FOLIA MEDICA CRACOVIENSIA
Vol. LXIII, 3, 2023: 133–156
PL ISSN 0015-5616
DOI: 10.24425/fmc.2023.147219

What is the safest method of orthodontic debonding — a systematic review of the literature

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Abstract: The objective of this study was to review the current knowledge based on in vitro and in vivo studies, that evaluated the enamel damage connected with removal of metal and ceramic orthodontic brackets taking into account different debonding methods. Brackets fracture was also assessed. The protocol for this study was constructed according to the PRISMA statement. The literature review was performed in MEDLINE via PubMed, Cochrane and Scopus databases in May 2021. The searching was repeated in Journal of Stomatology, Orthodontic Forum and grey literature was screened using Google Scholar. Out of eligible studies 207 were screened by title and abstract, 85 subjected to full-text analysis and 30 were qualified for the research. The prevalence of enamel fracture ranged from 0 to 94.4%. The results of our review do not allow to identify the manual method of debonding that minimizes the risk of enamel damage. Thermal method and laser irradiation reduce the risk of enamel fracture.

Keywords: orthodontic debonding, enamel cracks, orthodontic brackets, debonding pliers.

Submitted: 03-Apr-2023; **Accepted in the final form:** 30-Aug-2023; **Published:** 30-Oct-2023.

Introduction

It has been proved that brackets removal does cause some irreversible damage to the tooth surface which may increase susceptibility to caries and plaque and stain accumulation on the rough enamel [1, 2]. Numerous studies show that the extend of enamel fracture depends on many variables like type of bracket, type of adhesive or debonding method and is highly correlated with the magnitude of bond strength

[3, 4]. Although it has been suggested that forces between 6 and 8 MPa are optimal for clinical use [5] and forces higher than 17 MPa are connected with higher risk of enamel damage [4], there are studies where both metal and ceramic brackets represent values higher than recommended (20.2 MPa and 24.25 MPa respectively) [3, 6].

Different methods of debonding have been proposed to reduce bond strength, such as ultrasonic, laser or electrothermal method, but mechanical debonding with debonding pliers, Weingart pliers, side cutters and lift off debonding instrument (LODI) are the most popular methods used in experiments and clinical practice. It is commonly believed that the site of bond failure is closely related to the risk of enamel fracture and according to Artun and Bergland the enamel is protected if the line of fracture is located exclusively within the adhesive [7]. Debonding methods that break the interface laying between the adhesive and bracket base are considered to be the most safe in terms of preserving enamel integrity. The aim of this systematic review was to review literature on the available methods of orthodontic metal and ceramic brackets debonding in terms of iatrogenic enamel damage in order to assess the risk connected with fixed appliance therapy and to find an optimal method for this procedure.

Material and Methods

The literature review was performed in MEDLINE via PubMed, Cochrane and Scopus databases in May 2021. Then searching was repeated in Journal of Stomatology, Orthodontic Forum and grey literature was searched using Google Scholar. English and Polish-language articles were taken into account without specifying the time frame. The index words used was “orthodontic debonding”. Only original articles were searched and as a criterion for inclusion in the study, the compliance of the information with the specific work objectives was evaluated. Animal studies using bovine incisors were excluded from the review due to the fact, that bovine enamel offers lesser resistance than human enamel (44% for permanent and 21% for deciduous teeth) [8]. Studies conducted on bleached, fluorosed or hypomineralized teeth, composite and porcelain restorations and lingual brackets were rejected from the research. The systematic review was reported according to the PRISMA statement.

Metal brackets

The authors identified thirteen studies describing effects of metal brackets debonding. There was only one study comparing the effect of debonding of metal brackets with different base design [9]. Brackets in the study were debonded with Weingart pliers. The increase in the number of cracks after debonding was significant but there was no significant difference between mesh base brackets and anchor pylons base brackets.

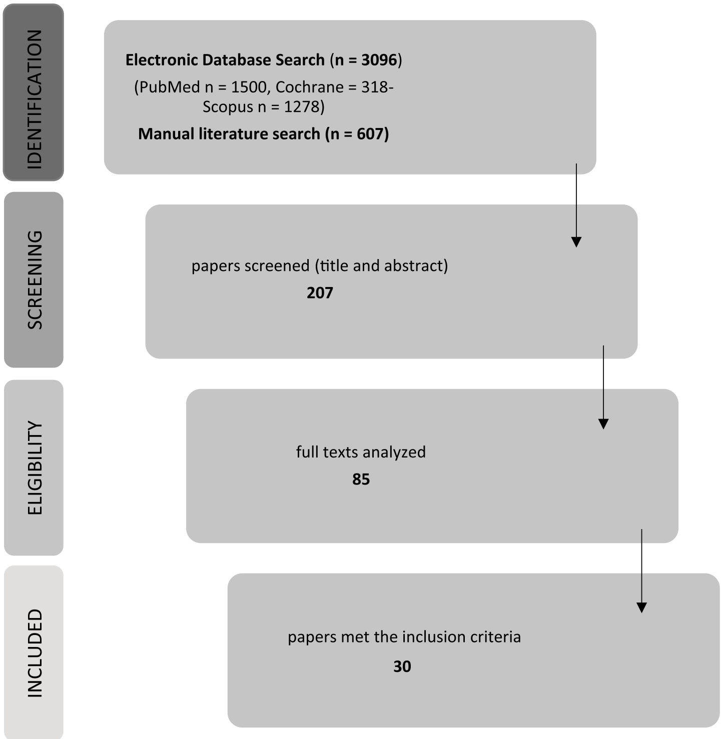

Fig. 1. The protocol of literature review.

Nevertheless, anchor-pylon base group presented significantly greater increase of mean length of enamel cracks and most of the adhesive remained on the bracket base as opposed to mesh brackets, where most of the adhesive remained on the enamel.

Eleven studies describe the effect of debonding of metal brackets using different methods (bracket debonding pliers- four studies, Weingart pliers- three studies, ligature cutting pliers- one study, comparison of different methods- four studies). In three studies pliers were mounted to the testing machine, in nine studies brackets were removed manually. All three studies assessing enamel after manual bracket debonding with Weingart pliers (by gentle squeezing of the mesiodistal edges of bracket wings) report increase in the number of enamel microcracks after debonding [10–12]. According to Dumbryte, new microcracks were identified in 40% of samples. Moreover, the mean width of existing microcracks also increased after debonding (3.82 μm on average) and more microcracks was visible in the cervical region [10]. In another study, where difference between teeth with and without microcracks was compared, Dumbryte confirmed formation of new microcracks and reported on the similar increase in the number of EMCs in both groups (15.4% and 23.1% respectively) [11]. In the third study, authors detected enamel breakouts in 27% of samples [12].

