TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2020.19067

Original Article

In Vitro Evaluation of Direct and Indirect Effects of Sonic and Ultrasonic Instrumentations on the Shear Bond Strength of Orthodontic Brackets

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Cite this article as: Oduncuoğlu BF, Yamanel K, Şahinoğlu Koçak Z. In Vitro Evaluation of Direct and Indirect Effects of Sonic and Ultrasonic Instrumentations on the Shear Bond Strength of Orthodontic Brackets. Turk J Orthod 2020; 33(1): 37-42.

ABSTRACT

Objective: Sonic and ultrasonic instrumentations generate vibrations that may influence debonding characteristics. The objective of this in vitro study was to assess the direct and indirect effects of sonic and ultrasonic periodontal instrumentations on the shear bond strength (SBS) and the adhesive remnant index (ARI) scores of metallic orthodontic brackets.

Methods: Metallic brackets were bonded to 75 extracted mandibular central incisors that were embedded in acrylic resin. Instrumentations around the bracket base performed with ultrasonic (UltrasonicB group, n=15) and sonic (SonicB group, n=15) scalers were used to evaluate the direct effects on the SBS of brackets. Lingual surface instrumentations with ultrasonic (UltrasonicL group, n=15) and sonic (SonicL group, n=15) scalers were performed to assess the indirect effects. The control group (n=15) did not have any treatment. Instrumentations were performed for 30 s with 0° scaler tip angulations with settings recommended by manufacturers. The SBS of the brackets tested with a universal testing machine and ARI scores were recorded. Data were analyzed by Kruskal–Wallis and Mann–Whitney U tests.

Results: The mean SBS of the control group was significantly higher than that of the UltrasonicB and SonicB groups (p=0.008). The UltrasonicL and SonicL group instrumentations also decreased the SBS, although the difference was statistically insignificant. UltrasonicB instrumentations caused significantly higher frequency of ARI scores than the control group.

Conclusion: The decrease of the SBS of metallic brackets indicates the influence of ultrasonic and sonic instrumentations on the breakage behavior at the bracket–resin interface. Instrumentations around the bracket base should be conducted with caution to decrease the bond failure risk of metallic brackets.

Keywords: Ultrasonics, orthodontic brackets, periodontics, dental bonding, dental prophylaxis

INTRODUCTION

Orthodontic treatment with fixed appliances increases the plaque retention areas and impairs the appropriate oral hygiene measures by patients. Changes in oral microbiota can be detected that might be associated with the observed white spot lesions, carie, and periodontal problems (1-5). In addition to increased plaque accumulation, patients often exhibit gingival enlargements, bleeding, and calculus formation during the orthodontic treatment (6). Although the importance of oral hygiene measures was emphasized to all patients before and during the orthodontic treatment, the necessity of professional oral hygiene procedures, including plaque removal and scaling that were accomplished by manual and power-driven instrumentations, is observed frequently for patients with fixed appliances.

Power-driven instruments, which have been proven to have less treatment time and reduce the subgingival biofilm to the same extent compared with manual instrumentation, vary in their clinical efficiency and mechanism

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Received: May 31, 2019
Accepted: August 25, 2019

of action (7-9). In sonic scalers, air-turbine-generated vibrations range between 2 and 6 kHz/3000 and 8000 cycles/s, and scaler tip oscillates almost circularly (10-12). In piezoelectric ultrasonic instruments, a quartz crystal that was inserted into the handpiece is provided with high-frequency alternating current causing dimensional changes of crystal generating the vibrations. The scaler tip vibration is linear, and the vibration frequency ranges between 25 and 42 kHz/25,000 and 50,000 cycles/s (10-12). In addition to physical action of oscillating tip, cavitational effect and acoustic microstreaming may influence the removal of deposits from the root surface (13, 14). The direct effect of oscillating scaler forms on surface contact with the tip and the influence of vibrations transmitted through the tooth defines the indirect effect of power-driven instrumentations. During ultrasonic scaling procedures, transmission of acoustic energy through the tooth has been demonstrated (15).

