Recycling Debonded Metal Orthodontic Brackets - A Comprehensive Review and Meta-Analysis

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Abstract

AIM: This work provides orthodontic practitioners with an updated literature review and meta-analysis on the practicality of reusing debonded metal orthodontic brackets.
METHODS: An electronic search from January 1989 to June 2017 on MEDLINE-PubMed and EBSCOhost Research Databases yielded 63 studies after removing duplicates. Following initial screening, 47 potentially relevant articles were identified. Detailed scrutiny led to the exclusion of 19 studies. The remaining 19 studies were divided into two groups: Group I (same bracket brand and bonding agent) and Group II (different bracket brand and bonding agents). Meta-analysis and sensitivity tests were conducted using RevMan Analysis in Review Manager (version 5.3).
RESULTS: The mean shear bond strength (SBS) for debonding a new bracket was 10.16 MPa. Five chairside recycling methods were compared: erbium laser, aluminum oxide sandblasting, high-speed grinding, slow-speed grinding, and direct flaming. Average reductions in SBS were 0.65 MPa, 0.89 MPa, 2.82 MPa, 3.49 MPa, and 3.93 MPa, respectively.
CONCLUSION: Erbium laser recycling is highly efficient, though cost-prohibitive. Chairside aluminum oxide sandblasting with a microetcher offers a cost-effective alternative with comparable SBS. High-speed grinding surpasses slow-speed grinding, but both exhibit less favorable rebonding strength than sandblasting. Direct flaming yields the lowest SBS. Chairside sandblasting emerges as the most practical and economical method for recycling debonded metal orthodontic brackets.

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1 Introduction

Bonding of orthodontic attachment to etched enamel with dental resins was made possible through Buonocore's study in 1951 (Buonocore, 1955). Buonocore showed that a simple method to increase the mechanical bond between acrylic filling and enamel surfaces was through etching the enamel surfaces with 85% phosphoric acid for 30 seconds. His discovery greatly widens the scope of orthodontics as orthodontic practitioners are able to simply bond directly to the enamel surfaces.

However, failure of the bonded brackets is not uncommon. Studies had reported between 4.7 to 23% of clinical bracket bond failure (O'Brien and Roberts, 1989; Lovius et al., 1987). In addition, orthodontic practitioners may also wish to reposition the brackets throughout the course of orthodontic treatment. Regardless of the reason, replacing the debonded brackets with new brackets every time is very costly. For both economical and environmental reason, orthodontic practitioners have resorted to recycle the brackets, in-office or commercial methods.

Older studies (Mascia and Chen, 1982; Wright and Powers, 1985; Hixson et al., 1982; McClea and Wallbridge, 1986) casted a doubt on recycling brackets, claiming that reconditioned brackets showed a decrease in bond strength to an extent that might interfere with orthodontic treatment. Other studies showed that reconditioned brackets not only had a decrease in corrosion resistance (Maijer and Smith, 1986) and weakening of metal structure (Buchman, 1980), reusing reconditioned appliances could even lead to dermatitis and enamel staining (Park and Shearer, 1983).

Orthodontics has come a long way in the last 20 years. New developments in bracket materials, designs of bracket mesh system, new adhesive materials for orthodontic bonding and reconditioning methods make it possible to recycle orthodontic appliances to an acceptable standard. Buchwald in his research showed that with proper reconditioning, it was not only possible to save, but also to achieve a performance similar to a new bracket (Buchwald, 1989). Wheeler and Ackerman (Wheeler and Ackerman, 1983) found that single recycling was of negligible clinical importance whereas other studies showed that brackets could be reconditioned up two to five times (Mehta et al., 2016; Matasa, 1989), that is savings of up to 90% of treatment cost. One in vivo study (Cacciafesta et al., 2004) found that there was no significant differences in bond failure percentages when comparing a 12-month follow up of new brackets and recycled brackets.

Various recycling methods were described and tested in the literature: In-office recycling methods and commercial recycling. However, the findings in the literature provided contradictory results with the shear bond strength (SBS) of rebonded attachments (Mui et al., 1999). Regan et al. (1990) and Martina et al. (1997) found that recycling orthodontic brackets up to five times showed no difference of SBS when compared to new brackets (Regan et al., 1990; Martina et al., 1997), whereas Khosravanifard et al. (2011) found that sandblasting the metal brackets with 50µm Aluminium Oxide at 90psi and 5mm produced SBS which was even higher than new brackets (Khosravanifard et al., 2011). Sunna and Rock (1998), Reynolds (1975), and Montasser et al. (2008) showed that bond strengths between 6 to 8 MPa were sufficient to withstand normal orthodontic forces clinically (Sunna and Rock, 1998; Reynolds, 1975; Montasser et al., 2008). Some studies claimed that the maximum bond strength should be less than the breaking strength of enamel, which was about 14 MPa (Retief, 1974; Bowen and Rodrigues, 1962).

Therefore, the aim of the recycling method is to be able to produce a SBS between 6 and 14 MPa. Bonding strength within this range is able to withstand normal orthodontic force and at the same time prevent enamel fracture when debonded accidentally or intentionally. A search in the literature showed that up to June 2017, there are no literature review and meta-analysis ever done on this topic.

The aim of this work is to provide clinicians with an up to date comprehensive literature review and meta-analysis on the practicality of reusing or recycling debonded metal orthodontic brackets.

