

Comparison of Wear Resistance Between Innovative Composites and Nano- and Microfilled Composite Resins

Sohrab Asefi,^{1*} Solmaz Eskandarion,² Farhad Shafiei,³ and Mohammad Javad Kharazifard⁴

¹Department of Orthodontic, Shahid Beheshti University of Medical Sciences, Tehran, IR Iran

²Dental Material Department, Dentistry School, Shahid Beheshti University of Medical Sciences, Tehran, IR Iran

³Dental Material Department, Dental School, Tehran University of Medical Sciences, Tehran, IR Iran

⁴Deputy of Research, School of Dentistry, Tehran University of Medical Sciences, Tehran, IR Iran

*Corresponding author: Sohrab Asefi, Department of Orthodontic, Shahid Beheshti University of Medical Sciences, Tehran, IR Iran. Tel: +98-2177794887, Fax: +98-219124265985, E-mail: sohrabasefi67@yahoo.comsohrabasefi67@gmail.com

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Abstract

Background: One of the most common causes of failure in class 2 posterior composite restorations is occlusal and proximal wear. Estelite composites used supra-nano monodispersing spherical fillers and a new photoinitiator, and the manufacturer claimed that the wear of these composites is less than 1 mm³ volumetric wear.

Objectives: Compare the wear resistance of new Estelite composites with that of other composites generations.

Materials and Methods: Thirty-five specimens were evaluated in five groups: three kinds of Estelite composites (Estelite Sigma Quick, Estelite Flow Quick, and Estelite Flow Quick High Flow), Filtek Z350, and Filtek Z250. All specimens were prepared in 25 mm disks and cured with laboratory light for 120 seconds (60 s for each side). Then, they were polished by 600 grit sand paper and stored for one week in distilled water at room temperature. We used a two-body abrasion test and the pin-on-disk method with distilled water as medium. All specimens were worn under 15 N load, 0.05 m/seconds speed, 100 m distance, and steatite ceramic balls antagonists. After wearing, we measured wear volume by calculating the wear track cross-section area with a profilometer and analyzed the data with the one-way analysis of variance (ANOVA) test.

Results: The wear amounts of the composites are as follows in order: Estelite sigma quick (1886.9 ± 518.5 μm²), Estelite flow quick (2708.9 ± 578.1 μm²), Estelite high flow (3206 ± 2445.1 μm²), Filtek Z350 (3840 ± 1963.4 μm²), and Filtek Z250 (4667.2 ± 2351.1 μm²). No statistical difference was found among the groups (P value > 0.05).

Conclusions: Estelite sigma quick composite had wear resistance similar to that of nano- and microfilled composites. Estelite flowable composites demonstrated similar wear resistance to that of a posterior composite.

Keywords: Dental Restoration Wear, Composite Dental Resin, Filtek Z350

1. Background

The demand for esthetic and tooth-colored restorations has increased in recent years. Dental composites introduced in the mid-1960s have great acceptance for their color match and excellent esthetics. Bonding to tooth structure, conservative cavity preparation, and low thermal conductivity are characteristics that appeal to dentists. Therefore, much effort has been made to improve the physical and mechanical properties of dental composites in previous years.

Wear resistance is necessary for posterior restoration (1). One of the most common reasons for the failure of posterior composites is occlusal and proximal wear of class 2 cavities (2). The failure rate for both class 1 and 2 restorations has been reported to be 40% - 50% (3).

High wear resistance for composites leads to increased lifetime, color stability, and function; conversely, low wear

resistance may lead to tooth migration, temporomandibular disorders, muscular tenderness, and periodontal diseases (4-7). Composite wear is influenced by filler type, volumetric percentage and filler size, resin matrix nature, and coupling agent.

New monomers, filler size, content change, and filler silanization are used for improving the physical and mechanical properties of dental composites (8-10).

