric Dentistry also included children at high risk with anterior and/or posterior decay, and children requiring general anesthesia [4]. Historically, such restorations have been in the form of stainless steel crowns (SSCs).

Stainless steel crowns were introduced in 1947 by the Rocky Mountain Company [5] and popularized by Humphrey [6] in 1950. With only 0.2 mm metal thickness, these crowns are strong, resilient and malleable. They do not fracture and can be modified by crimping to ensure proper adaptation to the prepared tooth structure. Several studies have reported their superiority, in terms of better retention and less recurrent decay, relative to posterior composite resin and amalgam Class II restorations [7, 8]. Yilmaz et al. 2006 [9] showed that after two years of clinical use, the rate of perforations or dents of SSCs was only 12%. Also SSCs do not require complete isolation for bonding, as do crowns made of composite resin, nor do they require a preparation incorporating mechanical retention into the design, as do amalgam restorations.

Over the years, design modifications have simplified the fitting procedure and improved the morphology of the crown so that it more accurately duplicates the anatomy of primary molar teeth and thus, the SSC have become the standard for restoration of compromised pediatric dentition [3,10,11] and proved to function satisfactorily for over 36 months [12-14]. However, these crowns have one potential drawback owing to the unattractive color of the restorative material, which fails to meet the esthetic demands of patients' parents [9].

In order to address parents' esthetic wishes while effectively treating the decay, Preveneered Stainless Steel Crowns "PSSCs" were introduced in the early 1990's, initially developed for anterior teeth, but later for primary molars [15]. These are basically SSC with a tooth colored material (either a resin composite or porcelain) coating that is chemically or mechanically attached to the metal coping. The composite veneer covers the facial, occlusal, mesial, and distal aspects of the crown, and its thickness varies from 0.6 mm at the mesio-buccal to 1.5 mm at the occlusal surface in order to withstand the patient's occlusal forces [16]. These crowns combine the thin strong foundation of stainless steel, with the tooth colored appearance of composite or porcelain. As such, they can provide full coverage, durability, ease of placement and aesthetics.

Although PSSCs resolve some problems associated with SSCs, they still have several shortcomings; They require a greater reduction of tooth structure during preparation than is the case for traditional SSCs. The greater occlusal reduction can increase the risk of exposing vital pulp, necessitating vital pulpotomy, a procedure which [17] increases chair time and cost [18]. In addition, these crowns cannot always be crimped [19] to fit to the prepared tooth. Crimping could cause fracture or chipping of the esthetic facing [20]. Esthetic facing may also get fractured if exposed to uniaxial force and repair of fractured coatings may entail complete replacement [21, 22]. Fracture of an esthetic SSC can lead to loss of space in the developing pediatric dentition, as well as increased retention of plaque [23].

For decades, dentists had been limited to those two types of full coronal coverage for primary molars. However, the overwhelming need for lifelike restorations that mimic natural tooth [24] have driven the profession towards metal free whenever possible. In pediatric dentistry, this is represented through the use of zirconia crowns which are considered "cosmetic" in nature compared to other alternative crown materials.

Initially, zirconia crowns were predominantly fabricated with a zirconia coping layered or pressed with different types of porcelain. Recently, monolithic (full-contour) zirconia crowns have been developed, which are extraordinarily strong, and argued to be just as aesthetic as layered zirconia crowns [25, 26].

Initially, zirconia ceramic parts were just applied as the cores for manufacturing dental crowns in the form of bi-layer

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restorations, with veneer porcelain shells fused on them. Therefore, the porcelain made of softer amorphous silicates is the one that comes in contact with the natural tooth structure. Nowadays, by increasing the translucency of zirconia ceramics, full contour zirconia crowns are used to reestablish the posterior teeth. This type of ceramic restorations made of one single material by computer assistant design (CAD) and computer assistant machining (CAM) approach shows excellent mechanical properties. They were proved to be extraordinarily strong, and argued to be just as aesthetic as layered zirconia crowns [25, 26].