2 Methods

The search of relevant data was done on two main online platforms, namely MEDLINE-PubMed (National library of Medicine) and EBSCOhost Research Databases. The keywords used in the search includes "Orthodontic Brackets", "Reuse", "Recycle", "Rebond". Boolean Operators (AND, OR, NOT) were used to connect the keywords to narrow the relevant search results. Sixty-three articles were identified as a result of the initial search. Search results and citations were viewed and were further refined through careful screening of the title and abstract of each individual articles. Full text articles were received and analysed. The final articles that were selected in this literature review must fulfil the following inclusion and exclusion criteria:

Inclusion Criteria:

1. Laboratory studies that were carried out between Year 2006 and June 2017 were included. Published studies earlier than 2006 were excluded. Bracket design and adhesive materials change significantly over time. Therefore laboratory studies with materials carried out earlier than 2006 were considered not applicable.
2. Laboratory studies that were carried out using human teeth only. Experimental results from animal studies will not be included.
3. Only the most recent report from the same study will be included.
4. Studies carried out measuring shear bond strength will be included.
5. Only studies that used premolar metal brackets on premolars will be included.

Exclusion Criteria:

1. Articles that were presented in a language other than English.
2. Laboratory studies carried out on teeth other than premolars. This allows for a more accurate comparison between the results.
3. Laboratory studies that used half or incomplete crowns of the teeth were omitted.

After careful reading of each articles, the following data were recorded where available: (A) year of publication and study settings (B) total sample size and individual group sample size (C) type of bracket (including brand and bonding surface area of the bracket) (D) type of bonding and adhesive material used (E) tooth number used (F) storage methods of extracted tooth prior to studies (G) methods of testing (H) methods of recycling (I) means and standard deviations of the outcomes of shear bond strength tests in megapascals (MPa). Heterogeneity of the included studies was analysed by reviewing the source of teeth for experiment, storage methods of the sample teeth prior to experimental studies, and the experimental designs, settings and protocols.

2.1 Statistics

Statistical heterogeneity was assessed based on a graphical display of the mean difference of SBS between recycling methods and control with 95% confidence intervals. Meta-analysis and sensitivity tests were undertaken using RevMan Analysis statistical package in Review Manager (version 5.3) and reported using forest plots and statistical table (Review Manager, 2014).

3 Results

The search result returned 63 studies after removal of duplicates. All abstracts were reviewed and 47 potentially relevant articles were identified and retrieved in full. Further screening of the reference lists returned additional 3 articles for review. After detailed reading and assessment of the remaining studies, 18 studies were excluded with 32 studies remaining. A further 13 studies were excluded with 19 remaining to meet the inclusion and exclusion criteria (Figure 1). The final included 19 studies were grouped into Group I which includes studies with same bracket brand and using same bonding agents and Group II which includes studies with different bracket brand and bonding agents (supplemental **Table S1** and S2).

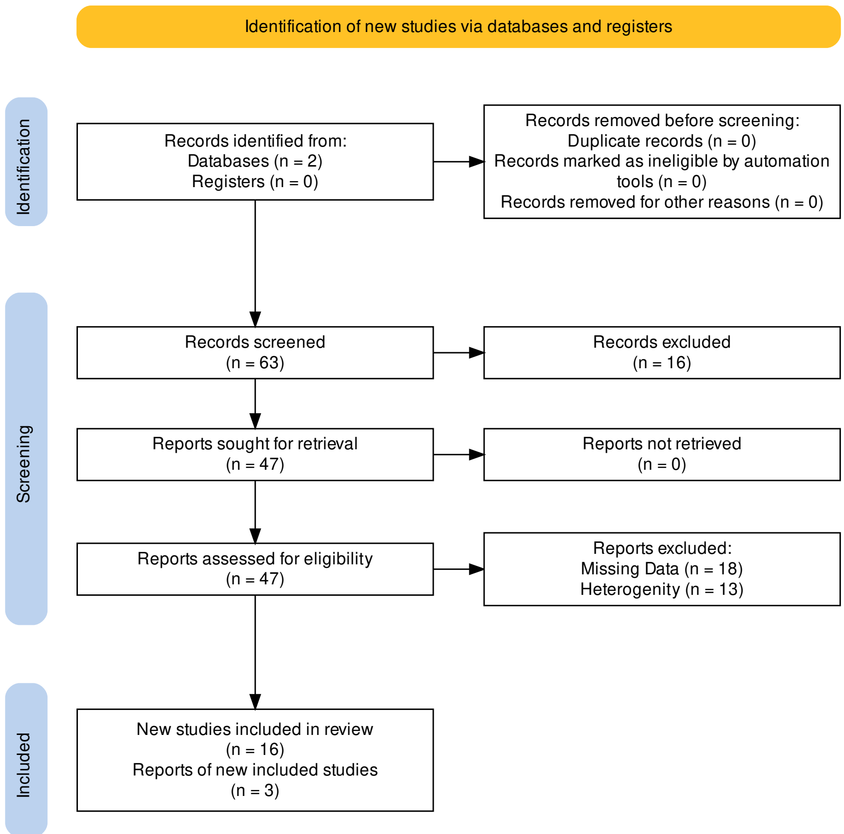

Figure 1. PRISMA flow diagram for identification of studies via databases.

