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Effect of Orthodontic Debonding and Adhesive Removal on the Enamel – Current Knowledge and Future Perspectives – a Systematic Review

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Statistical Analysis C
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Manuscript Preparation E
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After orthodontic treatment, brackets are debonded and residual adhesive is removed, causing iatrogenic enamel damage. The aim of this study was to review the methods of orthodontic adhesive removal, find clear evidence, and provide a rationale for this procedure.


A literature search was performed in PubMed, Dentistry and Oral Sciences, Scopus, Cochrane, Google, and Google Scholar using keywords: orthodontic adhesive removal, orthodontic debonding, orthodontic clean-up. Studies concerning human enamel roughness or loss from debonding and adhesive removal were considered. Forty-four full-text articles were analyzed and 3 were rejected after detailed reading; finally 41 papers were included.

Fifteen qualitative studies, 13 studies based on indices of enamel surface, and 13 quantitative studies were found. No meta-analysis could be performed due to a lack of homogenous quantitative evidence. The most popular tools were tungsten carbide burs, which were faster and more effective than Sof-Lex discs, ultrasonic tools, hand instruments, rubbers, or composite burs. They remove a substantial layer of enamel and roughen its surface, but are less destructive than Arkansas stones, green stones, diamond burs, steel burs, and lasers. Multi-step Sof-Lex discs and pumice slurry are the most predictable enamel polishing tools.

Arkansas stones, green stones, diamond burs, steel burs, and lasers should not be used for adhesive removal. The use of tungsten carbide bur requires multistep polishing. Further efforts should be made to find tools and methods for complete removal of adhesive remnants, minimizing enamel loss and achieving a smooth surface.

MeSH Keywords: **Dental Debonding • Dental Enamel • Orthodontic Brackets**

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Background

Orthodontic treatment is extremely popular in modern society. Bonding of attachments to enamel is based on acid etching, resulting in microporosity that allows micro-retention of resin infiltrating into the enamel.

After active orthodontic treatment, brackets are mechanically debonded and residual adhesive must be mechanically removed, since resin remnants accumulate dental plaque and might discolor [1].

Currently, no technique allows removal of the composite remnants without any damage of the enamel surface. The underlying reasons are acid etching resulting in resin infiltration into the enamel [2], and hardness of the enamel (about 5 in the Mohs scale) lower than that of the abrasive materials used (quartz, aluminium, carbon steel, zirconium oxide 7, and tungsten carbide 8).

Efforts are made to minimize the loss of the enamel external layer, because it is hardest and richest in fluoride. Moreover, the enamel surface should be left as smooth as possible after debonding, since deep scratching is not polished through the years by tooth brushing [3].

The aim of this systematic review was to review papers on the available methods of orthodontic adhesive removal after debonding metal brackets from human teeth in terms of iatrogenic enamel damage in order to find clear evidence and provide a rationale for this procedure.

Search strategy

We searched the literature in PubMed using the keywords: orthodontic adhesive removal, orthodontic debonding, orthodontic clean-up. Search results and related citations were viewed. Grey literature was searched using Google and Google Scholar (last search date was 23 September 2013). Then searching was repeated in Dentistry and Oral Sciences (last search 27 September 2013), Scopus (last search 3 October 2013), and Cochrane (last search 7 October 2013). No language limit was established.

The titles and abstracts received were analyzed. Studies concerning enamel surface roughness or enamel loss after debonding brackets and subsequent adhesive removal were accessed. Papers describing removal of composite alone bonded to enamel were not included, since our review aimed at finding data on cumulative effect of debonding and adhesive clean-up. After consideration, we decided to include papers on non-ceramic brackets only in order to increase the consistency between clinical

results of different studies. Studies concerning demineralized, remineralized, or bleached enamel were included only if a control group of intact teeth was present. All methods of enamel clean-up and assessment of its surface alteration in terms of iatrogenic damage were included. Animal studies were excluded from analysis. Assessment of eligibility was conducted by 2 independent reviewers. Disagreements were resolved by discussion. Full-text articles were obtained and analyzed. Hand searching was performed using reference lists of the articles received.