While using different restorations, it always remains the issue of avoiding or minimizing the pathological damage of natural teeth during the friction process between restorations and natural teeth. Surface wear of enamel is a physiological process going with the opposite movement between upper and lower teeth through mastication [27]. This natural process may be accelerated by the introduction of restorations whose properties of wear differ from those of the tooth structure that they slide against. Therefore and despite the truth that a constant wear of the entire dentition is possible independent of dental restorations, [28] it is desirable that wear behavior of restorative materials is similar to natural enamel, because excessive wear could lead to clinical problems such as damage of teeth occluding surfaces, loss of vertical dimension of occlusion, poor masticatory function associated with temporomandibular joint remodeling, dentine hypersinsivity or death of the tooth and at least may lead to esthetic impairment [29-31].

It is therefore of particular interest to carry out in vitro friction tests between dental materials and natural teeth [32-35]. With the increasing development of new esthetic full coverages for primary teeth, and the relatively short application time of the newest addition of zirconia crowns, there is an increasing demand for analyzing the resultant pathological tooth wear against these types.

Unfortunately, clinical documentation of enamel wear, when opposing restorative materials, is difficult to obtain. However, these data can be acquired from in vitro studies. Analyzing enamel wear after in vitro cycling and loading. The present study investigated the amount of wear in primary enamel, caused by zirconia crowns, preveneered stainless steel crowns and stainless steel crowns. In addition, the wear behaviors and patterns were characterized by examination using scanning electron microscopy.

Materials and Methods

A total of 30 extracted and/ or exfoliated primary molars were used in the present study, along with 10 SSCs[1], 10 preveneered SSCs (Heat treated composite resin facing)[2], and 10 zirconia crowns[3] *(Figure 1).*

Teeth were collected and stored in artificial saliva till used. The teeth with worn-out cusps or too sharp or fractured teeth were excluded. Specimens of the natural teeth were prepared by embedding the primary teeth in custom made standard acrylic resin mould (12 X12 mm) with only exposure of its occlusal surface to act as the antagonistic surface [36] *(Figure 2)*. Then, the specimens were weighed using digital balance to determine the initial weight in grams.

Thirty primary molars ready-made crowns were selected to be opponent to the selected extracted teeth and of corresponding sizes. They constitute the three tested groups: group A (zirconia), group B (PSSCs)and group C (SSCs). The test specimens were embedded in custom made standard acrylic resin mould with exposure of the occlusal surface *(Figure 3).*

A wear test was conducted using the custom made abrasive machine (Dental Biomaterials Department, Faculty of Dentistry, Alexandria University). Each test specimen was attached and fixed in the lower sample holder, while the natural teeth specimen was fixed in the upper sample holder to simulate the primary occlusion *(Figure 4).* The entire procedure was carried out to 200,000 cycles, which is equivalent to approximately one years of wear [37,38] in the presence of artificial saliva as chewing media. with occlusion pathway of 6mm.

The natural teeth specimens were weighed again using the same digital balance to get the weight difference. The percentage of weight loss was calculated and represented the amount natural teeth wear.

Scanning Electron Microscope

Representative samples of each group were analyzed by scanning electron microscopy. The sample were dried by

Figure 1. *Three types of preformed crowns used for primary molars (a). zirconium crown .(b). preveneered stainless steel crown.(c). stainless steel crown*

[1] Primary Stainless Steel Crowns. 3M ESPE Dental 3M Centre United Kingdom PLC Cain Road, Bracknell, RG12 8HT

[2] NuSmile Signature NuSmile Pediatric Crowns 3315 West 12th Street Houston, Texas 77008. USA

[3] NuSmile ZR NuSmile Pediatric Crowns 3315 West 12th Street Houston, Texas 77008. USA

ethanol then placed on filter paper. Specimens were coated with a thin layer of gold (10-30nm) and mounted on aluminum stubs using a conductive paste (carbon paste) and placed in the JFC-1100E ion sputtering device. When the vacuum was attained an argon leak was introduced into the system which caused discharge and vaporization of the gold that coat the specimen [39].

SEM Examination

After gold coating the specimen, they were examined by SEM JSM-5300, at operating magnifications ranging from X1.500 to X15.00 at 15 KV to study the surface of the enamel. Photomicrographs were taken to achieve comparison between the different study groups.