Table 1. Studies comparing debonding of metal brackets with foil mesh and with anchor pylons.

Atashi *et al.* 2018	88 extracted human premolars	1) Metal brackets with mesh base design 2) Metal brackets with anchor pylons *Light-cured adhesive Transbond XT*	Weingart pliers (squeezing mesial and distal wings)	Microscopic evaluation (stereomicroscope ×40) of number and length of enamel cracks. Evaluation of ARI.	The increase in the number of cracks after debonding was significant but there was no significant difference between groups. Mean length of enamel cracks increased significantly after debonding and was greater in anchor-pylon base group. According do ARI scores, in anchor pylons group most of the adhesive remained on the bracket base, in case of mesh brackets most of the adhesive remained on the enamel.	Not tested

Table 2. Studies describing debonding of metal brackets by means of different methods.

Dalaie *et al.* 2020	80 extracted upper and lower human premolars	Metal brackets *Self-cure adhesive* *Chemical Cure Adhesive*	BRP, fixed on the UTM machine, through five methods based on location of plier on brackets: 1) OGwing (occlusogingival), 2) MDwing (mesiodistal), 3) Oblique, 4) OGbase (occlusogingival), 5) Cusp-base.	Microscopic evaluation (stereomicroscope ×12.6). Debonding force, length of enamel cracks and ARI index were evaluated.	The average length of enamel cracks before debonding in all groups was 8.99 ± 6.33 mm. After debonding, the average length of enamel cracks was 11.38 ± 7.26 mm. In all groups, length of cracks was increased after debonding. There was no significant difference between groups in ARI and enamel cracks length change.	Not tested
Heravi *et al.* 2015	60 extracted upper central incisors	Metal bracket *1) Transbond XT* *2) Self-adhesive composite cement*	BRP mounted on Zwick (blades of the pliers placed at the bracket-adhesive interface, squeezing force)	Microscopic evaluation (stereomicroscope ×23.9). Debonding force, number, length and direction of enamel cracks and ARI index were evaluated.	There were significantly more enamel cracks in the Transbond XT group after debonding (5.09) compared to the Maxcem Elite group (3.9). In each group, a significant increase in the length of enamel cracks was noticeable after debonding (5.20 ± 1.52 and 9.23 ± 1.41 in Maxcem goup, 5.60 ± 1.48 and 9.33 ± 1.83 in Transbond group).	Not tested
Ghaffari *et al.* 2017	60 extrated human premolars	Metal brackets	BRP	Microscopic examination (stereomicroscope, ×38).	The increase in the number of enamel cracks was 1.87 in the acid-etching	Not tested

		30 teeth- acid-etching 30 teeth- laser-etching with *Transbond XT*	(a shear peeling force applied on bracket wings)	The number and length of enamel cracks were recorded. The ARI score was calculated.	group and 1.69 in the laser group. The increase in length (μm) of enamel cracks was 4637.59 for acid-etched group and 3301.49 for laser-etched group. The ARI scores of the acid-etched group were significantly higher (more adhesive on the enamel).	
Zanarini 2013	1068 metal brackets from 60 patients	Metal brackets *Transbond XT*	BRP (gently squeezing the mesial and distal wings)	Sample of 100 brackets presenting some remnants on the base was observed under SEM and energy dispersive X-ray spectrometry was performed to obtain quantitative data in terms of presence of enamel within the remnants.	The prevalence of enamel damage in respect to the whole bracket population was 5.4%. The presence of enamel was found in 100% of brackets at the energy dispersive X-ray spectrometry, but only 7% showed sizable enamel fragments at the SEM analysis.	Not tested
Janiszewska--Olszewska *et al.* 2015	15 extracted human molars	Molar tubes *Chemical-cure orthodontic adhesive*	Ligature cutting pliers (positioned occlusally and gingivally, peeling force)	Scanning of teeth surface with 3D scanner. Residual adhesive heights, enamel loss depths, residual adhesive volume and enamel loss	Mean depths of enamel loss ranged from 0.0076 mm to 0.0416 mm. Highest maximum depth of enamel loss was 0.207 mm. Median volume of enamel loss was 0.104 mm^3 and maxi-	Not tested

				volume have been calculated.	mum volume was 1.484 mm^3.	
Dumbryte *et al.* 2013	45 extracted human teeth (3 incisors, 3 canines 29 premolars)	Appropriate metal brackets *Resin adhesive*	Utility/Weingart pliers (the mesiodistal edges of bracket wings were squeezed gently)	Microscopic evaluation (SEM ×50–100). The length and width of the longest enamel micro-crack were measured.	The mean increase in width of micro-cracks was 3.82 μm. More micro-cracks was formed in the cervical third. New enamel micro-cracks were found in 40% of examined teeth.	Not tested
Dumbryte *et al.* 2021	26 patients (99 teeth); 13 patients had initially visible micro-cracks before bonding, 13 did not	Metal brackets *Transbond XT*	Weingart pliers (the mesiodistal edges of bracket wings were squeezed gently)	The number of teeth with visible EMCs and the number of premolars without EMCs were recorded for each subject before bonding and after debonding. Teeth sensitivity was also assessed.	The formation of new EMCs was noticed after debonding. Changes in the number appeared to be similar for the patients having teeth with and without visible EMCs at the beginning of treatment (15.4% and 23.1% respectively). A higher incidence of visible EMCs was associated with more frequent tooth sensitivity perceptions after debonding.	Not tested
Ryf *et al.* 2012	75 extracted human molars	The upper second molar brackets *Transbond XT adhesive*	Weingart pliers (gently squeezing)	Silicone impressions of buccal surfaces of the teeth were taken and replicas of teeth after debonding were made in dental	Enamel breakouts after debonding were detectable in 27% of all cases, with a mean volume loss of 0.02 mm3 (± 0.03 mm3) and depth of 44.9 (μm) (± 48.3 (μm)). The overall ARI	Not tested