Data extraction

The following data were extracted from each study included: number and sort of objects assessed, methods of adhesive removal, methods of assessment of enamel surface, and main results.

The studies were assigned as qualitative if they were based on descriptive criteria, as quantitative if they were based on subjective descriptive criteria, and quantitative if they were based on instrumental measurements.

The flow-diagram for the PubMed search is presented in Figure 1. Subsequent searches in other databases did not allow for the inclusion of any additional manuscripts. Finally, 44 full-text articles were accessed and analyzed. After detailed reading, 2 studies were rejected because the study did not include bracket bonding, and 1 study was excluded because no adhesive removal was performed. Finally, 41 full-text papers were included.

Various tools were used for adhesive removal, but the most popular was a tungsten carbide bur. The teeth examined were mainly premolars. No meta-analysis could be performed due to a lack of homogenous quantitative evidence. The high diversity of the instrumental measurements and outcome variables reported made it difficult to make comparisons between the studies.

Qualitative studies [4–18] (and qualitative results of the study by Fitzpatrick and Way [19], which also contained quantitative data) based on visual subjective assessment of the enamel surface are presented in Table 1.

Gwinnett and Gorelick [16] concluded that a green rubber wheel was more effective and less destructive to enamel than a tungsten carbide bur, giving a macroscopic polish; fine scratches visible microscopically were easily removed with pumice prophylaxis paste. Zarrinnia et al. [9] compared 7 different adhesive removal procedures and concluded that carbide burs were efficient in adhesive removal, but produced unsatisfactory

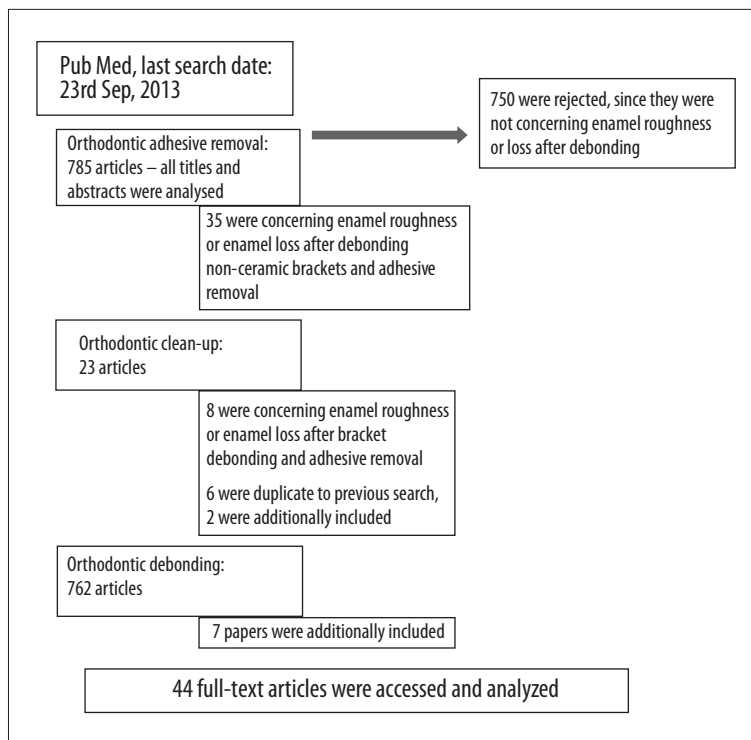


Figure 1. The flow-diagram for the PubMed search.

Table 1. Qualitative studies based on subjective visual assessment of enamel surface following orthodontic debonding and clean-up in chronological order (from earliest to most recent).