During the professional oral hygiene procedures of patients with orthodontic brackets, sonic and ultrasonic instrumentations were performed around the bracket base and at the lingual (reciprocal tooth surface) surface if necessary. The generated instrumentation vibrations could have influenced the brackets on the tooth as high-frequency vibrations of sonic and ultrasonic instruments are also known to facilitate the removal of posts, crowns, and bridge restorations and debonding of orthodontic brackets (16-19). While performing professional oral hygiene procedures, the instrumentation around the bracket base presents a *direct effect* as the scaler tip mostly works in contact with brackets and the vibrations directly influence the bracket base area. On the other hand, instrumentation at the lingual (reciprocal) surfaces *indirectly affects* the tooth–bracket interface as the vibrations were transmitted through the tooth without any scaler tip contact to the bracket base. However, the effect of instrumentation on the shear bond strength (SBS) of brackets has not been investigated until the study conducted by Bonetti et al. (20) that revealed that prolonged ultrasonic instrumentation around the bracket base has been shown to reduce the SBS of metallic orthodontic brackets.

Considering the differences of vibration frequencies and tip actions, sonic and piezoelectric ultrasonic instrumentations were suggested to vary by means of direct and indirect effects on the SBS of metallic orthodontic brackets. The tested null hypothesis was that direct and indirect applications of sonic and ultrasonic instrumentations do not decrease the SBS values of orthodontic brackets. Therefore, the aim of the present study was to evaluate the direct and indirect effects of sonic and piezoelectric ultrasonic instrumentations on the SBS and failure type of metallic orthodontic brackets.

METHODS

The study was approved by the Institutional Review Board and Ethics Committee of Başkent University (project no. D-KA14/15) and supported by the Başkent University Research Fund.

The sample size was calculated by using G*Power 3.1.9.2 (21). Given an α level of 0.05 (difference between two independent means) with a power of 80%, a minimum number of 14 specimens were required for each group.

A total of 75 mandibular central incisors, which were extracted for periodontal reasons, without any presence of caries, restorations, decalcifications, microcracks, and enamel fractures were collected. After extraction, all teeth were debrided, washed, and stored in distilled water.

Each tooth was individually embedded in autopolymerizing acrylic resin (Meliodent; Heraeus Kulzer, Hanau, Germany) blocks using the cemento-enamel junction as the lower limit. During the embedding procedure, all teeth were centered, and crowns were oriented as perpendicular to the bonding labial surface and parallel to the force to be applied for the SBS test. All resin blocks were code-numbered for identification.

Buccal surface prophylaxis was performed with pumice slurry using rubber cups. All teeth were washed with water spray and dried with air spray for 15 s. The bonding procedures were performed by one operator. The brackets (Ormco Mini 2000; Ormco Corporation, Glendora, CA, USA) were bonded according to the manufacturer's instructions, with 30 s of etching with 37% phosphoric acid gel (Pulpdent Corporation, Watertown, MA, USA), followed by washing for at least 15 s and drying with water–air spray until a characteristic frosty white etched area was observed on the enamel. A thin uniform layer of bonding agent (Transbond™ XT Lightcure adhesive primer; 3M™ Unitek, Monrovia, CA, USA) was applied. The brackets were bonded with light cure adhesive paste (Transbond™ XT) and were adjusted to ensure that the SBS test force to be applied would be perpendicular to the bracket base. Brackets were pressed lightly in their final position, the excess adhesive was removed with a sharp scaler, and the adhesive was cured with a LED light curing unit (Ortholux™, 3M™ Unitek, Monrovia, CA, USA) for 20 s (5 s on each of the mesial, distal, gingival, and incisal margins).

The specimens were randomly divided into five groups: UltrasonicB group, ultrasonic instrumentation of specimens around the bracket base; UltrasonicL group, ultrasonic instrumentation of specimens on the lingual surface; SonicB group, sonic instrumentation of specimens around the bracket base; SonicL group, sonic instrumentation of specimens on the lingual surface; and control group, specimens without any instrumentation. In the UltrasonicB and SonicB groups, the scaler tip was applied in contact with the bracket base. These groups represented the direct effect, and the UltrasonicL and SonicL groups represented the indirect effect as the instrumentations were performed on the reciprocal-lingual surface to evaluate the effects of vibrations transmitted through the tooth.