In previous studies, the wear of older composite resins was 50 - 75 μm per year, but new composites have significantly lesser wear (10 - 20 μm per year) (11, 12). Using indirect composite restoration in the posterior region has also been suggested because of their probable higher mechanical properties. However, direct posterior composite restoration can provide similar durability based on clinical conditions (13). Moreover, operator performance, type of cavity, surface area of restoration, and quadrant of restoration can influence the final volume or vertical wear of

restoration (14, 15). Increasing the clinical performance of dental restorations by improving their mechanical properties by altering composite ingredients, such as filler type or size, is logical. Obtaining a better and shorter polymerization time may also lead to a higher degree of polymerization and subsequent better mechanical properties. Consequently, probable oral fluids or moisture contamination can decrease during composite polymerization because of operator inadequacy.

2. Objectives

We sought to determine whether Estelite composites (restorative and flowables), with an innovative filler type and through polymerization, have a significant wear resistance over other kinds of composite to prove their clinical performance as posterior restoration materials.

3. Materials and Methods

We conducted an experimental study and evaluated 35 specimens in 5 groups with 7 specimens included in each group. The sample size was calculated by Minitab software based on Yesil et al.'s study using one-way ANOVA test (16) and considering $\alpha = 0.05$, $\beta = 0.2$, standard deviation of 0.06, and 0.1 as the significant level of difference. The list of composites and their compositions is shown in Table 1. We used a two-body abrasion test with the pin-on-disk method for wear testing. The specimens were prepared in a disk shape 25 mm in diameter by using a two-piece aluminum mold with the gyrate space removed in the middle. The diameter of the disks was 25 mm because this size was the least applicable size for the pin-on-disk wear device. After packing the composite in the mold, we used two thin glass blocks for compressing and smoothing the surface; we light-cured each side of every disk for 40 seconds with a handheld LED light cure (Ultralume LED, Ultra-dent, USA) in an overlapping manner. After initial curing, all specimens were cured with a laboratory light-curing device (LabolightLV-Unknown Character, GC, Tokyo, Japan) for 60 seconds on each side to assure the proper degree of polymerization in each specimen. Then, all specimens were polished by 600 grit sandpaper manually by an operator to reduce variation in the applied force or speed of polishing. This procedure was used to assimilate the surface roughness of specimens. All specimens were stored in distilled water at room temperature for one week, similar to Yesil et al.'s study (16), to remove soluble ingredients. The specimens were worn by a pin-on-disk device in the Tribology laboratory of the metallurgy school of Tehran university (Figure 1). All specimens were worn by steatite

ceramic balls (Hoechst Ceram Tec, Wunsiedel, Germany, 5 mm in diameter) under 15 N force and 0.05 m/second velocity from 100 m distance. The inserted load was measured and controlled by the digital load cell of the pin-on-disk device. After the wear test, the wear volume of the specimens was evaluated by a profilometer (T8000, Hommelwerke, Germany). The profilometer measured the surface roughness and indirectly constructed a surface structure graph in the micrometer scale. The wear areas were shown by a groove in the section of each specimen by μm^2 (Figure 2). We calculated the surface area of each groove with a software device and measured the wear amount of each specimen by multiplying this amount to the circle perimeter of the wear track. Collected data were analyzed by the one-way ANOVA test, with 0.95 set as the level of significance and the PASW18 software.

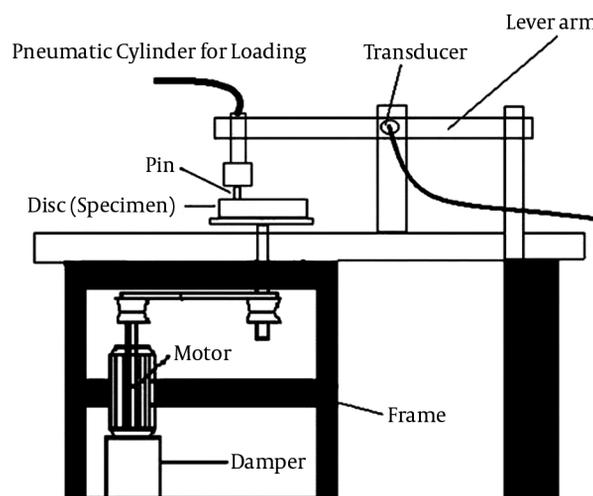


Figure 1. Schematic View of the Pin-on-Disk Wear Device

3. Results

Wear amounts were calculated by multiplying the perimeter of the circle with 22 mm diameter by the wear area of each specimen. The wear average is shown in Table 2.