				stone. ARI, depth of enamel cracks and volume loss was measured.	scores was 3 (all adhesive on the tooth).	
Heravi *et al.* 2008	75 extracted upper and lower premolars	Metal brackets *composite adhesive (Dent Zar Inc., USA)*	1) ligature cutters 2) single-blade bracket remover 3) a two-blade bracket remover	Microscopic evaluation (stereomicroscope ×23.9). Length and direction of enamel cracks and ARI was recorded.	There were significantly more enamel cracks in all groups after debonding and the difference in the number of cracks among the groups was not statistically significant. Increases in the lengths of the enamel cracks were consistent: 3.2 mm in the ligature cutter group, 3.5 mm in the single-blade remover group, and 3.1 mm in the two-blade remover group. In about 95% of the samples more than half of the adhesive was left on the tooth surface, irrespective of the method of debonding.	Not tested
Knosel *et al.* 2010	96 osteotomed human third molars	Premolar metal brackets with mesh base *1) Light-activated adhesive Monolok2* *2) Light-cured glass-ionomere Fuji Ortho*	1) BRP 2) Side-cutter (SC) 3) Lift-off Debonding Instrument (LODI) 4) Air pressure pulse device (The Corona Flex)	Scanning electron microscopy evaluation of enamel surface (×20 and ×50).	Enamel damage was detected in 10% of samples (LODI 21%, SC 17%, Corona Flex 0%, BRP 4%. In case of Corona Flex the line of breakage was located at the interface between the bracket base and the adhesive, in BRP group most of adhesive	Not tested

					remained on the bracket, in case of LODI and SC there was mixed pattern of breakage.	
Salehi *et al.* 2013	120 extracted human premolars	Premolar metal brackets *1) Light-cured composite resin "Transbond XT"* *2) Self-cured composite resin "Unite"*	1) LODI (tensile force) 2) BRP(shear-peel force; squeezing bracket wings)	4 groups were formed: 1) T-LODI, 2) T-BRP, 3) U-LODI, 4) U-BRP Microscopic evaluation (stereomicroscope ×38). ARI, the number and length of enamel cracks were assessed.	Teeth in group 4 had the lowest adhesive remnants on the enamel surface and the highest increase in the number of enamel cracks among the groups. No significant differences were found in the length of enamel crack caused by BRP and LODI.	Not tested
Su *et al.* 2012	90 extracted human premolars	Metal brackets *A light-curing adhesive, ENLIGHT*	1) A How plier (squeezing method) 2) A Direct Bond Bracket Remover (shearing force) 3) LODI (tensile method) All devices were mounted to the universal testing machine.	Microscopic evaluation (stereomicroscope ×25). REA index was assessed. The size and fracture pattern on the enamel surface was determined.	The mean dobonding force and REA were: 54.3N and 99.5% in group 1.32N and 77.3% in group 2, 6.8N and 98.7% in group 3. Three specimens appeared to have vertical fractures on their enamel prisms when using the shearing method.	Not tested

Table 3. Debonding of ceramic brackets.

Ahrari *et al.* 2012	90 upper and lower premolars	1) a chemically retained ceramic brackets 2) a mechanically retained ceramic brackets *Transbond XT*	1) conventional debonding: Weingart pliers for chemically retained brackets (CC group), debonding pliers for mechanically retained brackets (MC group) 2) debonding through a CO2 laser followed by pliers (CL and ML groups)	Microscopic evaluation (steromicroscope ×23.5). ARI, incidence of bracket and enamel fracture, and the lengths, frequency, and directions of enamel cracks were examined.	There was a higher percentage of ARI score 0 in CC and MC groups. In CL group the increased incidence of cohesive failure in the adhesive resin was observed. In ML group bond failure occurred predominantly at the bracket–adhesive interface. The mean increases in the lengths of enamel cracks were 6.7 mm (100%) for CC group, 5.0 mm (77%) for CL group, 4.9 mm (78%) for MC group, and 3.9 mm (73%) in ML group. Laser debonding caused a significant decrease in the frequency of enamel cracks, compared to conventional debonding.	Bracket fracture: 45% for CC group, 15% for MC group. No case in CM and ML group.
Bishara *et al.* 1995	90 extracted human teeth (60 maxillary incisors and 30 maxillary and mandibular third molars).	Polycrystalline ceramic brackets with mechanically retentive bases	BRP in Instrom Model Unversal Testing Machine	Debonding strengths, ARI and enamel damage with the use of transillumination. The enamel was examined with 10× lens.	The ARI scores ranged between 2 and 4 indicating a cohesive type of bond failure. Most of the teeth (82.02%) experienced no increase in enamel cracks after debonding. The mean debonding strength	1 out of 85

					(11.1 MPa) of the teeth with an increase in the number of cracks was significantly higher ($p < 0.05$), than those with no increase in the number of cracks (7.1 MPa).	
Bishara *et al.* 2008	30 maxillary premolars	Precoated ceramic brackets *a light-cured composite adhesive*	1) Weingart pliers 2) a new Debonding Instrument (3M Unitek)	Microscopic evaluation (×10) and transillumination for assessment of bracket fracture and residual adhesive on the enamel surface.	The incidence of enamel damage following debonding was similar in the two groups. Brackets debonded with the new instrument showed a greater tendency for the adhesive to be removed from the tooth during debonding.	Weingart pliers-fracture of 20% of brackets. Debonding Instrument decreased the incidence of bracket fracture.
Chen *et al.* 2007	90 extracted human premolars	Mechanically retained mono and polycrystalline ceramic brackets. *The dual-cured adhesive*	1) How pliers 2) specifically designed plastic pliers. Debonding was performed manually and with the same pliers connected to the testing machine.	Microscopic evaluation of the enamel and brackets (SEM). Variables evaluated: force needed to remove the brackets, ARI, frequency of bracket fracture, enamel damage.	There was no significant differences in the distribution of the ARI scores among the groups. Adhesive fracture at the ceramic-resin interface was predominant. No enamel damage was found after bracket removal.	Slightly more brackets were fractured in testing machine comparing to manual method.
Kitahara-Ceia 2008	45 extracted human premolars	1) Ceramic brackets with mechanical retention 2) Ceramic brackets with epoxy-	1) Group 1 brackets removed with a How pliers 2) Group 2 brackets removed	Microscopic evaluation (stereomicroscope ×60). ARI and enamel damage were assessed.	The mechanical retention brackets left the most adhesive on the enamel. In case of chemical retention brackets in most cases fracture was noticed	Not tested