Ultrasonic instrumentation was performed using a piezoelectric ultrasonic scaler (Suprasson® P5 Newtron SATELEC; ACTEON, Merignac, France). The scaler tip (Universal tip, #1, SATELEC; ACTEON) was used with a 0° scaler tip angulation. A sonic scaler (SONICflex 2000N; KaVo Dental GmbH, Biberach, Germany) was used for sonic instrumentation procedures. The scaler insert (SONICflex scaler tip no. 6; KaVo Dental GmbH) was used with a

Table 1. Descriptive data of shear bond strength (MPa) analysis of the test and control groups

Group	n	Mean±SD	Minimum	Maximum	Median
UltrasonicL	15	10.52±4.48	4.70	18.50	9.86
UltrasonicB	15	7.93±3.10*	0.00	14.20	7.79
SonicL	15	9.36±2.36	6.37	13.07	8.18
SonicB	15	8.16±2.26†	5.52	13.34	7.33
Control	15	12.19±4.16*, †	6.69	18.20	9.63

*p=0.002, †p=0.004 (same characters on the same column indicate statistical significance).
SD: standard deviation; UltrasonicL: ultrasonic instrumentation of specimens on the lingual surface; UltrasonicB: ultrasonic instrumentation of specimens around the bracket base; SonicL: sonic instrumentation of specimens on the lingual surface; SonicB: sonic instrumentation of specimens around the bracket base; Control: control specimens without any instrumentation

0° scaler tip angulation. A new scaler tip was used in each study group. The manufacturer's recommended power settings were applied (settings of 14–15 for ultrasonic instrumentation and medium for sonic instrumentation). All instrumentation procedures were conducted by one experienced operator. A pilot study to maintain reproducible and the least possible load application was performed by the operator, with a reproducibility of 92% based on intraclass correlation coefficient index.

A pilot study of professional oral hygiene procedures was performed with sonic or ultrasonic instrumentation to estimate the time required for applications for patients with fixed orthodontic appliances. Periodontal procedures at the buccal or lingual sites were completed within 30 s/tooth for both sonic and ultrasonic instrumentations. Depending on the results of the pilot study, the instrumentation period was determined as 30 s for each of the specimens in the test groups. In the UltrasonicB and SonicB groups, instrumentation was performed for 10 s on each mesial, distal, and incisal side of the bracket base. The gingival bracket side instrumentation was excluded in the present study as the selected scaler tip angulation restricted the appropriate access to the area. The tip angulation was ensured by positioning the ultrasonic/sonic scaler tip parallel to the bonding surface and perpendicular to the bracket base for buccal instrumentation in the UltrasonicB and SonicB groups.

In the UltrasonicL and SonicL groups, instrumentation was performed on the lingual surfaces of each specimen excluding the incisal 1/3 part of the crown. With maintaining scaler tip parallel to the long axis of the crown in an apico-coronal direction, the 0° angulation of the scaler tip in contact to tooth surfaces was achieved, and instrumentation on the lingual surfaces was performed continuously for 30 s in an apico-coronal direction.

All samples were stored for 24h in distilled water before SBS testing. The test was performed using a standard knife-edge chisel in a universal testing machine (3343, Instron Corporation, Norwood, MA, USA) with a crosshead speed of 0.5 mm/min. The specimens were positioned to ensure the long axis of the incisors, and the bracket base was parallel to the direction of the applied force. An occlusogingival load was applied to the bracket at the incisal groove, producing a shear force at the bracket–tooth interface. The breaking loads required for debonding were recorded in Newtons (N) and converted into stress values in megapascals (MPa) that were calculated by dividing the failure load (N) by the surface area of the bracket base (7.386 mm^2).

After the SBS testing, the teeth and bracket surfaces were examined using a stereomicroscope (Leica MS5; Leica Microsystems, Singapore) at ×16 magnification to determine the type of failure. The adhesive remnant index (ARI) scoring system was used to assess the amount of adhesive left on the enamel surface of each specimen (22). The ARI scores were as follows: 0, no adhesive remained on the tooth; 1, less than half of the adhesive remained on the tooth; 2, more than half of the adhesive remained on the tooth; and 3, all of the adhesive remained on the tooth with a distinct impression of the bracket base.

Statistical Analysis

All statistical analyses were performed by using Statistical Package for Social Sciences version 20.0 for Windows (IBM Corp.; Armonk, NY, USA). Shapiro–Wilk test was used for the distribution of data. Data were not normally distributed. Levene test was used for the evaluation of homogeneity of variances. Kruskal–Wallis test was used to determine whether the differences in the SBS and ARI scores among the groups were statistically significant or not. Mann–Whitney U test was used for comparisons of all groups, and Bonferroni correction (p<0.01) was applied for controlling Type I error.