Results

An ideal dental restoration should have appropriate frictional coefficient with natural teeth in order to minimize wear of teeth. In the present study, the wear behaviors of primary enamel were studied against different coronal coverages.

The results showed that the degrees of wear of the antagonistic teeth based on the type of crown were greatest in group A, and lowest in group B, with a percentage weight loss of 2.11 ± 0.05, 1.57 ± 0.10, and 1.83 ± 0.07 in groups A,B and C respectively. The one-way ANOVA showed a statistically significant difference among the groups *(Table 1)*.

Results of Scanning Electron Microscopic examination

Representative SEM images reveal the microstructure of the worn primary enamel. The three types of crown coverage caused different wear patterns in the antagonistic enamel surfaces. Zirconia crowns antagonistic samples showed multiple cracking with complete absence of normal enamel rods and inter-rods appearance *(Figure 5)*. PSSC antagonistic samples showed multiple areas of atypical orientation of enamel rods, with the presence of areas of normal enamel *(Figure 6)*. SSC antagonistic samples showed multiple crater formation with hypomineralized erosive patterns *(Figure 7)*.

Discussion

Wear of teeth differs according to the different restorative materials used as antagonist. Ceramic reconstructions have become increasingly popular as a result of rising patient demands for more aesthetics. But the main disadvantage of ceramics is their high abrasiveness to opposing enamel [40-41].

The null hypothesis for this study was that there would be significant differences in quantitative wear and micromorphology of the worn surfaces of primary enamel caused by the different types of crown coverage. Although, more wear was expected from zirconia, because zirconia has

Table 1. *Comparison between the three studied groups according to the percentage of weight loss in each dental specimen.*

	Group A	Group B	Group C	p
%Weight loss	2.11 ± 0.05	1.57 ± 0.10	1.83 ± 0.07	$<0.001^*$
Sig. bet. grps	$p_1<0.001^*$, $p_2<0.001^*$, $p_3<0.001^*$			

Normally distributed data was expressed in mean ± SD and was compared using F test (ANOVA) and Post Hoc test (LSD)

p_1: p value for comparing between group A and group B

p_2: p value for comparing between group A and group C

p_3: p value for comparing between group B and group C

*: Statistically significant at $p \leq 0.05$

Figure 2. *Tooth specimen mounted on an acrylic mold.*

Figure 3. *Specimens of prefabricated crowns mounted in acrylic molds.*

Figure 4. *Attachments used for mounting antagonistic specimens in the abrasive machine.*

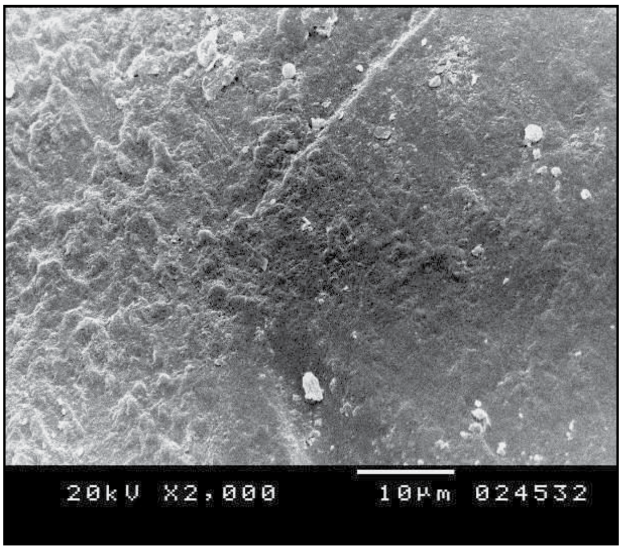

Figure 5 (a). *Scanning electron micrographs view of group "A" samples, showing sever erosion structure. Complete absence of normal enamel rods and inter-rods appearance [×2000].*