3.1 Experimental design and measurement of shear bond strength

Bovine teeth were frequently used in the studies because they were more easily obtained. Similarity between human enamel and bovine enamel allowed researcher to justify their use, however, Oesterle et al. (1998) observed that bovine enamel from deciduous and permanent teeth presented respectively 21% and 44% less SBS strength than human enamel (Oesterle et al., 1998). Therefore, all the selected included studies were conducted in vitro, using extracted human premolars only. Laboratory studies that used any teeth other than human premolars will be excluded for more precise comparison.

Bond strength of bracket can vary depending on the method of testing. Studies that measured SBS will be used for analysis and comparison as majority of the studies evaluated SBS of recycled brackets. The machines that were used to conduct the studies included Instron Universal Testing Machine or Lloyd Universal Testing machine. The rate of force applications varied between studies from 0.5mm/min to 5mm/min however, Klocke and Kahl-Nieke, (2005) showed that the variations in crosshead speed between 0.1 and 5 mm/min did not have a significant influence on debonding forces. The testing machines provided the result of the force to release the bracket in kilograms (kg), which was converted to megapascals (MPa) using the following formula: shear bond strength (SBS) = (force in kg x 9.81) / (base area of bracket).

Mean SBS to debond a new bracket derived from the forest plot (**Figure 2**) consisting of 18 studies was 10.16 MPa (95% Confidence Interval [CI], 8.50, 11.82). One study did not provide the data on control. Random effect model was chosen because all the studies were fuctionally unequivalent as the data was accumulated from a series of studies that had been performed by different researchers operating independently.

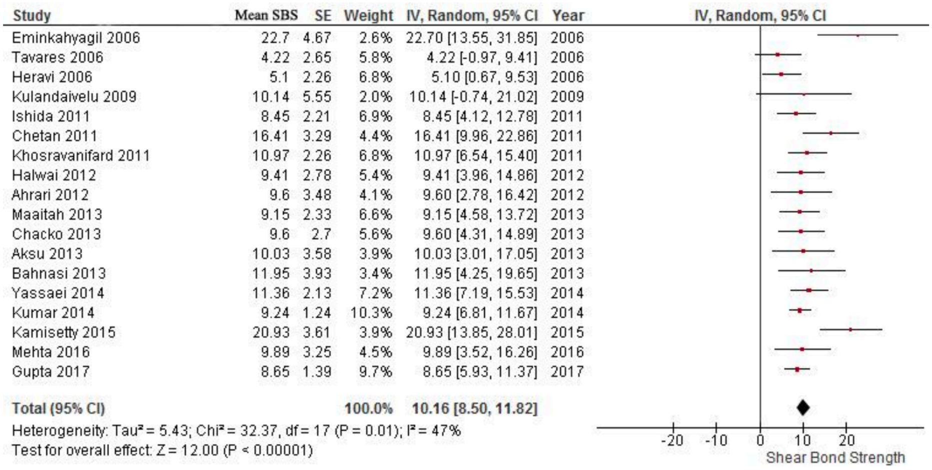

Figure 2. Forest plot for mean shear bond strength of control group.

3.2 Recycling of orthodontic brackets

The aim of recycling is to remove adhesive from the bracket base completely without causing substantial deformation to the bracket so that the bracket can be rebonded with adequate bond strength between bracket-bond interfaces (Maccoll et al., 1996). Many laboratory studies that measured SBS ended with conflicting results because there were so many different parameters that were not comparable between the studies. The three main parameters that may affect the outcome of the studies were *tooth morphology* (Buonocore, 1955), *bracket mesh pad design* (O'Brien and Roberts, 1989) and *bonding material* (Lovius et al., 1987). Therefore for the purpose of accuracy in comparison of the result, included studies only used human premolars as sample teeth. The selected articles were further grouped into group I (**Table S1**: Studies using Gemini (3M) brackets and Transbond XT bonding agent) and group II (**Table S2**: Studies using assorted brackets and bonding agents).

3.3 In-office recycling methods

There were many different in-office recycling methods described in the literature. The three most common methods described and frequently tested were grinding, flaming and sandblasting. Using laser to recondition the orthodontic brackets has gathered more interests in the last decade. As there are sufficient data for the aforementioned four methods, we will do a comparison by extracting the data from each articles. Apart from the recyling methods mentioned above, the literature also mentioned the following less common methods: ultrasonic cleaning, silicoating method, acid bath method, Esmadent method and Buchman method. There were insufficient data for comparison.

3.3.1 Sandblasting method

All included studies were divided into two groups to determine whether the use of the same bracket brand and bonding material had an effect on the outcome of shear bond strength. Random effect model was chosen since all the studies were fuctionally unequivalent. The mean SBS difference derived from the seven studies in group I, involving a total of 300 brackets, was -1.96 MPa (95% CI, -3.26, -0.66 (**Figure 3**)). Sensitivity analysis were not carried out as all the studies were deemed to be high quality since the sample size were 20 specimens or more in each group. Fox et al. (1994) suggested that each group should have at least 20 specimens if valid conclusions were to be drawn from in vitro bond strength testing (Eminkahyagil et al., 2006).