After statistical analysis, no significant difference in wear was found among the composite groups. The Z250 group had the most and the Estelite sigma quick group had the least wear mean among the groups. However, none of the groups showed statistically significant wear ($P = 0.175 > 0.05$).

Table 1. Composite Groups Used in the Study

| Material Manufacturer | Classification | Organic Matrix | Type of Filler | Filler by Weight, % Volume | Mean Particle Size of Filler, μm | Shade | LOT | City/Country |
|---|----------------|-------------------------------|---|----------------------------|---|-------|---------|--------------|
| ESTELITE Σ Quick (Tokuyama Dental Corp.) | Nanofilled | Bis-GMA, UDMA, TEGDMA | Silica-zirconia supra-nano monodispersing spherical | 71 | 0.2 | OA2 | 066E11 | Tokyo/Japan |
| ESTELITE Flow Quick (Tokuyama Dental Corp.) | Nanofilled | Bis-GMA,UDMA, TEGDMA | Silica-zirconia supra-nano monodispersing spherical | 71 (53) | Microfiller: 0.4 Nanofiller: 0.07 | A3 | 019E11 | Tokyo/Japan |
| ESTELITE Flow Quick High Flow (Tokuyama Dental Corp.) | Nanofilled | Bis-GMA, TEGDMA | Silica-zirconia supra-nano monodispersing spherical | 68 (49) | Microfiller: 0.4 Nanofiller: 0.07 | OPA2 | 028EY0 | Tokyo/Japan |
| Filtek Z250 (3M ESPE) | Microfilled | Bis-GMA, UDMA, TEGDMA | Zirconia-silica cluster | 32 - 50 | 0.6 | A3 | N302745 | St. Paul/USA |
| Filtek Z350XT (3M ESPE) | Nanofilled | Bis-GMA, Bis-EMA UDMA, TEGDMA | Silica nanocluster, cluster | 57 | Nanocluster: 0.075 Cluster: 0.64 - 1.4 | A3 | N207516 | St. Paul/USA |

Table 2. Average Wear Volume (μm^2) of Each Group in Comparison With That of Other Groups ^{a,b}

| | Mean \pm SD |
|----------------|----------------------------|
| Sigma quick | 1886.9857 \pm 518.55611 |
| Flow quick | 2708.9714 \pm 578.14781 |
| High flow | 3206.0857 \pm 2445.16520 |
| Z350 | 3840.0714 \pm 1963.41687 |
| Z250 | 4667.2429 \pm 2351.18088 |
| Total (n = 35) | 3261.8714 \pm 1935.35078 |

^a n = 7.

^b P value = 0.066.

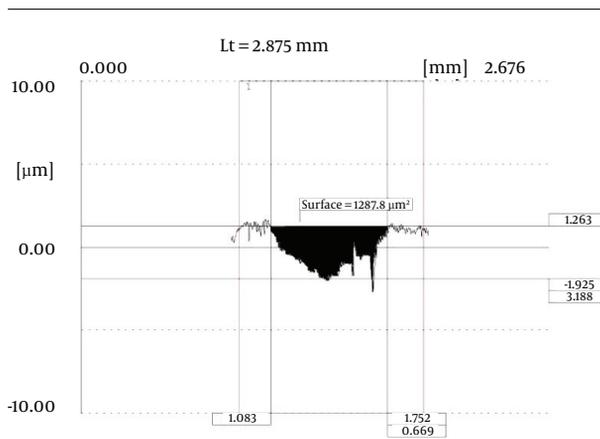


Figure 2. Surface Roughness Graph for Calculating the Worn Surface Area of Each Specimen

4. Discussion

Composite wear is a complex procedure that depends on many internal and external factors such as surface structure, contact stress, lubricant, temperature, wear duration (17), and material characteristics, including filler level, conditioning, degree of polymerization (18), operator performance, cavity type and surface area, and/or region of restoration (14, 15).