Authors, year of publication, [reference No.]	Objects assessed	Methods of adhesive removal	Method of assessment of enamel surface after clean-up	Main results
Ulusoy, 2009 [4]	80 extracted premolars	Tungsten carbide bur, Sof-Lex disc, SuperSnap multi-step disc, SuperSnap one-step disc, PoGo multistep and one-step micropolishers, Optishine one-step brush	SEM, visual subjective assessment	PoGo produced the best surface finish, but was most time-consuming
Eminkahyagil et al., 2006 [5]	80 extracted premolars	Tungsten carbide bur, Sof-Lex discs, microetcher	SEM visual assessment	Tungsten carbide bur was the quickest, but most hazardous to enamel. Sof-Lex was time-consuming and left resin remnants
Radlanski, 2001 [6]	70 human incisors	Eight-bladed carbide finishing bur	SEM, qualitative assessment	Tungsten carbide bur removes adhesive and large areas of enamel. It was not possible to smooth out the lesions. The new tungsten carbide bur was found less aggressive
Smith et al., 1999 [7]	100 extracted human premolars	Tungsten carbide bur, CO2 laser	SEM, Enamel Damage Score	Enamel damage from laser depends on the power used, enamel pitting and burning is caused, laser may be more destructive than tungsten carbide bur
Osorio et al., 1998 [8]	35 extracted human premolars	Tungsten-carbide burs, Sof-Lex aluminium oxide discs, Arkansas stone, Enhance composite finishing Discs and Polishing Cups	SEM, subjective visual assessment	The roughest surface was observed following adhesive removal with Arkansas stone, the smoothest – Enhance and Sof-Lex discs. No technique allowed adhesive removal without a significant enamel damage

Table 1 continued. Qualitative studies based on subjective visual assessment of enamel surface following orthodontic debonding and clean-up in chronological order (from earliest to most recent).

Authors, year of publication, [reference No.]	Objects assessed	Methods of adhesive removal	Method of assessment of enamel surface after clean-up	Main results
Zarrinnia et al., 1995 [9]	60 human extracted premolars	Diamond burs, carbide bur, stainless steel bur, sandpaper discs, Sof-Lex discs, shofu wheels from enamel adjustment kit	ESEM, qualitative assessment	Diamond burs were extremely destructive, stainless steel bur was inefficient and tungsten carbide bur was efficient, but left "unsatisfactory enamel surface". Sof-Lex discs produced surfaces, which "could be readily restored satisfactory after receiving a final polish", but were slow in resin removal
Campbell, 1995 [10]	Maxillary central and lateral incisors and canines extracted because of periodontal involvement (number of teeth not provided)	Greenstone, diamond bur, sharp band remover, tungsten carbide fluted bur, cross-cut tungsten carbide bur, abrasive disc	SEM – visual assessment	Tungsten carbide bur followed by polishing with pumice in a rubber cup was leaving the smoothest surface
Krell et al., 1993 [11]	Polyvinyl siloxane impressions of labial surfaces of 30 extracted human premolars	Tungsten carbide bur followed by Sof-Lex Discs, ultrasonic clean-up, ultrasonic debonding with tips designed for the removal of Maryland Bridges followed by ultrasonic clean-up	SEM assessment of silicone impressions of the labial surfaces	The use of tungsten carbide bur left scratched surfaces with evidence of excessive enamel removal. Debonding with pliers followed by ultrasonic clean-up left cleanest surface, often with visible perikymata and required less chair-time than the other two techniques
Vieira et al., 1993 [12]	9 extracted teeth (four bicuspid and five cuspids)	Tungsten carbide bur without pumicing, after 10 and 30 seconds pumicing	SEM subjective visual assessment	Pumicing is necessary after adhesive removal with tungsten carbide bur. However, even after 30 seconds polishing, the surfaces do not have the same smoothness as untreated controls
Rouleau et al., 1982 [13]	Epoxy replicas of forty five teeth of twelve orthodontic patients	Hand scaler, carbide burs followed by pumicing	SEM, qualitative assessment	The smoothest surface was resulting from the use of ultrafine tungsten carbide bur
Retief and Denys, 1979 [14]	38 extracted central incisors	Bracket removing instrument Hand scaler Superfine diamond bur Finishing carbide bur Stainless steel finishing bur Sof-Lex discs Ceramisté wheels	SEM – subjective visual assessment	Bracket removing instrument was leaving severe gouging, scalers produced prominent grooves, finishing diamonds – abrasion marks, carbide finishing bur – paralel grooves, stainless steel bur was removing resin with difficulty, producing gauges and becoming blunt, multistep Sof-Lex discs showed a progressive decrease in irregularities. Ceramisté wheels showed a progressive decrease in abrasive marks. Final polishing allowed achieving a satisfactory surface after the use of carbide burs, Sof-Lex discs and Ceramisté wheels