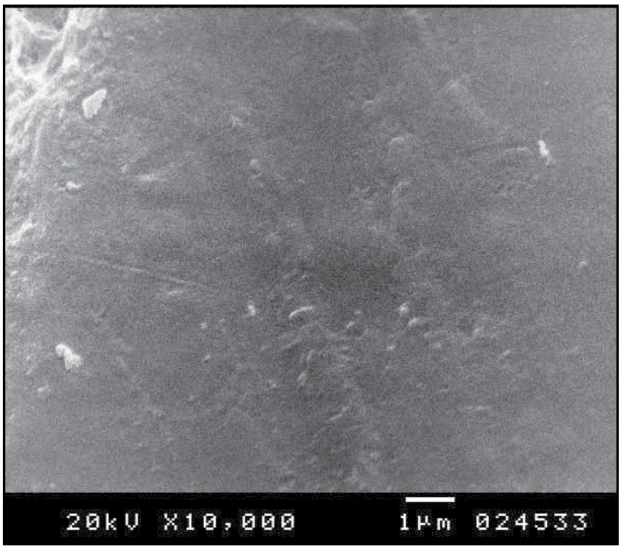

Figure 5 (b). *A higher magnification displaying evident loss of normal enamel structure [×10000].*

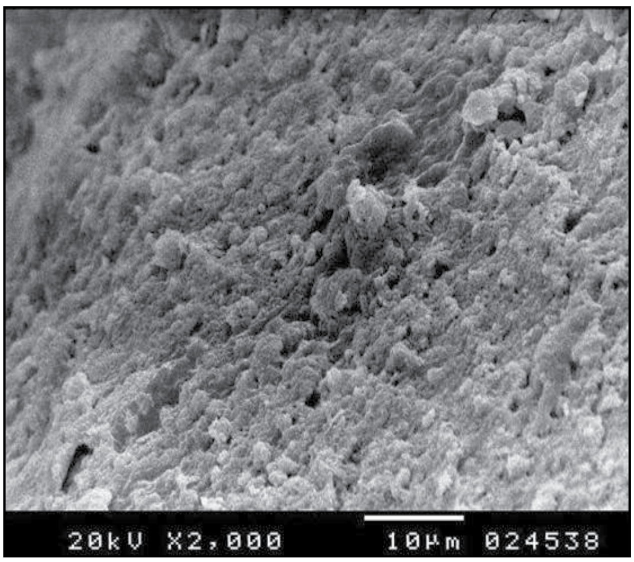

Figure 6 (a). *Scanning electron micrographs view of a sample of group "B", showing enamel structure with the fish scale appearance due to the presence of enamel rods surrounded by inter-rod enamel [×2000].*

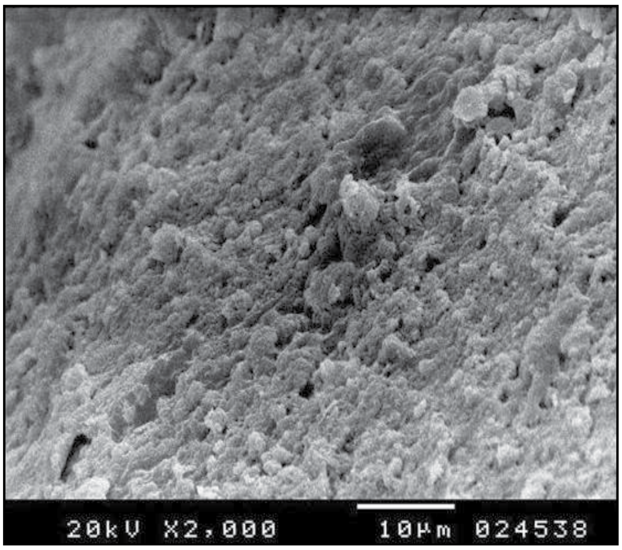

Figure 6 (b). *A Higher magnification showing areas of normal and others areas of atypical orientation of enamel rods and inter-rods crystals [×10000].*