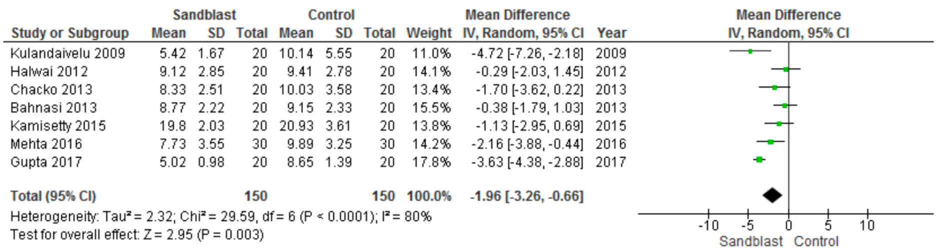

Figure 3. Forest plot for sandblasting method versus control in group I with same bracket brand (Gemini 3M) and same bonding agent (Transbond XT).

The mean SBS difference derived when combining the result of group I and group II, involving a total of 672 orthodontic brackets of assorted brand and type was -0.56 MPa (95% CI, -1.50, 0.39 (**Figure 4**)). Sensitivity analysis were carried out by removing study Eminkahyagil et al. (2006), Tavares et al. (2006), Ahrari et al. (2012) and Kumar et al. (2014) which were deemed low quality due to small sample size. The resulting mean SBS difference based on the data from 582 brackets was -0.89 MPa (95% CI, -1.96, 0.17) indicating similar result. The difference between group I (same bracket and bonding material) and group II (assorted brackets and bonding material) after sensitivity test was 1.07 MPa, indicating similar result regardless of bracket brand or bonding material used for testing.

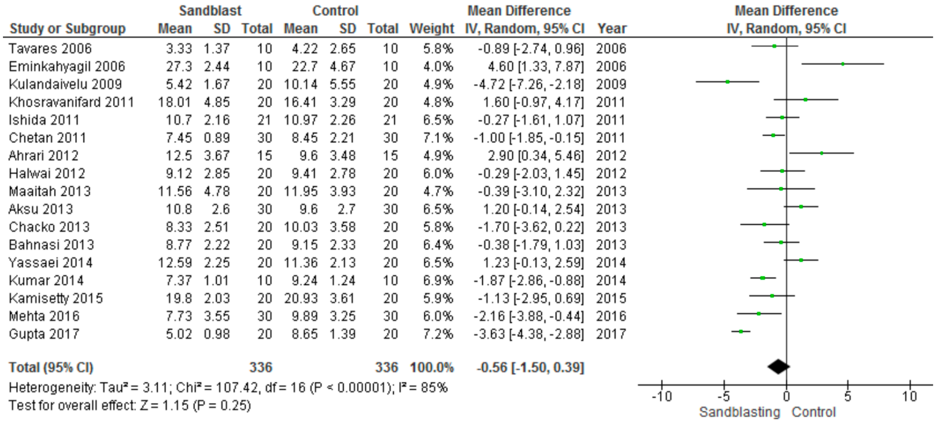

Figure 4. Forest plot for sandblasting method versus control in group I and II (assorted bracket brands and bonding agents).

3.3.2 Direct flaming method

For direct flaming method, the mean SBS difference derived from five studies in group I, involving a total of 200 brackets was -4.06 MPa (95% CI, -5.79, -2.33 (**Figure 5**)). No sensivity test were carried out as all the studies in group I meet the minimal requirement of 20 brackets in each group of testing. When combining all the included eight studies in group I and group II, the mean SBS difference derived from eight studies involving a total of 320 brackets was -3.89 MPa (95% CI, -4.81, -2.96 (**Figure 6**)). The study by Kumar et al. (2014) was removed for sensitivity test and the resulting mean SBS difference based on 300 brackets was -3.93 MPa (95% CI, -5.06, -2.80) indicating similar result. The difference between group I and group II without sensivity test was 0.13 MPa indicating similar result regardless of bracket brand or bonding material used for testing.

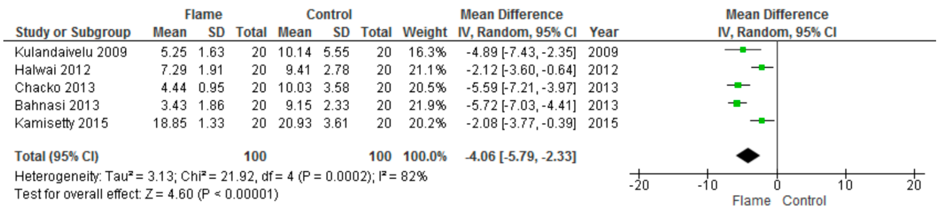

Figure 5. Forest plot for flaming method versus control in group I (same bracket brand and bonding agent).

3.3.3 Slow speed grinding method

After careful analysis of the included studies, we further divided the studies into 2 groups: (i) slow speed grinding method (O'Brien and Roberts, 1989) and (ii) high speed grinding method. This allowed us to determine if there was any mean SBS difference when using different grinding speed. There were not enough data to carry out separate analysis of group I and group II.

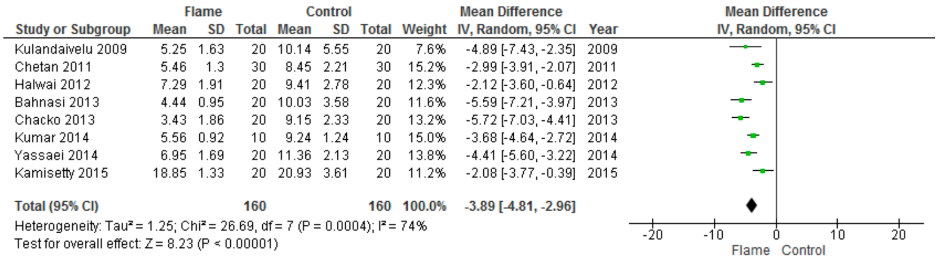

Figure 6. Forest plot for flaming method versus control in group I and II (assorted bracket brands and bonding agents).