		base mechanical retention 3) Ceramic brackets with chemical retention *Adhesive resin Concise*	with the blades of an orthodontic wire cutter 3) Group 3 brackets removed with Weingart pliers		at the enamel-adhesive interface. In the chemical retention group statistically significant enamel damage was observed after debonding.	
Strobi *et al.* 1992	48 extracted human molars 45 extracted human incisors	1) Polycrystalline ceramic brackets for the maxillary central incisor 2) Monocrystalline ceramic brackets for the mandibular canines *A two-paste mix Concise*	Debonding with the application of a torque force perpendicular to the bracket-enamel interface without and with the CO_2 or YAG laser activation.	Microscopic evaluation (SEM). Force needed to debond the bracket, the incidence of bracket failure, ARI, the presence of enamel damage were assessed.	No enamel damage was observed in laser and no-laser group. After mechanical debonding most adhesive remained on the enamel surface. The laser-aided debonding significantly reduced the debonding force and the risk of failure at the enamel-adhesive interface.	Without laser: polycrystalline 27%, monocrystalline 40%. With laser: polycrystalline 0%, monocrystalline 20%, without laser
Theodorakopoulou *et al.* 2004	80 extracted human premolars	1) Polycrystalline ceramic brackets (Clarity) 2) Monocrystalline ceramic brackets (Inspire) *Transbond XT*	1) Universal testing machine (Instron) 2) Weingart pliers for Clarity brackets 3) Special debonding instrument for Inspire brackets	Microscopic evaluation (SEM ×18 and ×23). The locations of failure sites, modified ARI, shear bond strength were measured.	No significant differences between the brackets in shear bond strength and ARI index. No loss of enamel structure in the case of Clarity brackets, in 2.5% in the Inspire brackets group.	0 of the Clarity brackets and 15% of Inspire brackets showed bracket fracture when removed with pliers.
Yassaei *et al.* 2015	30 human premolars	Polycrystalline ceramic brackets	1) BRP 2) Diode laser with a wavelength of	Microscopic evaluation (stereomicroscope ×10).	There was a significant increase in the number and lengths of enamel	0%

		Resilience	980 nm, than debonding pliers	Number and length of enamel cracks and ARI were measured.	cracks in all samples. Samples debonded without laser had significantly more enamel cracks, also the length of cracks was significantly longer. The differences in ARI were not statistically significant.	
Bora 2021	80 extracted human premolars	Ceramic brackets *Enlight*	1) Piezoelectric ultrasonic scaler 2) BRP 3) Ligature cutter 4) Thermal method (hairdryer)	Enamel surface damage after debonding was evaluated using ESI (Enamel Surface Index) scoring. ARI was assessed.	Mean ESI scores differences among four debonding techniques were not significant. The mean ARI scores: — ultrasonic scaler 1.8 — debonding plier 2.6 — ligature cutter 2.0 — thermal method 2.4 (0 — no adhesive on the tooth, 3 — all adhesive on the tooth).	Not tested

Table 4. Comparison of debonding of metal and ceramic brackets.

Cićkiewicz *et al.* 2013	35 extracted human premolars	1) metal brackets 2) ceramic brackets *Monolok2*	BRP	Assessment with the use of a scanning electron microscope and transillumination. Number, nature and extend of the cracks and ARI were calculated.	Enamel damage in ceramic brackets group was 94.4% (breakage line in different interfaces) and 64.7% in the case of metal brackets (breakage line often located at the bracket-adhesive interface). Area of damage was significantly larger in the case of ceramic brackets.	Fracture of the brackets: ceramic 66.7%, metal 5.9%.
Habibi *et al.* 2007	36 extracted maxillary human premolars	1) ceramic brackets (chemical bond) 2) ceramic brackets (mechanical bond) 3) Metal brackets *Monolok2*	BRP in universal testing machine	Microscopic evaluation (stereomicroscope ×10). Number and length of enamel cracks and ARI were calculated.	There was no difference in the number and length of enamel cracks between the groups (increase in the number of cracks was 25% for group 1 and 3 and 33.3% for group 2). The bond failure for chemically retained brackets occurred at the adhesive-bracket interface and for mechanically retained and metal brackets within the adhesive.	No bracket fracture was observed.
Cochrane *et al.* 2017	81 patients. Brackets from the maxillary right to left canine.	1) metal brackets 2) ceramic brackets *a) Transbond XT* *b) Fuji Ortho*	1) the debracketing instrument for metal brackets (444–761; 3M Unitek)	Microscopic evaluation of the brackets (backscattered scanning electron microscopy ×60). Energy dispersive x-ray	Enamel damage was 31.9% in the ceramic brackets group and 13.3% in the metal brackets group. Greater enamel damage was noticed when	Fracture of brackets: ceramic 14.6%, metal 0%.

			2) debonding pliers for ceramic brackets	spectrometry to determine the presence of enamel on the bracket base pad. The amount of adhesive remnant on the bracket calculated (BARI).	more adhesive was present on the bracket.	
Dumbryte *et al.* 2015	60 maxillary premolars	1) metal brackets 2) ceramic brackets (mechanically retained *Transbond XT*	1) Weingart pliers for metal brackets 2) Debonding instrument for ceramic brackets	Microscopic evaluation (SEM ×50, ×100). Visibility, direction, length, and location of the cracks were assessed.	The likelihood of having greater extent enamel defects was higher for the teeth with pronounced cracks. Using ceramic brackets raised the risk of greater tooth structure defects 1.45 times (45%).	
Dumbryte *et al.* 2016	90 maxillary premolars	1) metal brackets (MB) 2) ceramic brackets (CB) *Transbond XT*	1) Weingart pliers for metal brackets 2) Debonding instrument for ceramic brackets	Microscopic evaluation (SEM ×50, ×100) to divide teeth into 3 groups: 1 — teeth having pronounced EMCs; 2 — teeth showing weak EMCs; 3 — a control group. The location, length, and width of the longest EMC were determined.	Changes in width for pronounced EMCs were 0.57 mm with MB and 0.30 mm with CB; for weak EMCs, 0.32 mm with MB and 0.30 mm with CB. Pronounced EMCs did not predispose to greater EMCs increase after debonding MB and CB.	Not tested