Table 1 continued. Qualitative studies based on subjective visual assessment of enamel surface following orthodontic debonding and clean-up in chronological order (from earliest to most recent).

Authors, year of publication, [reference No.]	Objects assessed	Methods of adhesive removal	Method of assessment of enamel surface after clean-up	Main results
Burapavong et al., 1978 [15]	26 mandibular premolars scheduled for extraction for orthodontic reasons bonded and extracted after adhesive removal	Hand scaler, green stone, ultrasonic scaler	SEM qualitative assessment	Green stone was leaving deep abrasive striations. All the techniques left gauging, which was smoothed, but not removed by final pumicing
Gwinnett and Gorelick, 1977 [16]	Unknown number of human extracted teeth	Green stone followed by white stone and pumice, sandpaper discs followed by pumice, green rubber wheel followed by pumice, tungsten carbide bur followed by pumice, steel bur followed by pumice, acrylic steel bur followed by pumice	SEM, qualitative assessment	Green rubber wheel was most effective, gave a macroscopic polish and produced fine scratches identified microscopically, which were easily removed by pumicing. Tungsten carbide burs removed a substantial layer of enamel, leaving scratches, faceting and large pits. Faceting and pits were not removed by pumicing
Zachrisson, 1977 [17]	705 different teeth in 46 children	Hand scaler, tungsten carbide bur	Macroscopic visual assessment	Direct bonding is not associated with signs of enamel damage or visible discoloration up to 12 months subsequent to bracket removal
Fitzpatrick and Way, 1977 [18]	Silicone impressions of 32 teeth scheduled for extraction for orthodontic reasons	Fluted bur followed by rubber cup and Zircate	SEM visual assessment	Bracket placement, removal and clean-up resulted in a smooth surface, clinically and microscopically similar to untouched enamel
Caspersen, 1977 [19]	38 teeth and twelve as controls, extracted for orthodontic reasons after bracket debonding	Surgical scalpel, abrasive wheel, polishing with pumice	SEM visual assessment	Well-defined scratches were found on enamel surface. Subsequent polishing smoothed, but not removed the scratches

enamel surface, which should be finished using Sof-lex discs and then finally polished with a rubber cup and Zircate paste.

Attempts were made to perform a quantitative assessment using SEM; thus, four different indices aiding visual enamel evaluation were found in the literature [3,20–27].

Studies using different indices [3,20–30] are listed in Table 2. Zachrisson and Årthun [3] compared green rubber wheel and tungsten carbide bur, and scored enamel surface after adhesive removal with green rubber as 3 and with tungsten carbide bur as 1. The results were contradictory to those by Gwinnett and Gorelick [16] due to different methods of enamel surface assessment.

Table 2. SEM studies based on indices of enamel roughness or damage.