For slow speed grinding method, the mean SBS difference derived from 9 studies, involving a total of 350 brackets was -2.59 MPa (95% CI, -4.35, -0.83 (**Figure 7**). Sensitivity analysis were carried out by removing the studies from Eminkahyagil et al. (2006) and Ahrari et al. (2012) which were deemed to be of low quality. The resulting mean SBS difference was -3.49 MPa (95% CI, -5.28, -1.79), indicating similar result of a difference of 0.9 MPa.

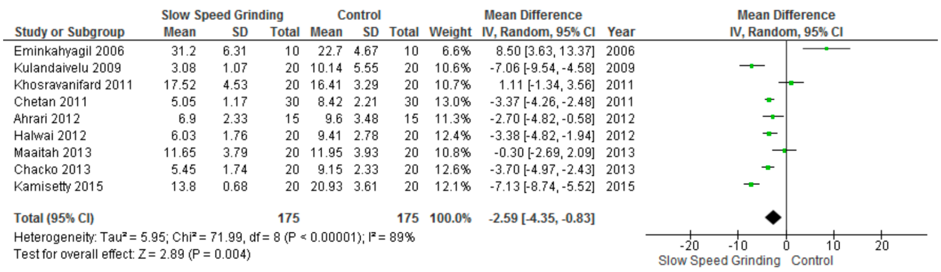

Figure 7. Forest plot for slow speed grinding method versus control in group I and II.

3.3.4 High speed grinding method

For high speed grinding method, the mean SBS difference derived from four studies involving a total of 160 brackets was -0.78 MPa (95% CI, -4.89, -3.32 (**Figure 8**). The same study of Eminkahyagil et al. (2006) was removed for sensitivity analysis. The resulting mean SBS difference was -2.82 MPa (95% CI, -6.81, 1.17).

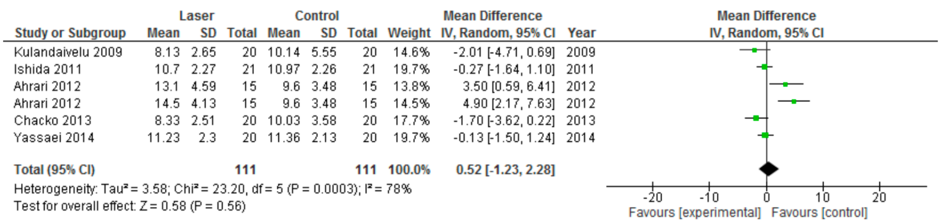

Figure 8. Forest plot for high speed grinding method versus control in group I and II.

3.3.5 Erbium laser recycling method

Using laser to recondition the orthodontic brackets has gathered more interests in recent years. There were five articles in the included studies that made a comparison using laser. The mean SBS difference derived from a total of 222 brackets were 0.52 MPa (95% CI, -1.23, 2.28 (**Figure 9**). Sensitivity test was carried out by removing the study of Ahrari et al. (2012) and the resulting SBS was -0.65 MPa (95% CI, -1.47, 0.18).

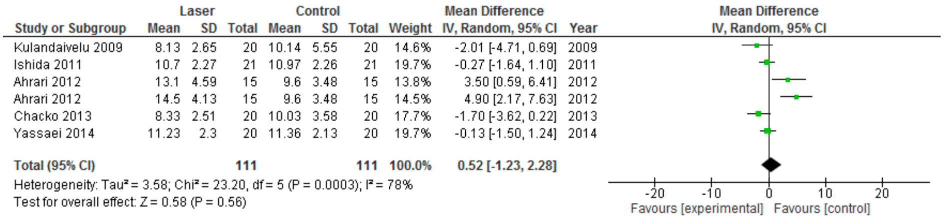

Figure 9. Forest plot for laser recycling method versus control in group I and II.

3.4 Commercial recycling methods

The two main commercially available methods to recycle orthodontic brackets use either thermal or chemical method to remove the adhesive from the bracket base. Esmadent (ESMA Inc., IL, USA) uses heat whereas Ortho-cycle (Ortho-cycle Co. Inc., FL, USA) employs chemical solvents. The disadvantages of both methods are a degree of metal loss in the brackets and a reduction in the dimension of mesh strand. Some studies (Mascia and Chen, 1982; Wheeler and Ackerman, 1983; Postlethwaite, 1992) reported that recycled brackets were more prone to corrosion, particularly brackets made from type-304 (AISI) stainless steel. Further criticism includes long turnover time and the inability to recognize the recycled brackets. Montero et al. (2015) claimed that there were no differences in SBS between sandblasting method and commercial recycling after the first recycle. In the same study, he also claimed that SBS was significantly higher for commercially reconditioned brackets after second and third recycle (Montero et al., 2015). Reddy et al. (2011) also reported the increase of SBS after industrial recycling despite the reduction to the mesh strand diameter. However, there were insufficient studies to make a conclusive comparison with the in-office recycling methods.

Table 1. Combining all the results of the mean SBS (MPa) reduction of different recycling methods for group I and group II after sensitivity test. LR = Laser recycling. SB = Sandblasting. HSG = High-speed grinding. SSG = Slow-speed grinding. DF = Direct flame.