Filho *et al.* 2015	120 extracted human incisors	1) Metal brackets 2) Ceramic brackets *Transbond Plus Color Change*	1) Side Cutter (SC) 2) Anterior BRP	Enamel assessment with optical coherence tomography (OCT). Adhesive remaining area, enamel fracture area and area of the bracket fragments on the enamel were evaluated.	Damage to the tooth tissue occurred only after debonding of ceramic brackets. The type of pliers did not influence the incidence and extent of enamel damage. The type of debonding technique and the type of bracket did not influence the amount of adhesive remaining after debonding.	Bracket fractures occurred only in the samples bonded with ceramic brackets.
Stratmann *et al.* 1996	42 ceramic brackets debonded from incisors 42 metal brackets debonded from first and second molars	1) ceramic brackets 2) metal brackets	1) Thermodebonding of ceramic brackets Dentaurum) 2) BRP for metal brackets	Evaluation of brackets by SEM and by energy dispersive X-ray microprobe to detect the area of the enamel and assess the area of adhesive fracture.	Mechanical debonding entails a fourfold risk of enamel surface fracturing (47.6%) as compared to electrothermal debonding (11.9%). Site of fracture: in thermodebonding group in 79% of specimens between the adhesive and the bracket base, after mechanical debonding in 45% of the specimens at the adhesive-enamel interface	Not tested
Choudhary 2014	138 extracted maxillary premolars	1) metal brackets 2) ceramic brackets 3) composite brackets	1) BRP 2) New Debonding Instrument (Unitek 3M)	Microscopic evaluation (stereomicroscope ×10). A modified ARI was used.	When the New Debonding Instrument was used 10–100% of the adhesive remained on the tooth. In case of conventional debonding pliers less than 10% of the adhesive remained on the tooth.	Not tested

Additionally, mean volume and depth of enamel loss were measured (0.02 mm^3 and 44.9 μm respectively). In most cases all adhesive remained on the tooth.

All authors using bracket debonding pliers as a debonding method observed changes in the morphology of the enamel. In Dalaie *et al.* study, mean increase in enamel cracks length after debonding was 2.39 mm [13]. Additionally, there was no relationship between shear bond strength and crack length change. According to Heravi *et al.*, mean increase in the length of enamel cracks was 4.03 mm and 3.73 mm depending on the type of adhesive used [14], while in the study designed by Ghaffari *et al.* mean increase in the length of EMCs was 4.64 mm [15]. The number of EMCs increased from 0.20 to 2.07 [15]. Study in which presence of enamel remnants on bracket base was tested showed, that the enamel damage was present in 5.4% of teeth [16]. In Ghaffari's study brackets were removed manually, while in the remaining two protocols brackets were detached on testing machine, but it seems that debonding method did not affect the final result. In one study ligature cutting pliers applying peeling force occlusally and gingivally were used, resulting in mean depths of enamel loss ranging from 0.0076 mm to 0.0416 mm for particular teeth [17].

In study of Heravi *et al.* [18], comparing different methods of manual debonding, significantly more enamel cracks was observed in all groups after brackets removal, but the difference between the groups was not statistically significant. There was also consistent increase in the length of EMCs (3.2 mm in the ligature cutter group, 3.5 mm in the single-blade remover group and 3.1 mm in the two-blade remover group). In 95% of samples more than half of the adhesive remained on the tooth surface. Also Salehi *et al.* found no significant difference in the length of EMCs caused by debonding pliers and LODI [19]. In the study described by Knosel *et al.* [20] majority of damage resulted from LODI (21% samples) and side-cutter (17%), while bracket removal pliers caused enamel damage only in one case (4%) and air pressure pulse device (The Corona Flex) in no cases. Su *et al.* comparing debonding with a How pliers, a direct bond bracket remover and LODI (all devices mounted to the testing machine) found fractures only in a direct bond remover group (10% of samples) [21].

Ceramic brackets

Nine studies testing ceramic brackets debonding were selected by the authors. In three articles effect of polycrystalline brackets debonding was described. Bishara *et al.* concluded, that after removal of polycrystalline brackets with mechanically retentive bases by means of debonding pliers in testing machine, 17.98% of teeth experienced an increase in enamel cracks [22]. The same author in another study reported on similar incidence of enamel damage in case of debonding with Weingart pliers and a new debonding instrument [23]. Yassaei *et al.* evaluated the enamel after brackets removal with debonding pliers with and without laser irradiation and observed, that there was significant increase in the number and length of enamel cracks in all samples, but samples debonded without laser had significantly more enamel cracks and the length of cracks was longer [24].

In one study [25] authors compared debonding of ceramic brackets with the use of piezoelectric ultrasonic scaler, debonding plier, ligature cutter and thermal method and concluded, that there was no significant difference between the groups in terms of enamel damage.

Three studies compared effect of debonding of poly and monocrystalline ceramic brackets. According do Chen *et al.* no enamel damage was reported after removal of polycrystalline brackets with How pliers and monocrystalline brackets with specifically designed plastic pliers despite the fact, that forces needed to remove polycrystalline brackets were 76.89 N and 17.92 N in the case of monocrystalline brackets [26]. Also Strobi *et al.* [27] and Theodorakopoulou *et al.* [28] found no enamel damage in groups with mono and polycrystalline brackets regardless of the method used. Nevertheless, laser activation prior to debonding proved to reduce the debonding force [27].

In two studies authors compared debonding of chemically retained and mechanically retained ceramic brackets. Ahrari *et al.* [29] observed in the study testing conventional and laser-aided debonding that debonding of chemically retained brackets with the use of pliers caused mean increase of length of enamel cracks equal 6.7 mm, while in case of laser irradiation mean cracks length was 5.0 mm. In mechanically retained groups mean increase of enamel cracks was 4.9 mm for conventional debonding and 3.9 mm for laser debonding. Kitahara-Ceia found, that while there was no statistically significant enamel damage in the group of mechanical retention base brackets, chemical retention group manifested statistically significant enamel damage after debonding [30]. In the case of mechanical retention brackets most of the adhesive remained on the enamel, in chemical retention group bond failure was noticed between the enamel and the adhesive.