Authors, year of publication, [reference No.]	Objects assessed	Methods of adhesive removal	Index use to assess enamel surface after clean-up	Main results
Sessa et al., 2012 [21]	Epoxy replicas of 32 premolars of four patients	Tungsten carbide bur, polishing cup	Enamel Surface Index (ESI)	The most frequent scores were 1 and 2, no differences were found between different bonding materials in terms of iatrogenic damage resulting from adhesive removal
Baumann et al., 2011 [24]	Epoxy replicas of 394 teeth of 22 patients	Tungsten carbide bur plus ultrasound and air-flow (on proximal and cervical areas) followed by silicon polishers with slurry	Enamel Damage Index (EDI), Line Angle Grooves (LAG)	EDI 0 and 1 were the most frequent scores. The use of dental loupes significantly reduced enamel damage
Alessandri Bonetti et al., 2011 [23]	Epoxy replicas of 36 second premolars of twelve patients	Twelve-blade tungsten carbide bur, 20000 rpm without water cooling followed by Sof-lex discs from medium to ultra-fine	Enamel Damage Index (EDI)	Score 1 was the most frequent. No differences were found between uncoated and precoated brackets in terms of enamel damage from adhesive removal
Schiefelbein and Rowland, 2011 [27]	60 extracted premolars	Adhesive removing pliers, 12-fluted carbide bur, white stone, Sof-Lex discs	Enamel Surface Rating System (ESRS)	Sof-Lex discs produced the smoothest surface, however rougher than untreated controls. White stone caused the most severe damage
Pont et al., 2010 [20]	Epoxy replicas of 62 upper anterior teeth	Tungsten carbide burs, polish cup and paste followed by rubber points	Enamel Surface Index (ESI)	Score 3 was the most frequent and anterior teeth were the most affected by iatrogenic damage. Enamel damage is not dependent on the amount of adhesive remnants
Almeida et al., 2009 [28]	16 extracted premolars, including 4 control	Tungsten carbide bur, ER: Yag Laser	Own scale	ER: Yag Laser caused a significantly more severe enamel damage than tungsten carbide bur
Tecco et al., 2008 [29]	80 extracted first premolars	Debonding pliers followed by tungsten carbide bur	Visual assessment, own scale, assessment of enamel cracks	Enamel damage from adhesive removal is not dependent on the bonding material used
Schuler and van Vaes, 2003 [22]	Epoxy replicas of 48 central incisors, 52 lateral incisors, 52 canines, 80 premolars, 52 first molars from 13 patients	Tungsten carbide bur with polishing	Enamel Damage Index (EDI)	Aproximal and cervical areas were most affected by iatrogenic damage
Hong and Lew, 1995 [26]	50 premolars extracted for orthodontic reasons	Band removing plier, tungsten carbide bur, ultrafine diamond bur, white stone finishing bur, time limited to 15 seconds	Surface Roughness Index (SRI)	No method was considered ideal for adhesive removal. Tungsten carbide burs gave the best surface smoothness. The ultrafine diamond bur was most efficient, but produced the roughest surface

Table 2 continued. SEM studies based on indices of enamel roughness or damage.

Authors, year of publication, [reference No.]	Objects assessed	Methods of adhesive removal	Index use to assess enamel surface after clean-up	Main results
Oliver and Griffiths, 1992 [30]	30 extracted premolars or canines	Hand scaler, ultrasonic scaler, pneumatic band driver, tungsten carbide bur	Modified ESI	Both hand and ultrasonic scalers were inefficient, band driver produced unacceptable surface. Tungsten carbide bur was superior to the other methods tested
Howell and Weeks, 1990 [25]	135 extracted premolars	Tungsten carbide bur followed by medium fine Sof-Lex disc or polishing paste	Surface Roughness Index (SRI)	Medium fine Sof-Lex disc used as a polishing procedure produced the roughest surface, whereas pumice slurry alone – the smoothest
Zachrisson and Årthun, 1979 [3]	55 young extracted premolars	Diamond fissure bur Green rubber wheel (Dedeco medium) sandpaper discs tungsten carbide bur	Enamel Surface Index (ESI)	Diamond bur received the worst score, whereas tungsten-carbide bur – the best

Alessandri Bonetti et al. [23] assessed enamel damage index following the use of tungsten carbide bur as grade 0 in 8 teeth, grade 1 in 13 teeth, grade 2 in 3 teeth, and grade 3 in 0 teeth. They found “no clinically relevant enamel damage”, but the original enamel surface could not be restored.