Group	LR	SB	HSG	SSG	DF
I	-	-1.96	-	-	-4.06
I, II	-0.65	-0.89	-2.82	-3.49	-3.93

4 Discussion

There is a lack of standardization in the methodology of in vitro SBS tests in orthodontics (Kulandaivelu et al., 2009), making it difficult to make comparisons of the results obtained by different studies. There are also no reliable protocol to estimate the in vivo strength provided by bonding system. The bond strength recorded in the in vitro studies may be higher than those observed clinically. Most studies in the articles used the universal testing machine to measure pure shear forces; however, there are shear, tensile and torsional forces present during in vivo debonding. In addition, the universal testing machine applies a constant rate of loading whereas it is not standardized or constant in vivo debonding. In vitro studies may however provide us a guideline when choosing recycling methods.

While the pooled estimate of SBS of different recycling methods are most likely representative, it is likely that this figure fluctuates among operators as well as patients. Nevertheless, from the statistical analysis carried out, we can conclude that bracket brand and bonding material did not significantly affect the SBS when recycling the bracket using sandblasting and direct flaming method. This result contradicted the findings of Wang et al. (2004), Sharma-Sayal et al. (2003) and Willems et al. (1997). This could be due to similarity of the bracket base width and bracket mesh design between different manufacturers used in the included studies. MacColl et al. (1996) reported that there were no statistically significant differences in SBS among brackets wider than 6.82 mm. From the information provided, all included studies that provided the width of the bracket ranges from 9.00 mm to 12.13 mm. Hence, this could be the possible explanation to the insignificant difference of SBS. Bonding agents did not affect the bond strength significantly because the bond between bracket-resin interfaces was purely mechanical and majority of the bond failure occurs at the bracket base-adhesive resin interfaces.

From the statistical analysis carried out (**Table 1**), we can conclude that by using erbium laser as recycling method, the recycled orthodontic brackets can produce SBS which is almost the same as new brackets with the mean reduction of only 0.65 MPa. Ishida et al. (2011) in their study showed that even with second rebond, the reduction of SBS was still clinically acceptable with a mean on 9.86 MPa and standard deviation of 2.28 MPa. The two types of erbium laser that was used in the studies were Er:YAG and Er,Cr:YSGG. Both types of laser produced similar results as we now know that erbium lasers are effective in composite removal (Ahrari et al., 2012). The advantages of using erbium laser are that it has a lower penetration energy and a selective absorption towards the composites (Almeida et al., 2009). Hence, not only the surface area and retention grooves of the bracket mesh will not be altered, composite can be efficiently removed. Erbium laser was also found to be able to micro-roughen the bonding pads with some microscopic impressions observed on the mesh surface under scanning electron microscope (Ahrari et al., 2012) which potentially explaining the minimal reduction of SBS. The main disadvantage of using laser is cost, making it not practical for every orthodontic practice to own a laser machine. In addition, adequate protection such as protective eyewear has to be worn during usage. In a busy orthodontic practice setting, it may not be a practical and efficient method.

Based on the result of the analysis, sandblasting method comes after erbium laser method with a mean reduction of 1.96 MPa in group I and 0.89 MPa in group I and II after sensitivity tests. Different chairside sandblaster were used in the laboratory studies. The most common was Microetcher (Danville Materials, Carlsbad, USA). Analysis showed that chairside sandblasting carried out using 50 µm Aluminium Oxide at a distance of 5mm to 10mm with 72.5 to 90 psi for 15 to 40 seconds will produce adequate SBS. The possible explanation is that sandblasting within the aforementioned parameters not only will not damage the mesh strand, it will at the same time create roughened surfaces for more retention. This was seen under SEM in the study carried out by Ahrari et al. (2012). Chairside sandblaster such as Microetcher is an affordable tool for any orthodontic practice. It can efficiently recycle the debonded orthodontic brackets in a very short time. Protection eyewear is also recommended during usage.

Chairside grinding method can be easily carried out and it is a very practical method. Statistical analysis showed that using high speed grinding had a mean SBS reduction of 2.82 MPa whereas using slow speed grinding, the mean SBS reduction was 3.49 MPa. Both methods produced adequate SBS however analysis showed that high speed grinding had a higher SBS than slow speed grinding. This may be because high speed grinding dislodge adhesive in larger fragments whereas slow speed grinding tends to wear down the adhesive slowly with the higher chance of wearing down the bracket mesh as well. The disadvantage of this method is the damage it caused to the multi-stranded structure of the bracket mesh (Wright and Powers, 1985; Basudan and Al-Emran, 2001; Tavares et al., 2006) and leave at least 30% of adhesive on the bracket base under the SEM. Basudan et al. (2001) showed a nearly continuous adhesive coverage above the wire mesh level after reconditioned by green stone. This explained the low SBS when this method is used. In addition, grinding a small orthodontic bracket can be hazardous if not cautious, especially when using high speed grinding.