Ceramic and metal brackets

In eight studies comparison of debonding of metal and ceramic brackets was performed. Three out of four articles testing the increase in the number of enamel cracks after debonding proved that damage occurs more frequently with the removal of ceramic brackets than with metal brackets [31–33]. According to Cićkiewicz *et al.* enamel damage connected with debonding with bracket removal pliers occurred in 94.4% of ceramic brackets and in 64.7% of metal brackets [31]. The type of pliers (side cutter and anterior bracket removal plier) did not influence the incidence and extent of enamel damage [33].

Results of one study, where all brackets were debonded with bracket removal pliers, indicate, that the increase of enamel cracks after debonding was 25% for metal and chemically retained ceramic brackets and 33.3% for mechanically retained brackets [34].

All three studies measuring the magnitude of enamel fracture (area, width, length) proved that changes were significantly greater in case of ceramic brackets [31, 35, 36].

In one study comparing bracket removal with bracket removal plier and electrothermal debonding the authors found, that mechanical debonding entails a fourfold risk of enamel damage (47.6% of samples) as compared to thermodebonding (11.9%) [37]. Choudhary *et al.* [38] compared debonding of metal, ceramic and composite brackets with bracket removal pliers and New Debonding Instrument and the results indicate that in case of conventional pliers the failure occurs close to the enamel, but when New Debonding Instrument is used the failure takes place within the adhesive or at the adhesive-bracket interface.

Bracket fracture

Eleven studies provides with the information regarding bracket fracture. Three authors reported that ceramic brackets are more susceptible to destruction comparing to metal brackets [31–33]. In two studies no bracket fracture was observed during debonding regardless of the method used (laser or mechanical debonding) [24, 34]. Two authors reported that laser activation protects the ceramic bracket from damage while mechanical debonding is more often connected with bracket fracture [27, 29]. Results of two studies also suggest, that monocrystalline brackets are more susceptible to damage comparing to polycrystalline ones [27, 28].

Discussion

Regarding the design of orthodontic metal brackets two main details are employed in order to increase its retention to enamel, including the application of a metal "net" in the case of foil mesh brackets and incorporation of anchor pylons in one-piece brackets. Anchor pylon base brackets represent higher shear bond strength values [39] and study by Atashi [9] showed that debonding with Weingart pliers caused greater increase in length of enamel cracks comparing to mesh brackets. Weingart pliers were the only method used to test the effect of debonging of one-piece brackets.

In the case of foil mesh brackets, Weingart pliers, which represent squeezing force, were responsible for formation of new microcracks in 27% [12] to 40% [10] of samples and mean crack depth was 0.0449 mm [12]. In the study, where ligature cutters were used, mean depths of enamel loss for particular teeth ranged from 0.0076 mm to 0.0416 mm [17]. Unfortunately, since different type of brackets was used in abovementioned studies (brackets and tubes), exact comparison between these two debonding methods seem to be inaccurate.

Some authors suggest that the bracket-adhesive interface is more resistant to shear force than to a tensile stress and thus site of failure in case of bracket removal pliers is located closer to the enamel comparing to other methods [20]. Results of our review are less consistent. According to Filho *et al.* [33] bracket removal pliers caused no enamel damage and enamel cracks were detected as a presence of the enamel on the bracket base in 5.4% of samples in the study conducted by Zanarini *et al.* [16] which may suggest, that bracket removal pliers detach mesh brackets in a safer manner comparing to Weingart pliers. On contrary, Stratmann *et al.* [37] recorded enamel damage in 47.6% and Cićkiewicz *et al.* [31] in 64.7% of samples when brackets were debonded with bracket removal pliers. Also rather significant increase in enamel cracks length ranging from 2.39 mm [13] to 4.64 mm [15] and increase in the mean number of enamel cracks from 0.2 to 2.07 were recorded in studies testing bracket removal pliers. It is impossible again to perform exact comparison between selected for the review studies due to the fact, that different parameters were measured in individual experiments (number, width, length, depth, surface area of enamel cracks).

According to some studies LODI, which produces tensile force, creates the most consistent separation at the bracket-adhesive level leaving protective layer of the adhesive on the tooth surface [20]. Nevertheless Salehi *et al.* found no significant difference in the length of EMCs caused by debonding pliers and LODI [19] but in Knosel's *et al.* study [20] bracket removal pliers caused enamel damage in one case (4%), ligature cutters in 17% and majority of damage resulted from LODI (21% samples). On contrary, Su *et al.* observed no enamel damage when tensile force (LODI) and squeezing method (a How plier) were used, while shearing force caused vertical fractures of the enamel [21].

Properties of ceramic brackets differ significantly from metal brackets (smaller rigidity, greater brittleness) and it is commonly believed that debonding of ceramic brackets is connected with higher tendency to enamel cracks formation. However, results of our review do not support this statement. Habibi *et al.* [34] found no difference in number of enamel cracks between metal and ceramic brackets when bracket removal pliers were used. Chen observed no enamel damage after mechanically retained brackets removal with How pliers and plastic pliers [26] and Theodorakopoulou reported enamel cracks only in 1.25% of samples [26]. Results presented by Bishara *et al.* [22] are less optimistic since they observed increase in enamel cracks in 18% of mechanically retained brackets debonded with bracket removal pliers. Results obtained by Cićkiewicz *et al.* [31] differ significantly from other researchers since the prevalence of enamel damage in their study was 94.4% of samples removed with bracket removal pliers. Dumbryte *et al.* [36] noticed greater width and length of enamel microcracks in the case of ceramic brackets when compared to metal brackets, but different method of debonding was applied — Weingart pliers for metal brackets and debonding instrument for ceramic brackets.

Theoretically, placement of sharp edges of pliers at the enamel-adhesive level causes deformation of bracket base or cohesive fracture within the adhesive and reduces likelihood of enamel damage. Nevertheless, Bishara *et al.* did not find significant difference between debonding with Weingart pliers and a new debonding instrument [23] and Filho *et al.* [33] between Weingart pliers and side cutters in terms of incidence and extent of enamel damage. What was confirmed by the assessment of ARI score is, methods using force acting at the level of the bracket body tend to leave a significant amount of the adhesive on the enamel surface [23]. Bora *et al.* [25] also found no difference in terms of enamel damage after debonding with different methods (bracket removal plier, side cutter, piezoelectric ultrasonic scaler, thermal method). Consequently it is impossible to recommend one particular mechanical method for removal of ceramic brackets.