RESULTS

One specimen in the UltrasonicB group failed during the instrumentation, and it was accepted as a presentation of clinical instrumentation procedure, and the SBS value of this specimen was accepted as 0 MPa (20).

The SBS values and standard deviations for all groups are shown in Table 1. The SBS values of the lingual instrumentation groups were higher than those of the buccal instrumentation groups, although a statistical significance was not observed. Comparisons of instrumentation methods have shown that the SBS values of sonic instrumentation were lower than those of the UltrasonicL group and higher than those of the UltrasonicB group without any statistical significance. The SBS values of the UltrasonicB and SonicB groups were significantly lower than the highest SBS values of the control group (p<0.01, p=0.002 and p<0.01, p=0.004, respectively).

Kruskal–Wallis analysis revealed the presence of significant differences among the groups for ARI scores. The ARI scores of buccal instrumentations were higher than those of lingual instrumentations, although the difference was not statistically sig-

Table 2. Descriptive data and frequencies of the adhesive remnant scores (ARI) of the test and control groups

	n	ARI=0 (%)	ARI=1 (%)	ARI=2 (%)	ARI=3 (%)	Mean±SD
UltrasonicL	15	0 (0.0)	0 (0.0)	12 (80)	3 (20)	2.20±0.41
UltrasonicB	15	0 (0.0)	0 (0.0)	4 (26.7)	11 (73.3)	2.73±0.46*
SonicL	15	0 (0.0)	1 (6.7)	8 (53.3)	6 (40)	2.33±0.62
SonicB	15	0 (0.0)	1 (6.7)	5 (33.3)	9 (60)	2.53±0.64
Control	15	0 (0.0)	1 (6.7)	11 (73.3)	3 (20)	2.13±0.52*

*p=0.009 (same characters on the same column indicate statistical significance)
SD: standard deviation; UltrasonicL: ultrasonic instrumentation of specimens on the lingual surface; UltrasonicB: ultrasonic instrumentation of specimens around the bracket base; SonicL: sonic instrumentation of specimens on the lingual surface; SonicB: sonic instrumentation of specimens around the bracket base; Control: control specimens without any instrumentation

nificant. Intergroup comparisons showed that the ARI scores of the UltrasonicB group were significantly higher than those of the control group (p=0.009) (Table 2). The ARI scores of the UltrasonicB group were also higher than those of the SonicB group, but statistical significance was not revealed (p>0.01).

DISCUSSION

To the best of our knowledge, this is the first study investigating the direct and indirect effects of sonic and ultrasonic instrumentations on metallic orthodontic brackets' SBS and failure mode. Sonic and ultrasonic instruments are usually used for periodontal therapy of patients with fixed orthodontic appliances, disregarding their possible direct and indirect effects.

The type of scaler tip oscillations and the operating frequencies are different for sonic and piezoelectric ultrasonic instruments. Considering the characteristics of instruments, the effects of vibrations conducted on the tooth and tooth–resin–bracket interface could also be expected to be different, with similar clinical treatment outcomes. Instrumentations of the UltrasonicB and SonicB groups around the bracket base had been performed to determine the direct effects of vibrations, whereas instrumentations of the UltrasonicL and SonicL groups, that aimed to simulate periodontal therapy on the lingual surfaces, had been performed to define the indirect effects of vibrations on the SBS of orthodontic brackets.

The sonic scaler tip oscillates almost circularly performing a localized hammering effect on the tooth surface; on the other hand, the piezoelectric ultrasonic scaler tip has a linear vibration pattern. Depending on the oscillation patterns and vibration frequency ranges, piezoelectric ultrasonic instrumentations around the orthodontic bracket base were expected to be more "detrimental" on bond failure. Bonetti et al. (20) reported that prolonged piezoelectric ultrasonic instrumentation around the bracket base has been shown to decrease the SBS values significantly, indicating a higher risk of bracket bond failure. In agreement with the former study, the study results revealed that sonic and piezoelectric ultrasonic instrumentations around metallic orthodontic brackets have affected the SBS significantly compared with control specimens. Therefore, the null hypothesis that direct and indirect applications of sonic and ultrasonic instrumentations do not decrease the SBS values of orthodontic brackets was rejected. The decrease in the mean SBS of the UltrasonicB group specimens was more pronounced than that of the SonicB group specimens, which might be attributed to effects of higher frequencies of piezoelectric scaler than sonic scalers. The reduction of the SBS supports the direct effect of sonic and piezoelectric ultrasonic instrumentations on the tooth–bracket interface. The mean SBS of the control group specimens was higher than that of the UltrasonicL and SonicL group specimens, although the difference was statistically insignificant.