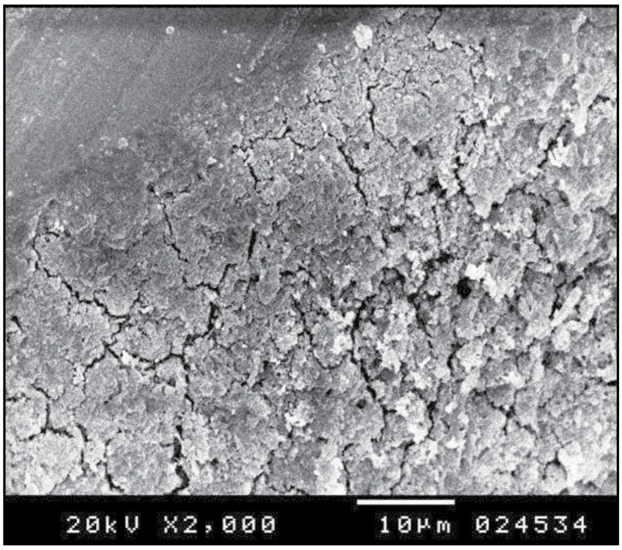

Figure 7 (a). *Scanning electron micrographs view of a sample of group "C", showing hyomineralized erosive patterns [×2000].*

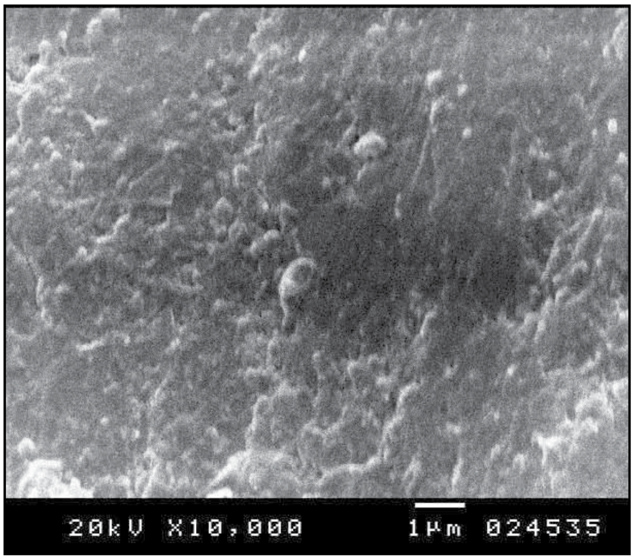

Figure 7 (b). *A higher magnification showing significant structural loss ,crater formation [× 10000].*

strong surface hardness, some investigations reported no wear traces for enamel against zirconia using a chewing simulation [42-43]. It was also reported that the wear rate of zirconia is bad in water and even under dry sliding conditions [44], similarly, some studies showed that the hardness of ceramics will not substantially lead to wear of the opposing teeth [45,46], that suggests that the hardness of the material alone is not a reliable predictor of the wear of opposing teeth.

An in vitro test was used to measure wear of primary tooth enamel, since direct measuring using clinical tooth wear indices is subjective and takes a long time to get significant results [47]. In addition, they measure tooth loss irrespective of etiology, thus they are not exclusive for mechanical wear.

This study also have investigated qualitatively the micro-morphological wear characteristics through surface morphology analysis imaged using scanning electron microscopy (SEM). The results revealed significant differences between the three types of crown coverage. This is most likely attributed to the differences in material composition and structure. Zirconia based crowns yielded the greatest wear of the three groups, which was confirmed by SEM micrograph. Since zirconium has the strongest surface hardness of the three materials [48, 49], and conventionally, greater hardness has been believed to cause more wear [50].

In addition, the rigidity and elastic modulus of zirconia are much higher than that of enamel, [51, 52] which may contributed to the great wear in group "A" caused by mechanical mismatching between zirconia and natural enamel. The mechanical properties of dental ceramics, such as zirconia with flexural strength >1000 MPa, elastic modulus 210 GPa, and hardness 10 GPa, are far above that of human enamel with flexural strength 280 GPa, elastic modulus 94 GPa and hardness 3.2 GPa [53, 54].

These results conform to previous studies [55-58] which investigated antagonistic wear of permanent teeth against zirconium crowns, and areas of chipped off enamel and plastic deformation were repeatedly seen on enamel surfaces.

In the present study, stainless steel crown by 3M – made of Ni-Cr alloy -yielded less amount of wear than zirconia. Similar results were obtained by WangL et al. [55] in which frictional coefficient was higher in zirconia than in Ni-Cr alloy specimens.