Wear conditions such as stress and temperature cannot be fully controlled in a real oral environment, but decreasing the operator mistakes and increasing the mechanical properties of composite materials can help to achieve higher clinical outcome and restoration durability. This outcome can be provided by altering the composite filler size or shape for better mechanical properties, by altering the composite polymerization process by increasing the degree of polymerization and subsequent increase in wear resistance of material, and by reducing the poly-

merization time to decrease the probable fluid contamination during the curing process, which is one of the operator mistakes (16).

Some of the most important factors of composite wear are the volume, size, and hardness of the fillers. The more the filler volume is, the less the composite wear. Increasing the filler content reduces the composite wear (19, 20). Clinical studies have revealed that composites with less than 60% filler volume have unacceptable wear pattern (21). A reduced filler size leads to better wear resistance. The larger the filler size is, the more matrix volume is removed from the composite structure (22). The critical distance for the inter-filler space is 0.1 - 0.2 μm (23). The extensive surface area of the ultrafine fillers is the limiting factor for filler size selection. Posterior hybrid composites with an average filler size between 1 μm and 3 μm and more than 60% filler volume have the best wear resistance (24). However, Yesil et al. (16) or Hahnel et al. (25) revealed that some microfilled composites could have higher wear resistance than other composite generations, but they could have lower filler content than the other microfilled or other composite generations with higher filler weights. A probable explanation for this phenomenon is the use of prepolymerized filler particles in these microfilled composites that play the role of filler particles that cannot be measured by routine thermogravimetric analysis by the manufacturer. Therefore, the overall filler content can be expected to be higher than the manufacturer's report.

Estelite sigma quick composite contains uniform silica-zirconia supra-nano monodispersing spherical fillers, with a filler size of 100 - 1000 nm and an average size of 200 nm. Their filler weight is 71%. Estelite flowable composites also have uniform silica-zirconia supra-nano monodispersing spherical fillers, but they contain micro- and nanofillers that are 0.4 and 0.07 μm , respectively. The filler weight in Estelite flow quick is 71% and that in Estelite flow quick high flow is 68% (26).

Filtek Z350XT is a nanofilled composite generation that uses silica nanocluster and cluster fillers that comprise 57% percent of its composite weight. Nanocluster fillers are 0.07 μm , and the clusters are 1.4 μm . Filtek Z250 is a microfilled composite that contains 0.6 μm zirconia-silica cluster fillers with a filler weight of 32% - 50% (27).

By decreasing the filler size and increasing the filler volume in composites, wear resistance of a material is expected to increase (20). This outcome was shown by the highest wear amount in Z250 and the least in Estelite sigma quick, which had the lowest and highest filler amount and size, respectively. Previous studies confirmed these results (19, 20, 23). However, this difference was not statistically significant.

Filler type is the most important characteristic of Estelite composites. They use supra-nano monodispersing spherical fillers. The filler particle diameter is relatively uniform (0.2 μm), and the filler size can be controlled by the filler synthesis reaction times. Stability of the esthetic features can be controlled by adjusting the refractive index in ambient light, which can be changed by balancing the material compounding ratio by controlling the particle diameter.

Other commercial dental composites use irregular fillers with different particle diameters (26). Other determinant factors are composite degree of conversion, type of coupling agent, amount of internal porosity, and final polishing. If the composite is polymerized more, it will resist wearing more (28). Moreover, previous reports showed that if a coupling agent is not used in the composite resin, composite wear will increase by 50% (22). We eliminated the degree of conversion influence as an interfering factor by providing a similar curing condition for all the experimental groups.

Estelite composites (Estelite sigma quick, Estelite flow quick, and Estelite flow quick high flow) use the rapid amplified photo polymerization initiator (RAP technology). Through this technology, camphorquinone molecules are recovered, and one of these molecules can create multiple free radicals that lead to decreased camphorquinone volume ratio to other conventional catalysts and decreased polymerization time (26).

Composite internal porosity increases wear in stress areas, and fine cracks are created at stress points. Therefore, the wear rate increases by increasing the size of restoration, locating more posterior arches, and delivering more occlusal forces. Light-cured composites show lesser internal porosity than self-cured composites, which lead to higher wear resistance. Therefore, we use light-cured composites for all groups.