As vibration formed during instrumentation with ultrasonic scaler is higher than sonic scalers, the mean SBS values of the UltrasonicL group, which had the highest mean value among the test groups, were unexpected. This result in the UltrasonicL group could be attributed to specimen-based characteristics that may affect the vibrations transmitted through the tooth structure, although a single type of tooth was used to determine the influence of instrumentations. For each of the instrumentation type, buccal applications have more efficiency on the SBS of metallic brackets than lingual instrumentation. The findings demonstrate that vibrations produced by sonic and piezoelectric ultrasonic instrumentations appear to have a limited indirect effect on the SBS of metallic brackets. The instrumentation of both buccal and lingual surfaces with sonic and ultrasonic scalers had not been performed. However, an increase of detrimental effects of both instrumentation types might be expected, as application on both buccal and lingual sides might generate a synergistic effect on the tooth–bracket interface. Further studies to evaluate the consecutive instrumentation of both buccal and lingual surfaces should be conducted to clarify this issue.

The scaler tip angulation has considerable effects on root substance removal and defect depth. The defect depth of piezoelectric ultrasonic instrumentation was found to be the highest at 45° angulations (23). The root damage was not severe with 0° tip angulation, and the tip angulation <15° or the scaler tip aligned parallel to the root surface during instrumentation was recommended to prevent severe root damage (12, 24, 25). Ultrasonic instrumentation around the bracket base with 0° and 45° tip angulations did not reveal significant differences by means of the effect on the SBS (20). Therefore, 0° tip angulation was selected for instrumentation in all test groups to decrease the possible damage. However, this scaler tip angulation prevented the appropriate access and instrumentation at the gingival side of the bracket base, which might have an effect on the bond strength, if it had been performed.

The time required for professional hygiene procedures depends on various factors, such as clinical case characteristics, experience of the dental professionals, and instrumentation-based considerations. The average times for a single session supra- and subgingival debridement of adult patients with periodontitis were determined as 4 min/tooth and 3.3 min/tooth for sonic and ultrasonic instrumentations, respectively (26). The mean time needed for ultrasonic instrumentation was 0.4 min/tooth for patients in maintenance periodontal therapy (27). In a study assessing the influence of ultrasonic instrumentation around metallic orthodontic brackets, instrumentation was performed for 60 s, which was reported to be overrated to simulate extreme conditions and to highlight the most detrimental effects (20). Instrumentation time was determined as 30 s in this in vitro study. The decreased levels of the SBS of brackets in test specimens compared with control specimens have shown that instrumentation time was long enough to affect the bracket bond failure. Considering that in clinical procedures power-driven instrumentation around the bracket base is generally shorter than 30 s, the given results represent the effects of prolonged instrumentation, although it was less than the mean application time reported in former studies.

The present study should be evaluated by considering other factors that might have an influence on the results. The mandibular central incisors used to test the SBS had been shown to have different bond failure probabilities at a particular stress compared with premolar teeth, which have been used frequently for SBS evaluating studies (28). In the UltrasonicB, SonicB, and SonicL groups, stress strength values were reduced with power-driven instrumentation, which may increase the probability of failure rates calculated (28). The failure rate probability of 1st premolars and central incisors was higher than that of 2nd mandibular premolars; therefore, conducting a study with different tooth types may reveal different results. The mandibular incisors also have the smallest bracket base area, and prolonged instrumentation around the bracket base might have decreased the stress strength more easily.

The absorption depth of vibrations by different tooth types or the influence of transmission of vibrations through the tooth has not been studied. Regarding the differences in tooth dimensions, tooth volumes, and structural characteristics, such as mineralization, thickness, and density of the enamel and dentin, the transmission and absorption of vibrations could be expected to be various if different tooth types have been tested. Another issue to be considered is the tooth-supporting structures, such as periodontal ligament and alveolar bone, that absorb or limit the effects transferred through the tooth. During the orthodontic treatment, bone remodeling and changes in periodontal ligament occur, which would have at least partly an impact on the absorption of vibrations by tooth or vibrations transferred through the tooth (29-30). Although a limited influence of vibrations transmitted through the tooth was detected, the dimensional and structural characteristics of the selected teeth might have affected the results in the present study. The lack of periodontal ligament simulation and testing of resin-embedded specimens in this study might also have an effect on results.