Some authors tested the effect of laser irradiation on debonding and the results suggest, the laser activity minimizes tendency to enamel damage. Strobi *et al.* observed no enamel damage after debonding of mono and polycrystalline bracket with and without laser activation [27], while Yassaei *et al.* reported on larger number and length of enamel cracks in no-laser group [24]. Positive effect of laser irradiation was also described by Ahrari *et al.* [29], where enamel cracks were 1 mm shorter in mechanically retained brackets group and 1.7 mm shorter in chemically retained when bracket were subjected to laser activity, comparing to the brackets debonded with conventional manner (Weingart pliers). Results of our review also show, that brackets with chemical retention are connected with higher risk of enamel fracture [30]. Apart from enamel assessment in terms of enamel cracks presence, numerous authors use the adhesive remnant index (ARI) and its modifications to evaluate the site of bracket failure, since the mode of fracture located and the bracket-adhesive interface is considered to be the safest for the enamel. According to our review, results are quite inconsistent and differ among authors. Considering bracket removal pliers, which are one of the most popular tools for debonding, two authors found that site of failure of metal brackets was predominantly located at the enamel-adhesive level [20, 38] while according to another two the failure took place at the bracket-adhesive interface [31, 32]. Methods using squeezing methods (Weingart and How pliers) [12, 26, 30] as well as laser irradiation and thermal method seem to predispose to the fracture at the bracket-adhesive interface [27, 37]. Nevertheless, location of the failure far from the enamel did not protect the enamel from the damage entirely [20, 31]. Since, according to some authors, a higher prevalence of microcracks predispose to tooth sensitivity perceptions after brackets removal [11], further efforts should be made to investigate consequences of orthodontic debonding with the regard to the method used.

Conclusion

Results of the review do not allow to identify an optimal method for orthodontic debonding. Nevertheless, thermal method and laser irradiation minimize the risk of enamel damage.

Author contributions

Conceptualization, M.G.-S.; methodology, M.G.-S., P.P; formal analysis, M.G.-S., P.P., M.P; investigation, M.G.-S., P.P; writing — original draft preparation, M.G.-S., P.P.; writing — review and editing, M.G.-S., M.P.; supervision, M.G.-S.; project administration, M.G.-S.

All authors have read and agreed to the published version of the manuscript.

Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not for-profit sectors.

Conflict of interest

None declared.

Abbreviations

BRP — bracket removal plier
CB — ceramic brackets
EMC — enamel microcracks
LODI — Lift-Off Debracketing Instrument
MB — metal brackets

References

1. *Dumbryte I., Vebriene J., Linkeviciene L., Malinauskas M.*: Enamel microcracks in the form of tooth damage during orthodontic debonding: A systematic review and meta-analysis of in vitro studies. Eur J Orthod. 2018; 40 (6): 636–648.
2. *Zachrisson B.U., Skogan Ö., Höymyhr S.*: Enamel cracks in debonded, debanded, and orthodontically untreated teeth. Am J Orthod. 1980; 77 (3): 307–319.
3. *Rix D., Foley T.F., Mamandras A.*: Comparison of bond strength of three adhesives: Composite resin, hybrid GIC, and glass-filled GIC. Am J Orthod Dentofac Orthop. 2001; 119 (1): 36–42.
4. *Hobson R.S., Ledvinka J., Meechan J.G.*: The effect of moisture and blood contamination on bond strength of a new orthodontic bonding material. Am J Orthod Dentofacial Orthop. 2001; 120 (1): 54–57.

5. *Clark S.A., Gordon P.H., McCabe J.F.*: An ex vivo investigation to compare orthodontic bonding using a 4-META-based adhesive or a composite adhesive to acid-etched and sandblasted enamel. J Orthod. 2003; 30 (1): 51–58.
6. *Joseph V.P., Rossouw E.*: The shear bond strengths of stainless steel and ceramic brackets used with chemically and light-activated composite resins. Am J Orthod Dentofacial Orthop. 1990; 97 (2): 121–125.
7. *Årtun J., Bergland S.*: Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod. 1984; 85 (4): 333–340.
8. *Oesterle L.J., Shellhart W.C., Belanger G.K.*: The use of bovine enamel in bonding studies. Am J Orthod Dentofacial Orthop. 1998; 114 (5): 514–519.
9. *Atashi M.H.A., Haghighi A.H.S., Nastarin P., Atashi S.A.*: Variations in enamel damage after debonding of two different bracket base designs: An in vitro study. J Dent Res Dent Clin Dent Prospects. 2018 Mar 14 [cited 2020], 12 (1): 56–62.
10. *Dumbryte I., Linkeviciene L., Malinauskas M., Linkevicius T., Peciuliene V., Tikuisis K.*: Evaluation of enamel micro-cracks characteristics after removal of metal brackets in adult patients. Eur J Orthod. 2013; 35 (3): 317–322.
11. *Dumbryte I., Malinauskas M.*: In vivo examination of enamel microcracks after orthodontic debonding: Is there a need for detailed analysis? Am J Orthod Dentofac Orthop. 2021; 159 (2): 103–111.
12. *Ryf S., Flury S., Palaniappan S., Lussi A., Meerbeek B., Zimmerli B.*: Enamel loss and adhesive remnants following bracket removal and various clean-up procedures in vitro. Eur J Orthod. 2012; 34 (1): 25–32.
13. *Dalaie K., Fatemi S.M., Behnaz M., Ghaffari S., Hemmatian S., Soltani A.D.*: Effect of different debonding techniques on shear bond strength and enamel cracks in simulated clinical set-ups. J World Fed Orthod. 2020; 9 (1): 18–24.
14. *Heravi F., Shafaee H., Abdollahi M., Rashed R.*: How Is the Enamel Affected by Different Orthodontic Bonding Agents and Polishing Techniques? J Dent. 2015; 12 (3): 188.
15. *Ghaffari H., Mirhashemi A., Baherimoghadam T., Azmi A., Rasooli R.*: Effect of Surface Treatment on Enamel Cracks After Orthodontic Bracket Debonding: Er,Cr:YSGG Laser-Etching Versus Acid-Etching. J Dent. 2017; 14 (5): 259–266.
16. *Zanarini M., Gracco A., Lattuca M., Marchionni S., Gatto M.R., Bonetti G.A.*: Bracket base remnants after orthodontic debonding. Angle Orthod. 2013; 83 (5): 885–891.
17. *Janiszewska-Olszowska J., Tandecka K., Szatkiewicz T., Stępień P., Sporniak-Tutak K., Grocholewicz K.*: Three-dimensional analysis of enamel surface alteration resulting from orthodontic clean-up — comparison of three different tools. BMC Oral Health. 2015; 15 (1).
18. *Heravi F., Rashed R., Raziee L.*: The effects of bracket removal on enamel. Aust Orthod J. 2008; 24 (2): 110–115.
19. *Salehi P., Pakshir H., Naseri N., Baherimoghaddam T.*: The effects of composite resin types and debonding pliers on the amount of adhesive remnants and enamel damages: a stereomicroscopic evaluation. J Dent Res Dent Clin Dent Prospects. 2013; 7 (4): 199–205.
20. *Knösel M., Mattysek S., Jung K., Sadat-Khonsari R., Kubein-Meesenburg D., Bauss O., et al.*: Impulse debracketing compared to conventional debonding. Angle Orthod. 2010; 80 (6): 1036–1044.
21. *Su M.Z., Lai E.H.H., Chang J.Z.C., Chen H.J., Chang F.H.F., Chiang Y.C., et al.*: Effect of simulated debracketing on enamel damage. J Formos Med Assoc. 2012; 111 (10): 560–566.
22. *Bishara S.E., Fonseca J.M., Boyer D.B.*: The use of debonding pliers in the removal of ceramic brackets: Force levels and enamel cracks. Am J Orthod Dentofac Orthop. 1995; 108 (3): 242–248.
23. *Bishara S.E., Ostby A.W., Laffoon J., Warren J.J.*: Enamel cracks and ceramic bracket failure during debonding in vitro. Angle Orthod. 2008; 78 (6): 1078–1083.
24. *Yassaei S., Soleimanian A., Nik Z.E.*: Effects of Diode Laser Debonding of Ceramic Brackets on Enamel Surface and Pulpal Temperature. J Contemp Dent Pr. 2015; 16 (4): 270–274.