The least amount of wear in this study was obtained when PSSCs (group B) were used. These crowns are basically stainless steel crowns with laboratory processed composite coverings. Previous study by Olivera et al 2008 [59] also revealed that the opposing enamel wear to the laboratory-processed composite (Targis) was significantly less than that caused by various ceramic materials. In fact, softer materials wear more easily than harder materials when two materials come into contact with each other. Shimane et al 2010 [60] studied Wear of opposing teeth by five different types of indirect composite resins, the results revealed that all types of composite resins tested have lower hardness numbers than enamel(VHN 350), hence they induced minimal antagonistic enamel wear.

Since tooth wear includes two-bodied wear and three-bodied wear (wear in the presence of other mediators such as food and paste), [61] this study has the limitation of measuring only two-bodied wear. Therefore, long-term clinical follow-up will be required to accurately estimate the effect of different crown coverage materials on primary enamel structure, especially with the relatively short application time of the full contour zirconia crowns in primary teeth.

Conclusions

The zirconium crowns induced the most severe wear in primary molars, followed by stainless steel crowns, and the least wear was induced by preveneered stainless steel crowns.

Recommendations

Clinical in vivo studies are needed to estimate the long term performance of zirconia crowns in primary molars.

References

1. Schulte A. Ready-made crowns in the deciduous dentition. Schweiz Monatsschr Zahnmed 1999; 109: 242-261.

2. Pinkham JR. Pediatric Dentistry: infancy through adolescent, 3rd ed. Philadelphia, WB Saunders Co., 1999.

3. American Academy of Pediatric Dentistry reference manual 2007-2008. *Pediatric Dentistry*. 2007-2008; *29(7 Suppl)*: 1-271.

4. AAPD, Reference Manual, Clinical Guidelines V 33 / No 6 11/12

5. Pokorney RL. Stainless steel preformed crowns. Rev Dent Lib 1965; 15: 20-6.

6. Humphrey WP. Chrome alloy in children's dentistry. *St. Louis Dental Society*. 1950; **21**: 15-6.

7. Messer LB, Levering NJ. The durability of primary molar restorations: II.Observations and predictions of success of stainless steel crowns. *Pediatric Dentistry*. 1988; **10**: 81-5.

8. Roberts JF, Sherriff M. The fate and survival of amalgam and preformed crown molar restorations placed in a specialist paediatric dental practice. *Brazilian Dental Journal*. 1990; **169**: 237-44.

9. Yilmaz Y, Simsek S, Dalmis A, Gurbuz T, Kocogullari ME. Evaluation of stainless steel crowns cemented with glassionomer and resin-modified glass-ionomer luting cements. *American Journal of Dentistry*. 2006; **19**: 106-10.

10. Seale NS. The use of stainless steel crowns. *Pediatric Dentistry*. 2002; **24**: 501-5.

11. Croll TP, Epstein DW, Castaldi CR. Marginal Adaptation of Stainless Steel Crowns. *Pediatric Dentistry*. 2003; **25**: 249-52.

12. Salama FS , Alowyyed IS. Quality Assessment of Primary Molars Stainless Steel Crowns

13. Sharaf AA, Farsi NM. A clinical and radiographic evaluation of stainless steel crowns for primary molars. *Journal of Dentistry*. 2004; **32**: 27–33.

14. Heintze SD, Cavalleri A, Forjanic M, Zellweger G, Rousson V. Wear of ceramic and antagonist--a systematic evaluation of influencing factors in vitro. *Dental Materials*. 2008; **24**: 433-49.

15. Croll TP, Helpin ML. Preformed resin-veneered stainless steel crowns for restoration of primary incisors. *Quintessence International*. 1996; **27**: 309-13.

16. Fuks AB, Ram D, Eidelman E. Clinical performance of esthetic posterior crowns in primary molars: a pilot study. *Pediatric Dentistry*. 1999; **21**: 445-8.

17. Dean JA, Mack RB, Fulkerson BT, Sanders BJ. Comparison of electrosurgical and formocresol pulpotomy procedures in children. *International Journal of Paediatric Dentistry*. 2002; **12**: 177-82.

18. Fuks AB, Ram D, Eidelman E. Clinical performance of esthetic posterior crowns in primary molars: a pilot study. *Pediatric Dentistry*. 1999; **21**: 445-8.