Evaluation of ARI scores revealed that piezoelectric instrumentation around the bracket base significantly affects the debonding characteristics on the tooth–resin–bracket system compared with control specimens. The vibrations formed during the instrumentation of the UltrasonicB groups in contact to the bracket appear to influence the breakage behavior at the bracket–resin interface. The remaining intergroup comparisons of ARI scores revealed non-significant differences. Bond failure type of all groups had a mean index >2, indicating that the failure was mostly confined to the bracket–resin interface and decreased risk of enamel damage after debonding could be expected.

The results indicate that sonic and ultrasonic periodontal instrumentations around the orthodontic metallic bracket base reduce the SBS of metallic orthodontic brackets that may increase bracket failure risk. Considering the displeasing outcomes of bracket failure on orthodontic treatment progression, such as prolonged treatment time, sonic and ultrasonic instrumentations around the bracket base should be conducted with caution. Further studies investigating the sonic and ultrasonic periodontal instrumentations should be interpreted to clarify the direct and indirect effects on the SBS of orthodontic metallic brackets and to reveal the influence of instrumentation- and specimen-based factors on the bond strength of orthodontic brackets.

CONCLUSION

The simulation of sonic and piezoelectric ultrasonic instrumentations reduced the bond strength of metallic orthodontic brackets tested in this in vitro study. Instrumentation around the bracket base was detected to have more dramatic effects on the SBS than instrumentation performed on the lingual surface. Sonic instrumentation applied around the bracket base demonstrated higher SBS than ultrasonic instrumentation. Given the results that sonic and ultrasonic periodontal instrumentations around the orthodontic metallic bracket base reduce the SBS of brackets, instrumentations particularly around the bracket base should be conducted with caution.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of Başkent University (Project no: D-KA14/15).

Informed Consent: N/A.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - B.F.O., Z.Ş.K.; Design - B.F.O, Z.Ş.K.; Supervision - B.F.O, Z.Ş.K., K.Y.; Materials - B.F.O, K.Y., Z.Ş.K.; Data Collection and/or Processing - B.F.O, Z.Ş.K.; Analysis and/or Interpretation - B.F.O, Z.Ş.K., K.Y.; Literature Search - B.F.O, Z.Ş.K.; Writing Manuscript - B.F.O, Z.Ş.K.; Critical Review - B.F.O, K.Y., Z.Ş.K.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