Diamond or carbide burs can produce heat, destroy the organic matrix, and make the surface crack during polishing. In some related articles, the 600 grit sand paper was used (16), and thus we used this size of sand paper manually for all groups (22). As wear resistance evaluation is the main aim of our study, and we used 600 grit sand paper for the specimen surface flattening before the wear test. Although using a profilometer is the common way for evaluating surface roughness, it is also used routinely in a wear-measuring procedure in the literature for calculating the wear depth of materials (29, 30). The unworn area is the reference line for calculating the wear depth or the surface area of the wear groove in a profilometer scan. Surface roughness is not important for us in wear calculation.

Wear studies are controversial because of the different specimen preparations, wear tests, and wear result evalu-

ation procedures. Yap et al. (31) revealed that microfilled composites have lesser wear resistance than nanofilled and ormocer composites. Conversely, Yesil et al. (16) showed that nanofilled composites have similar wear resistance with microfilled composites. Hahnel et al. found similar results in their study (25). All these studies confirm our result that nano- and microfilled composite groups have similar wear resistance. Beun et al. (32) found that this similar wear pattern could be attributed to the possible presence of 40 nm nanofillers in microfilled composites. Leinfelder and Suzuki (33) agreed with Clelland et al. (34) that microfilled composites have more wear resistance than packable composites. Schultz et al. showed that nanofilled composites have better wear resistance than hybrid composites (35). Conversely, Suzuki et al. (36) revealed conflicting results between nanofilled and nanohybrid composites, with some nanohybrid composites having higher wear resistance than nanofilled and one nanohybrid composite having lesser wear resistance. They indicated that using a profilometer as a wear depth measuring device could make an error in determining surface roughness and wear depth, as the tip radius of the profilometer could be larger than the narrow spaces between the protruding filler particles after the wear test. This issue is one of our study's shortcomings. According to several studies, we can evaluate the surface roughness only by using a profilometer. In future studies, other methods for the evaluation of these materials may be used.

Therefore, weight or volume percentage, size, type, and filler distribution of examined composites are the most important factors affecting wear resistance in our study. The filler size of composites is between 0.2 μm and 0.6 μm in our study. Based on our results and a similar range of filler range size, we can justify similar wear resistance between micro- and nanofilled composites.

4.1. Conclusions

Unlike the manufacturer's claims that the Estelite sigma quick composite has higher wear resistance than other composite products, it resists wearing similar to micro- or nano-filled composites. Although RAP technology and mono-dispersing spherical fillers have improved the mechanical and esthetical properties, our results show that they are not clinically significant except in Estelite flowable composites. These flowable composites show similar wear resistance to posterior composites, which are especially useful for fissure sealant or preservative restorative therapies (PRR) in primary or permanent posterior teeth.

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Footnotes

Conflict of Interest: We confirm that this publication has no known conflicts of interest.