19. Waggoner WF, Cohen H. Failure strength of four veneered primary stainless steel crowns. *Pediatric Dentistry*. 1995; **17**: 36-40.

20. Roberts C, Lee JY, Wright JT. Clinical evaluation of and parental satisfaction with resin-faced stainless steel crowns. *Pediatric Dentistry*. 2001; **23**: 28-31.

21. Beattie S; Taskonak B; Jones J; Chin J; Sanders B; Tomlin A; Weddell J. Fracture Resistance of 3 Types of Primary Esthetic Stainless Steel Crowns. *Journal (Canadian Dental Association)*. 2011; **77**: b90.

22. Ram D, Fuks AB, Eidelman E. Long-term clinical performance of esthetic primary molar crowns. *Journal of Pediatric Dentistry*. 2003; **25**: 582-4.

23. Randal RC, Vrijhoef MM, Wilson NH, Efficacy of Preformed metal crowns vs. amalgam restorations in primary molars. A systematic review. *Journal of the American Dental Association*. 2000; **131**: 337 - 43.

24. Morley J. The role of cosmetic dentistry in restoring a youthful appearance. *Journal of the American Dental Association*. 1999; **130**: 1166-72.

25. Guazzato M, Proos K, Quach L, et al. Strength, reliability and mode of fracture of bilayered porcelain/zirconia (Y-TZP) dental ceramics. *Biomaterials*. 2004; **25**: 5045-5052.

26. Vichi A, Louca C, Corciolani G, et al. Color related to ceramic and zirconia restorations: a review. *Dental Materials*. 2011; **27**: 97-108.

27. Smith BG, Bartlett DW, Robb ND. The prevalence, etiology and management of tooth wear in the United Kingdom. *Journal of Prosthetic Dentistry*. 1997; **78**: 367–72.

28. Sulong MZ, Aziz RA. Wear of materials used in dentistry: a review of the literature. *Journal of Prosthetic Dentistry*. 1990; **63**: 342–349.

29. Bani D, Bani T, Bergamini M. Morphologic and biochemical changes of the masseter muscles induced by occlusal wear: studies in a rat model. *Journal of Dental Research*. 1999; **78**: 1735–1744.

30. Oh WS, Delong R, Anusavice KJ. Factors affecting enamel and ceramic wear: a literature review. *Journal of Prosthetic Dentistry*. 2002; **87**: 451–459.

31. Ohlmann B, Trame JP, Dreyhaupt J et al. Wear of posterior metal-free polymer crowns after 2 years. *Journal of Oral Rehabilitation*. 2008; **35**: 782–788.

32. Li H, Zhou ZR. Wear behavior of human teeth in dry and artificial saliva conditions. *Wear*. 2002; **249**: 980–4.

33. Koczorowski R, Wloch S. Evaluation of wear of selected prosthetic materials in contact with enamel and dentin. *Journal of Prosthetic Dentistry*. 1999; **82**: 453–9.

34. Magne P, Won-Suck, Pintado MR. Wear of enamel and veneering ceramics after laboratory and chairside finishing procedures. *Journal of Prosthetic Dentistry*. 1999; **82**: 669–79.

35. Derand P, Vereby P. Wear of low-fusing dental porcelains. *Journal of Prosthetic Dentistry*. 1999; **82**: 460–3.

36. Fisher RM, Moore BK, Swartz ML, Dykema RW. The effects of enamel wear on the metal-porcelain interface. *Journal of Prosthetic Dentistry*. 1983; **50**: 627-31.

37. DeLong R, Sakaguchi RL, Douglas WH, Pintado MR. Thenwear of dental amalgam in an artificial mouth: a clinical correlation. *Dental Materials*. 1985; **1**: 238-42.

38. Sakaguchi RL, Douglas WH, DeLong R, Pintado MR. The wear of a posterior composite in an artificial mouth: a clinical correlation. *Dental Materials*. 1986; **2**: 235-40.

39. Hollenberg J, Erickson A. the scanning electron microscope: potential usefulness to biologists. *Journal of Histochemistry & Cytochemistry*. 1973; **21**: 109-30.