Quantitative studies of enamel surface roughness or enamel loss following debonding and adhesive removal based on instrumental measurements [18,31–42] are listed in Table 3. Most authors used tungsten carbide burs, despite reporting gauging faceting and enamel loss. Roughness analysis by Eliades et al. [39] supported irreversible changes in enamel surface. All authors using tungsten carbide burs stress the necessity of finishing and polishing procedures.

It should be noted that the analysis of the parameters of roughness by Eliades et al. [39] indicate that grooves produced by adhesive-removing tools remain after polishing, although height is reduced by removing material from the peak surface. Similarly, Ahrari et al. [31] stated that final polishing failed to restore enamel roughness to pretreatment values.

Karan et al. [33], in their atomic force microscopy study, found that a composite bur left a smoother surface compared to tungsten carbide, and even in pretreatment, but required longer time for adhesive removal. An advantage is that, contrary to tungsten carbide burs, fiber-reinforced composite burs are self-sharpening (i.e., abrasion of the fibers reveals a new fiber section and grinding remnants are removed by cooling water).

Concerning enamel loss, Fitzpatrick and Way [19] found 55 µm of enamel loss from orthodontic adhesive removal. Zachrisson

and Årthun [3] consider such an amount of enamel loss as alarming. Using anatomic landmarks (perikymata), they considered that they lose only 5–10 µm. However, Fjeld and Ogaard [2] found that perikymata may be present at a higher depth than previously thought. Al Shamsi et al. [35] reported that the loss of enamel after bracket debonding and adhesive removal with a tungsten carbide bur was 22.8 µm for light-cure adhesive and 50.5 µm for pre-coated brackets.

In the study by Alessandri Bonetti et al. [23], enamel surface following the use of a diamond bur received a score of 4, and it was concluded that diamond burs are unacceptable tools for adhesive remnants removal. A recent study by Ahrari et al. [31] reached a similar conclusion, both for diamond burs and for Er: Yag laser, indicating severe iatrogenic enamel damage.

Discussion

In considering adhesive removal, 2 aspects of iatrogenic enamel damage should be considered: enamel loss by etching, grinding, and subsequent polishing; and increasing enamel roughness by scratching or faceting.

Rotary instruments used for residual adhesive removal cause enamel abrasion in an amount dependent on the size and composition of the abrasive particles, the rotational speed, and the pressure against enamel surface [23]. Due to the latter factor, this procedure is operator-dependent. It is difficult to compare results from different studies based on subjective visual assessment of the enamel surface, since evaluation of the enamel surface damage with SEM is not completely objective.

Table 3. Quantitative studies concerning enamel surface or enamel loss following debonding and adhesive removal (in chronological order from latest to earliest).