Direct flaming of the debonded orthodontic brackets is a common practice among orthodontic practitioners because of its practicality. Using heat not only can decontaminate and sterilize orthodontic brackets, it will also remove the adhesive's polymeric matrix. The primary disadvantage of using this method is the charring effect through the formation of the adherent dark layer of oxides and carbides. To restore the lustre of the metal, practitioner send the brackets for electropolishing. However, electropolishing tends to distort the bracket slot, bracket wings and more important, level the bracket mesh. From the statistical analysis carried out, direct flaming method had the most mean SBS reduction comparing to other methods with a reduction of 3.93 MPa in group I and 4.06 MPa in group I and II after sensitivity test. It should be noted that the mean SBS to debond a new bracket was 10.16 MPa. Therefore, the mean of SBS to debond a recycled bracket using this method was barely the recommended SBS of 6-8 MPa to withstand normal orthodontic force (Reynolds, 1975; Sunna and Rock, 1998; Montasser et al., 2008). Regan et al. (1993) observed a 41% reduction in shear bond strength (SBS) for flamed brackets, corroborating our findings (Regan et al., 1993). Consequently, even though it is a convenient and rapid technique, caution should be exercised when opting for this method.

Conclusions

On the basis of this systematic review and meta-analysis, we can conclude that erbium laser is the most efficient chairside method when recycling metal orthodontic brackets. The rebonding strength could be as high as new brackets. However, the high cost of erbium laser may be a great barrier for their common use in orthodontics. Chairside sandblasting with a microetcher is the recommended method when taking cost and efficiency into consideration. It is an easy and fast method that produced SBS well above the recommmendation, hence well suited a busy orthodontic practice. If grinding method is chosen, high speed grinding should be the preferred option over slow speed grinding as analysis showed that high speed grinding produced slightly higher SBS than slow speed grinding. One should be catious however when using high speed handpieces to grind the small orthodontic brackets as it can be a hazardous procedure. Direct flaming of bracket base is the least recommended method despite its simplicity as the rebond strength barely reached the recommended SBS. Careful consideration should be taken when using this method. To conclude, chairside sandblasting is the most feasible and economical method for orthodontic practitioners to date.

Acknowledgements

Not applicable.

Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

Author notes

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References

Ahrari, F., Basafa, M., Fekrazad, R., Mokarram, M., Akbari, M. (2012). The efficacy of Er,Cr:YSGG laser in reconditioning metallic orthodontic brackets. Photomed Laser Surg, 30(1), 41-46.

Almeida, H.C., Vedovello Filho, M., Vedovello, S.A., Young, A.A., Ramirez-Yaz, G.O. (2009). Er:YAG laser for composite removal after bracket debonding: a qualitative SEM analysis. International Journal of Orthodontics, 20(1), 9-13.

Basudan, A.M., Al-Emran, S.E. (2001). The effects of in-office reconditioning on the morphology of slots and bases of stainless steel brackets and on the shear/peel bond strength. Journal of Orthodontics, 28(3), 231-236.

Bowen, R.L., Rodrigues, M.S. (1962). Tensile bond strength and modulus of elasticity of tooth structure and several restorative materials. J Am Dent Assoc, 64, 378-387.

Buchman, D.J. (1980). Effects of recycling on metallic direct-bond orthodontic brackets. American Journal of Orthodontics, 77(6), 654-668.

Buchwald, A. (1989). A three-cycle in vivo evaluation of reconditioned direct-bonding brackets. American Journal of Orthodontics and Dentofacial Orthopedics, 95, 352-354.

Buonocore, M.G. (1955). A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. Journal of Dental Research, 34, 849-853.

Cacciafesta, V., Sfondrini, M.F., Melsen, B., Scribante, A. (2004). A 12-month clinical study of bond failures of recycled versus new stainless steel orthodontic brackets. European Journal of Orthodontics, 26, 449-454.

Eminkahyagil, N., Arman, A., Cetin.ahin, A., Karabulut, E. (2006). Effect of Resin-removal Methods on Enamel and Shear Bond Strength of Rebonded Brackets. Angle Orthod, 76(2), 314-321.

Fox, N.A., McCabe, J.F., Buckley, J.G. (1994). A critique of bond strength testing in orthodontics. Br J Orthod, 21, 33-43.

Hixson, M.E., Brantley, W.A., Pincsak, J.J., Conover, J.P. (1982). Changes in bracket slot tolerance following recycling of direct-bond metallic orthodontic appliances. American Journal of Orthodontics, 81(6), 447-454.

Ishida, K., Endo, T., Shinkai, K., Katoh, Y. (2011). Shear bond strength of rebonded brackets after removal of adhesives with Er,Cr:YSGG laser. Odontology, 99(2), 129-134.

Khosravanifard, B., Nemati-Anaraki, S., Nili, S., Rakhshan, V. (2011). Assessing the effects of three resin removal methods and bracket sandblasting on shear bond strength of metallic orthodontic brackets and enamel surface. Orthodontic Waves, 70, 27-38.

Klocke, A., Kahl-Nieke, B. (2005). Influence of cross-head speed in orthodontic bond strength testing. Dent Mater, 21(2), 139-144.

Kulandaivelu, T.A., Ebenezara, A.V.R., Sumitha, M., Dhandapani, G. (2009). Comparative Evaluation of the Effectiveness of Er:YAG Laser and Other In-house Refurbishing Methods for Reconditioning Stainless Steel Brackets. J Oral Laser Applications, 9, 121-127.

Kumar, M., Maheshwari, A., Lall, R., Navit, P., Singh, R., Navit, S. (2014). Comparative Evaluation of Shear Bond Strength of Recycled Brackets using Different Methods: An In vitro Study. Journal of International Oral Health: JIOH, 6(5), 5-11.

Lovius, B.B., Pender, N., Hewage, S., O'Dowling, I., Tomkins, A. (1987). A clinical trial of a light-activated bonding material over an 18-month period. British Journal of Orthodontics, 14(1), 11-20.