40. Heintze SD. How to qualify and validate wear simulation devices and methods. Dental Materials. 2006; 22: 712–34.

41. Cattell MJ, Clarke RL, Lynch EJ. The biaxial flexural strength and reliability of four dental ceramics—Part II. *Journal of Dentistry*. 1997; **25**: 409–14.

42. Guazzato M, Albakry M, Ringer SP et al. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. *Dental Materials*. 2004; **20**: 449–56.

43. Jung YS, Lee JW, Choi YJ et al. A study on the in-vitro wear of the natural tooth structure by opposing zirconia or dental porcelain. *Journal of Advance Prosthodontics*. 2010; **2**: 111–5.

44. Rosentritt M, Preis V, BehrMet al. Two-body wear of dental porcelain and substructure oxide ceramics. *Clinical Oral Investigation*. 2012; **16**: 935–43.

45. Dahl BL, Oilo G. In vivo wear ranking of some restorative materials. *Quintessence International*. 1994; **25**: 561–5.

46. Seghi RR, Rosenstiel SF, Bauer P. Abrasion of human enamel by different dental ceramics in vitro. *Journal of Dental Research*. 1991; **70**: 221–5.

47. Taylor DF, Bayne SC, Sturdevant JR et al. Correlation of M–L, Leinfelder, and USPHS clinical evaluation techniques for wear. *Dental Materials*. 1990; **6**: 151–153.

48. Sundh A, Sjogren G. Fracture resistance of all-ceramic zirconia bridges with differing phase stabilizers and quality of sintering. *Dental Materials*. 2006; **22**: 778–784.

49. Aboushelib MN, de Jager N, Kleverlaan CJ et al. Effect of loading method on the fracture mechanics of two layered all-ceramic restorative systems. *Dental Materials*. 2007; **23**: 952–959.

50. Jung1 YS, Lee JW, Choi YJ, Ahn JS, Shin SW, Huh JB. A study on the in-vitro wear of the natural tooth structure by opposing zirconia or dental porcelain. *Journal of Advance Prosthodontics*. 2010; **2**: 111-5.

51. Kosmac T, Oblak C, Jevnikar P, et al. The effect of surface grinding and sandblasting on flexural strength and reliability of Y-TZP zirconia ceramic. *Dental Materials*. 1999; **15**: 426–33.

52. White SN, Miklus VG, Mclaren EA, et al. Flexural strength of a layered zirconia and porcelain dental all-ceramic system. *Journal of Prosthetic Dentistry*. 2005; **92**: 125–31.

53. Manicone PF, Rossi Iommetti P, Raffaelli L. An overview of zirconia ceramics: basic properties and clinical applications. *Journal of Dentistry*. 2007; **35**: 819–26.

54. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. *Journal of Prosthetic Dentistry*. 2007; **98**: 389–404.

55. Wang L, Liu Y, Si W, Feng H, Tao Y, Mac Z. Friction and wear behaviors of dental ceramics against natural tooth enamel. *Journal of the European Ceramic Society*. 2012; **32**: 2599–2606.

56. Manicone PF, Rossi Iommetti P, Raffaelli L. An overview of zirconia ceramics: basic properties and clinical applications. *Journal of Dentistry*. 2007; **35**: 819-26.

57. Yan HH, Huang HR, Zhang ZM, Yang JL. Comparison of friction and abrasion between six different dental materials and natural enamel. *Shanghai Journal of Stomatology*. 2007; **16**: 311-4.

58. Hmaidouch R, Weigl P. Tooth wear against ceramic crowns in posterior region: a systematic literature review. *International Journal of Oral Science*. 2013; **5**: 183–190.

59. Olivera AB, Marques MM. Esthetic Restorative Materials and Opposing Enamel Wear. *Operative Dentistry*. 2008; **33**: 332-337.

60. Shimane T, Endo K, Zheng JH, Tyanagi T, Ohno H. Wear of opposing teeth by posterior composite resins —Evaluation of newly developed wear test methods. *Dental Materials Journal*. 2010; **29**: 713–720.

61. Harrison A. Wear of combinations of acrylic resin and porcelain, on an abrasion testing machine. *Journal of Oral Rehabilitation*. 1978; **5**: 111-5.