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References

- Roulet JF. The problems associated with substituting composite resins for amalgam: a status report on posterior composites. *J Dent.* 1988;**16**(3):101-13. [PubMed: 3045171].
- Mazer RB, Leinfelder KF, Russell CM. Degradation of microfilled posterior composite. *Dent Mater.* 1992;**8**(3):185-9. [PubMed: 1521708].
- Raskin A, Michotte-Theall B, Vreven J, Wilson NH. Clinical evaluation of a posterior composite 10-year report. *J Dent.* 1999;**27**(1):13-9. [PubMed: 9922607].
- Carlsson GE, Egermark I, Magnusson T. Predictors of signs and symptoms of temporomandibular disorders: a 20-year follow-up study from childhood to adulthood. *Acta Odontol Scand.* 2002;**60**(3):180-5. [PubMed: 12166913].
- John MT, Frank H, Lobbezoo F, Drangsholt M, Dette KE. No association between incisal tooth wear and temporomandibular disorders. *J Prosthet Dent.* 2002;**87**(2):197-203. [PubMed: 11854677].
- Seligman DA, Pullinger AG, Solberg WK. The prevalence of dental attrition and its association with factors of age, gender, occlusion, and TMJ symptomatology. *J Dent Res.* 1988;**67**(10):323-33. [PubMed: 3049715].
- Mitchem JC, Gronas DG. The continued in vivo evaluation of the wear of restorative resins. *J Am Dent Assoc.* 1985;**111**(6):961-4. [PubMed: 2933440].
- Tabatabaee MH, Mahdavi H, Zandi S, Kharrazi MJ. HPLC analysis of eluted monomers from two composite resins cured with LED and halogen curing lights. *J Biomed Mater Res B Appl Biomater.* 2009;**88**(1):191-6. doi: 10.1002/jbm.b.31167. [PubMed: 18618467].
- Ruddell DE, Maloney MM, Thompson JY. Effect of novel filler particles on the mechanical and wear properties of dental composites. *Dent Mater.* 2002;**18**(1):72-80. [PubMed: 11740967].
- Koottathape N, Takahashi H, Iwasaki N, Kanehira M, Finger WJ. Two- and three-body wear of composite resins. *Dent Mater.* 2012;**28**(12):1261-70. doi: 10.1016/j.dental.2012.09.008. [PubMed: 23083806].
- Leinfelder KF, Taylor DF, Barkmeier WW, Goldberg AJ. Quantitative wear measurement of posterior composite resins. *Dent Mater.* 1986;**2**(5):198-201. doi: 10.1016/S0109-5641(86)80013-6. [PubMed: 3468024].
- Bayne SC, Heymann HO, Swift EJ. Update on dental composite restorations. *J Am Dent Assoc.* 1994;**125**(6):687-701. [PubMed: 8014334].
- Cetin AR, Unlu N. Clinical wear rate of direct and indirect posterior composite resin restorations. *Int J Periodontics Restorative Dent.* 2012;**32**(3):e87-94. [PubMed: 22408783].
- Palaniappan S, Bharadwaj D, Mattar DL, Peumans M, Van Meerbeek B, Lambrechts P. Nanofilled and microhybrid composite restorations: Five-year clinical wear performances. *Dent Mater.* 2011;**27**(7):692-700. doi: 10.1016/j.dental.2011.03.012. [PubMed: 21529923].