1. Freitas AO, Marquezan M, Nojima Mda C, Alviano DS, Maia LC. The influence of orthodontic fixed appliances on the oral microbiota: a systematic review. Dental Press J Orthod 2014; 19: 46-55. [CrossRef]
2. Chapman JA, Roberts WE, Eckert GJ, Kula KS, González-Cabezas C. Risk factors for incidence and severity of white spot lesions during treatment with fixed orthodontic appliances. Am J Orthod Dentofacial Orthop 2010; 138: 188-94. [CrossRef]
3. Richter AE, Arruda AO, Peters MC, Sohn W. Incidence of caries lesions among patients treated with comprehensive orthodontics. Am J Orthod Dentofacial Orthop 2011; 139: 657-664. [CrossRef]
4. Bollen AM, Cunha Cruz J, Bakko DW, Huang GJ, Hujoel PP. The effects of orthodontic therapy on periodontal health: A systematic review of controlled evidence. J Am Dent Assoc 2008; 139: 413-22. [CrossRef]
5. Atack NE, Sandy JR, Addy M. Periodontal and microbiological changes associated with the placement of orthodontic appliances. A review. J Periodontol 1996; 67: 78-85. [CrossRef]
6. Türkkahraman H, Sayin MO, Bozkurt FY, Yetkin Z, Kaya S, Onal S. Archwire ligation techniques, microbial colonization, and periodontal status in orthodontically treated patients. Angle Orthod 2005; 75: 231-6.
7. Tunkel J, Heinecke A, Flemmig TF. A systematic review of efficacy of machine-driven and manual subgingival debridement in the treatment of chronic periodontitis. J Clin Periodontol 2002: 29; 72-81. [CrossRef]
8. Petersilka GJ, Ehmke B, Flemmig TF. Antimicrobial effects of mechanical debridement. Periodontol 2000 2002; 28: 56-71. [CrossRef]
9. Baehni P, Thilo B, Chapuis B, Pernet D. Effects of ultrasonic and sonic scalers on dental plaque microflora in vitro and in vivo. J Clin Periodontol 1992; 19: 455-9. [CrossRef]
10. Menne A, Griesinger H, Jepsen S, Albers H, Jepsen K. Vibration characteristics of oscillating scalers. J Dent Res 1994; 73: 434.
11. Lea SC, Landini G, Walmsley AD. Displacement amplitude of ultrasonic scaler inserts. J Clin Periodontol 2003; 30: 505-10. [CrossRef]
12. Arabaci T, Ciçek Y, Canakçi CF. Sonic and ultrasonic scalers in periodontal treatment: a review. Int J Dent Hyg 2007; 5: 2-12. [CrossRef]
13. Laird WRE, Walmsley AD. Ultrasound in dentistry. Part 1-biophysical interactions. J Dent 1991; 19: 14-7. [CrossRef]
14. Khambay BS, Walmsley AD. Acoustic microstreaming detection and measurement around ultrasonic scalers. J Periodontol 1999; 70: 626-31. [CrossRef]
15. Walmsley AD, Laird WR, Williams AR. Intra-vascular thrombosis associated with dental ultrasound. J Oral Pathol 1987; 16: 256-9. [CrossRef]
16. Olin PS. Effect of prolonged ultrasonic instrumentation on the retention of cemented cast crowns. J Prosthet Dent 1990; 64: 563-5. [CrossRef]
17. Marchan SM, White D, Smith W, Dhuru V. The influence of sonic and ultrasonic vibration on the shear bond strength of a selected resin luting cement. Eur J Prosthodont Restor Dent 2015; 23: 29-32.
18. Bishara SE, Trulove TS. Comparisons of different debonding techniques for ceramic brackets: an in vitro study. Part II. Findings and clinical implications. Am J Orthod Dentofacial Orthop 1990; 98: 263-73. [CrossRef]
19. Krell KV, Courey JM, Bishara SE. Orthodontic bracket removal using conventional and ultrasonic debonding techniques, enamel loss, and time requirements. Am J Orthod Dentofacial Orthop 1993; 103: 258-66. [CrossRef]
20. Alessandri Bonetti G, Incerti Parenti S, Ippolito DR, Gatto MR, Luigi C. Effects of ultrasonic instrumentation with different scaler-tip angulations on the shear bond strength and bond failure mode of metallic orthodontic brackets. Korean J Orthod 2014; 44: 44-9. [CrossRef]
21. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007; 39: 175-91. [CrossRef]
22. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch pretreatment. Am J Orthod Dentofacial Orthop 1984; 85: 333-40. [CrossRef]
23. Flemmig TF, Petersilka GJ, Mehl A, Hickel R, Klaiber B. The effect of working parameters on root substance removal using a piezoelectric ultrasonic scaler in vitro. J Clin Periodontol 1998; 25: 158-63. [CrossRef]
24. Petersilka GJ, Draenert M, Mehl A, Hickel R, Flemmig TF. Safety and efficiency of novel sonic scaler tips in vitro. J Clin Periodontol 2003; 30: 551-5. [CrossRef]
25. Flemmig TF, Petersilka GJ, Mehl A, Hickel R, Klaiber B. Working parameters of a magnetostrictive ultrasonic scaler influencing root substance removal in vitro. J Periodontol 1998; 69: 547-53. [CrossRef]
26. Loos B, Kiger R, Egelberg J. An evaluation of basic periodontal therapy using sonic and ultrasonic scalers. J Clin Periodontol 1987; 14: 29-33. [CrossRef]
27. Badersten A, Nilveus R., Egelberg J. Effect of nonsurgical periodontal therapy. I. Moderately advanced periodontitis. J Clin Periodontol 1981; 8: 57-72. [CrossRef]
28. Hobson RS, McCabe JF, Hogg SD. Bond strength to surface enamel for different tooth types. Dent Mater 2001; 17: 184-9. [CrossRef]
29. King GJ, Keeling SD, Wronski TJ. Histomorphometric study of alveolar bone turnover in orthodontic tooth movement. Bone 1991; 12: 401-9. [CrossRef]
30. Davidovitch Z. Tooth movement. Crit Rev Oral Biol Med 1991; 2: 411-50. [CrossRef]