Maccoll, G.A., Rossouw, P.E., Titley, K.C., Yamin, C. (1996). The relationship between bond strength and base surface area using conventional and micro-etched foil-mesh bases. Am J Orthod Dentofacial Orthop, 109, 338-339.

Maijer, R., Smith, D.C. (1986). Biodegradation of the orthodontic bracket system. American Journal of Orthodontics and Dentofacial Orthopedics, 90(3), 195-198.

Martina, R., Laino, A., Cacciafesta, V., Cantiello, P. (1997). Recycling effects on ceramic brackets - a dimensional weight and shear bond strength analysis. European Journal of Orthodontics, 19(6), 629-636.

Mascia, V.E., Chen, S.R. (1982). Shearing strengths of recycled direct-bonding brackets. American Journal of Orthodontics, 82(3), 211-216.

Matasa, C.G. (1989). Pros and cons of the reuse of direct bonded appliances. American Journal of Orthodontics and Dentofacial Orthopedics, 95, 72-76.

Matasa, C.G. (2003). Orthodontic recycling at the crossroads. J Clin Orthod, 37(3), 133-139; quiz 147.

McClea, C.P., Wallbridge, D.J. (1986). Comparison of tensile and shear strength of new and recycled orthodontic metal brackets. New Zealand Dental Journal, 82(367), 11-14.

Mehta, F., Mehta, S., Kumar, A., Gandhi, V. (2016). Effect of Repeated Bonding On The Shear Bond Strength Of Transbond XT (3M Unitek). Journal of Dental and Medical Sciences, 15(5), 14-21.

Montasser, M.A., Drummond, J.L., Evans, C.A. (2008). Rebonding of Orthodontic Brackets. The Angle Orthodontist, 78(3), 531-536.

Montero, M.M.H., Vicente, A., Alfonso-Hernández, N., Jiménez-Lez, M., Bravo-González, L.A. (2015). Comparison of shear bond strength of brackets recycled using micro sandblasting and industrial methods. Angle Orthod, 85(3), 461-467.

Mui, B., Rossouw, P.E., Kulkarni, G.V. (1999). Optimization of a procedure for rebonding dislodged orthodontic brackets. Angle Orthodontist, 69, 276-281.

O'Brien, K.D., Roberts, C.T. (1989). A visible light activated direct bonding material: An in vitro comparative study. American Journal of Orthodontics and Dentofacial Orthopedics, 95, 348-351.

Oesterle, L.J., Shellhart, W.C., Belanger, G.K. (1998). The use of bovine enamel in bonding studies. Am J Orthod Dentofacial Orthop, 114(5), 514-519.

Park, H.Y., Shearer, T.R. (1983). In vitro release of nickel and chromium from simulated orthodontic appliances. American Journal of Orthodontics, 84(2), 156-159.

Postlethwaite, K.M. (1992). Recycling bands and brackets. British Journal of Orthodontics, 19, 157-164.

Reddy, Y.N., Varma, D.P., Kumar, A.G., Kumar, K.V., Shetty, S.V. (2011). Effect of thermal recycling of metal brackets on shear and tensile bond strength. The Journal of Contemporary Dental Practice, 12(4), 287-294.

Regan, D., LeMasney, B., Van Noort, R. (1993). The tensile bond strength of new and rebonded stainless steel orthodontic brackets. Eur J Orthod, 15, 125-135.

Regan, D., Van Noort, R., O'Keeffe, C. (1990). The effects of recycling on the tensile bond strength of new and clinically used stainless steel orthodontic brackets: an in vitro study. British Journal of Orthodontics, 17, 137-145.

Retief, D.H. (1974). Failure at the dentin adhesive-etched enamel interface. J Oral Rehabil, 1, 265-84.

Review Manager (RevMan) [Computer program]. (2014). Version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration. (Review Manager, 2014)

Reynolds, I.R. (1975). A review of direct orthodontic bonding. Br J Orthod, 2, 171-178.

Sharma-Sayal, S.K., Rossouw, P.E., Kulkarni, G.V., Titley, K.C. (2003). The influence of orthodontic bracket base design on shear bond strength. Am J Orthod Dentofacial Orthop, 124(1), 74-82.

Sunna, S., Rock, W.P. (1998). Clinical performance of orthodontic brackets and adhesive systems: A randomized clinical trial. British Journal of Orthodontics, 25, 283-287.

Tavares, S.W., Consani, S., Nouer, D.F., Magnani, M.B., Nouer, P.R., Martins, L.M. (2006). Shear bond strength of new and recycled brackets to enamel. Brazilian dental journal, 17(1), 44-8.

Wang, W.N., Li, C.H., Chou, T.H., Wang, D.D., Lin, L.H., Lin, C.T. (2004). Bond strength of various bracket base designs. Am J Orthod Dentofacial Orthop, 125(1), 65-70.

Wheeler, J.J., Ackerman, R.J. Jr. (1983). Bond strength of thermally recycled metal brackets. American Journal of Orthodontics, 83, 181-186.

Willems, G., Carels, C.E., Verbeke, G. (1997). In vitro peel/shear bond strength evaluation of orthodontic bracket base design. J Dent, 25, 271-278.

Wright, W.L., Powers, J.M. (1985). In vitro tensile bond strength of reconditioned brackets. American Journal of Orthodontics, 87(3), 247-252.