15. Palaniappan S, Elsen L, Lijnen I, Peumans M, Van Meerbeek B, Lambrechts P. Nanohybrid and microfilled hybrid versus conventional hybrid composite restorations: 5-year clinical wear performance. *Clin Oral Investig*. 2012;**16**(1):181-90. doi: [10.1007/s00784-010-0500-0](https://doi.org/10.1007/s00784-010-0500-0). [PubMed: [21221678](https://pubmed.ncbi.nlm.nih.gov/21221678/)].
16. Yesil ZD, Alapati S, Johnston W, Seghi RR. Evaluation of the wear resistance of new nanocomposite resin restorative materials. *J Prosthet Dent*. 2008;**99**(6):435-43. doi: [10.1016/j.prosdent.2008.08.016](https://doi.org/10.1016/j.prosdent.2008.08.016). [PubMed: [18514665](https://pubmed.ncbi.nlm.nih.gov/18514665/)].
17. Sarkar AD. Dental tribology. Friction and Wear. London: Academic Press; 1980.
18. Condon JR, Ferracane JL. In vitro wear of composite with varied cure, filler level, and filler treatment. *J Dent Res*. 1997;**76**(7):1405-11. [PubMed: [9207774](https://pubmed.ncbi.nlm.nih.gov/9207774/)].
19. Foroutan F, Javadpou J, Atai M, Rezaie HR. Mechanical Properties of Dental Composite Materials Reinforced With Micro and Nano-Size Al₂O₃ Filler Particles. *Iran J Mater Sci Eng*. 2011;**8**(2):25-33.
20. Mousavinasab SM. Effects of Filler Content on Mechanical and Optical Properties of Dental Composite Resin. INTECH Open Access Publisher; 2011.
21. Willems G, Lambrechts P, Braem M, Vanherle G. Three-year follow-up of five posterior composites: in vivo wear. *J Dent*. 1993;**21**(2):74-8. [PubMed: [8473595](https://pubmed.ncbi.nlm.nih.gov/8473595/)].
22. O'Brein WJ. Dental Materials and their Selection. Dental Materials and their Selection. 3rd. Chicago: Quintessence; 2002.
23. Jorgensen KD. Restorative resins: abrasion vs. mechanical properties. *Scand J Dent Res*. 1980;**88**(6):557-68. [PubMed: [6941370](https://pubmed.ncbi.nlm.nih.gov/6941370/)].
24. Soderholm KJ, Richards ND. Wear resistance of composites: a solved problem?. *Gen Dent*. 1998;**46**(3):256-63. [PubMed: [9693539](https://pubmed.ncbi.nlm.nih.gov/9693539/)].
25. Hahnel S, Schultz S, Trempler C, Ach B, Handel G, Rosentritt M. Two-body wear of dental restorative materials. *J Mech Behav Biomed Mater*. 2011;**4**(3):237-44. doi: [10.1016/j.jmbbm.2010.06.001](https://doi.org/10.1016/j.jmbbm.2010.06.001). [PubMed: [21316610](https://pubmed.ncbi.nlm.nih.gov/21316610/)].
26. Technical Report . Supra-nano-fill Dental Restorative Material. In: Dental T, editor. (Estelite@ sigma Quick). ; . .
27. Laboratory MDP. Filtek™ Z250 Universal Restorative System Technical Product Profile. St. Paul, MN, USA.: Laboratory, MDP; .
28. Ferracane JL, Mitchem JC, Condon JR, Todd R. Wear and marginal breakdown of composites with various degrees of cure. *J Dent Res*. 1997;**76**(8):1508-16. [PubMed: [9240388](https://pubmed.ncbi.nlm.nih.gov/9240388/)].
29. Cao L, Zhao X, Gong X, Zhao S. An in vitro investigation of wear resistance and hardness of composite resins. *Int J Clin Exp Med*. 2013;**6**(6):423-30. [PubMed: [23844265](https://pubmed.ncbi.nlm.nih.gov/23844265/)].
30. Kadokawa A, Suzuki S, Tanaka T. Wear evaluation of porcelain opposing gold, composite resin, and enamel. *J Prosthet Dent*. 2006;**96**(4):258-65. doi: [10.1016/j.prosdent.2006.08.016](https://doi.org/10.1016/j.prosdent.2006.08.016). [PubMed: [17052470](https://pubmed.ncbi.nlm.nih.gov/17052470/)].
31. Yap AU, Tan CH, Chung SM. Wear behavior of new composite restoratives. *Oper Dent*. 2004;**29**(3):269-74. [PubMed: [15195726](https://pubmed.ncbi.nlm.nih.gov/15195726/)].
32. Beun S, Glorieux T, Devaux J, Vreven J, Leloup G. Characterization of nanofilled compared to universal and microfilled composites. *Dent Mater*. 2007;**23**(1):51-9. doi: [10.1016/j.dental.2005.12.003](https://doi.org/10.1016/j.dental.2005.12.003). [PubMed: [16423384](https://pubmed.ncbi.nlm.nih.gov/16423384/)].
33. Leinfelder KF, Suzuki S. In vitro wear device for determining posterior composite wear. *J Am Dent Assoc*. 1999;**130**(9):1347-53. [PubMed: [10492543](https://pubmed.ncbi.nlm.nih.gov/10492543/)].
34. Clelland NL, Villarroel SC, Knobloch LA, Seghi RR. Simulated oral wear of packable composites. *Oper Dent*. 2003;**28**(6):830-7. [PubMed: [14653301](https://pubmed.ncbi.nlm.nih.gov/14653301/)].
35. Schultz S, Rosentritt M, Behr M, Handel G. Mechanical properties and three-body wear of dental restoratives and their comparative flowable materials. *Quintessence Int*. 2010;**41**(1):e1-10. [PubMed: [19907723](https://pubmed.ncbi.nlm.nih.gov/19907723/)].
36. Suzuki T, Kyoizumi H, Finger WJ, Kanehira M, Endo T, Utterodt A, et al. Resistance of nanofill and nanohybrid resin composites to toothbrush abrasion with calcium carbonate slurry. *Dent Mater J*. 2009;**28**(6):708-16. [PubMed: [20019422](https://pubmed.ncbi.nlm.nih.gov/20019422/)].