25. *Bora N., Mahanta P., Kalita D., Deka S., Konwar R., Phukan C.*: Enamel Surface Damage following Debonding of Ceramic Brackets: A Hospital-Based Study. Sci World J. 2021; 6; 2021: 5561040.
26. *Chen H.Y., Su M.Z., Chang H.F.F., Chen Y.J., Lan W.H., Lin C.P.*: Effects of different debonding techniques on the debonding forces and failure modes of ceramic brackets in simulated clinical set-ups. Am J Orthod Dentofac Orthop. 2007; 132 (5): 680–686.
27. *Strobl K., Bahns T.L., Wiliham L., Bishara S.E., Stwalley W.C.*: Laser-aided debonding of orthodontic ceramic brackets. Am J Orthod Dentofac Orthop. 1992; 101 (2): 152–158.
28. *Theodorakopoulou L.P., Sadowsky P.L., Jacobson A., Lacefield W.*: Evaluation of the debonding characteristics of 2 ceramic brackets: an in vitro study. Am J Orthod Dentofac Orthop. 2004; 125 (3): 329–336.
29. *Ahrari F., Heravi F., Fekrazad R., Farzanegan F., Nakhaei S.*: Does ultra-pulse CO 2 laser reduce the risk of enamel damage during debonding of ceramic brackets? Lasers Med Sci. 2012; 27 (3): 567–574.
30. *Kitahara-Céia F.M.F., Mucha J.N., dos Santos P.A.M.*: Assessment of enamel damage after removal of ceramic brackets. Am J Orthod Dentofac Orthop. 2008; 134 (4): 548–555.
31. *Cickiewicz M., Jodkowska E., Wasowicz M., Czochrowska E.*: Ocena mikrostruktury szkliwa po odklejeniu zamków ortodontycznych — badanie in vitro. Forum Ortod. 2013; 9 (2): 79–89.
32. *Cochrane N.J., Lo T.W.G., Adams G.G., Schneider P.M.*: Quantitative analysis of enamel on debonded orthodontic brackets. Am J Orthod Dentofac Orthop. 2017; 152 (3): 312–319.
33. *Leão Filho J.C.B., Braz A.K.S., de Araujo R.E., Tanaka O.M., Pithon M.M.*: Enamel quality after debonding: Evaluation by optical coherence tomography. Braz Dent J. 2015; 26 (4): 384–389.
34. *Habibi M., Nik T.H., Hooshmand T.*: Comparison of debonding characteristics of metal and ceramic orthodontic brackets to enamel: An in-vitro study. Am J Orthod Dentofac Orthop. 2007; 132 (5): 675–679.
35. *Dumbryte I., Jonavicius T., Linkeviciene L., Linkevicius T., Peciuliene V., Malinauskas M.*: Enamel cracks evaluation — a method to predict tooth surface damage during the debonding. Dent Mater J. 2015; 34 (6): 828–834.
36. *Dumbrytea I., Jonaviciusb T., Linkevicienec L., Linkeviciusc T., Peciuliened V., Malinauskas M.*: The prognostic value of visually assessing enamel microcracks: Do debonding and adhesive removal contribute to their increase? Angle Orthod. 2016; 86 (3): 437–447.
37. *Stratmann U., Schaarschmidt K., Wegener H., Ehmer U.*: The extent of enamel surface fractures. A quantitative comparison of thermally debonded ceramic and mechanically debonded metal brackets by energy dispersive micro- and image-analysis. Eur J Orthod. 1996; 18 (6): 655–662.
38. *Choudhary G., Gill V., Reddy Y.N.N., Sanadhya S., Aapaliya P., Sharma N.*: Comparison of the Debonding Characteristics of Conventional and New Debonding Instrument used for Ceramic, Composite and Metallic Brackets — An Invitro Study. J Clin Diagn Res. 2014; 8 (7): ZC53.
39. *Gibas-Stanek M., Williams S., Ryniewicz W.I., Loster B.W.*: Variations in orthodontic bracket retention related to base design. Comparison of foil mesh and anchor pylons brackets. J Stomatol. 2016; 69 (6): 680–694.