Authors, year of publication, [reference No.]	Objects assessed	Methods of adhesive removal	Method of assessment of enamel surface after clean-up	Main results
Ahrari et al., 2013 [31]	Forty premolars extracted for orthodontic purposes	Tungsten carbide bur, ultrafine diamond bur, Er: Yag laser	Contact profilometry	Both diamond burs and Er: Yag laser were leaving a rougher surface than tungsten carbide bur
Ryf et al., 2012 [32]	Plaster models of 75 extracted human molars	Carbide bur followed by different polishing procedures	Laser scanning, comparison of digital models to calculate changes in surface geometry	No significant influence of clean-up method on enamel loss volume was found
Karan et al., 2010 [33]	20 human upper premolars extracted for orthodontic reasons	Tungsten carbide bur, fiber-reinforced composite bur	Atomic force microscopy with measurement of initial roughness values	Higher roughness values were obtained for tungsten carbide bur, but the adhesive removal procedure was lasting longer with fiber-reinforced composite bur
Banerjee et al., 2008 [34]	Epoxy replicas of 30 extracted human premolars	Tungsten carbide bur, alumina air-abrasion, bio-active-glass air-abrasion, subsequent polishing	3D contact profilometry, volumetric assessment of enamel damage, SEM	Bioactive glass air-abrasion was removing less enamel than tungsten carbide bur
Al Shamsi et al., 2007 [35]	Plaster models of 60 premolars extracted for orthodontic reasons	Tungsten carbide bur	3D laser scanning, calculation of enamel loss depth	The mean depth of enamel loss was 50 μm
Ireland et al., 2005 [36]	80 extracted human premolars	Tungsten carbide burs, debanding pliers, ultrasonic scaler	Measurement with Planer Surfometer to calculate the depth of enamel loss	The use of low-speed tungsten carbide bur resulted in the lowest enamel loss depth (2–28 μm)
Hosein et al., 2004 [37]	90 maxillary premolars extracted for orthodontic purposes	Tungsten carbide burs, debanding pliers, ultrasonic scaler	Measurement with Planer Surfometer (contact profilometer with a diamond stylus) to calculate the depth of enamel loss	The median enamel loss was 2.76 μm . More enamel loss occurred after the use of high speed tungsten carbide bur or ultrasonic scaler than after slow-speed tungsten-carbide bur
Tüfekci et al., 2004 [38]	28 extracted premolars, white spot lesions were artificially created <i>in vitro</i>	Tungsten carbide burs, Soflex discs	Digitalization with a null-point contact stylus system, calculation of volume loss, maximum depth and mean maximum depth	Enamel loss was 0.16 μm^3 for tungsten carbide bur and 0.10 μm^3 for Sof-Lex discs
Eliades et al., 2004 [39]	30 premolars extracted for orthodontic reasons	Tungsten carbide bur, ultra-fine diamond bur followed by finishing with Soflex discs	Contact profilometry	Sequential use of multiple polishing tools is superior to the application of any one-step procedure
Roush et al., 1997 [40]	48 extracted premolars	Tungsten carbide bur, rubber cup, Sof-Lex discs, polishing cups, perladia porcelaine polishing cups	Profilometry	Tungsten carbide burs significantly roughen enamel surface. Multi-step Sof-Lex discs provide the smoothest surface. A pumice slurry smoothes the enamel roughened by tungsten carbide bur in a more predictable way than the other methods tested

Table 3. Quantitative studies concerning enamel surface or enamel loss following debonding and adhesive removal (in chronological order from latest to earliest).

Authors, year of publication, [reference No.]	Objects assessed	Methods of adhesive removal	Method of assessment of enamel surface after clean-up	Main results
Pus and Way, 1980 [41]	100 extracted premolars with steel markers placed in the enamel	High speed bur, green rubber wheel, low speed bur	Nikon profile projector fitted with a travel microstage calibrated in μm used for quantification of enamel loss, SEM – qualitative assessment	Enamel loss ranged from 26.1 μm to 41.2 μm . The reliability of anatomic landmarks has been questioned, since perikymata were visible even after removing 29 μm of enamel
Brown and Way, 1978 [42]	26 premolars scheduled for extraction	Hand scaler and carbide finishing bur, “when necessary”, followed by polishing with zirconium silicate on a brush	Measurement of enamel loss referring to a recessed steel marker	Median enamel loss was 17.5 μm and 44 μm (different for two groups of teeth analyzed) for unfilled adhesive and 40.8 μm and 60.5 μm for filled adhesive, respectively
Fitzpatrick and Way, 1977 [16]	Silicone impressions of 32 teeth scheduled for extraction for orthodontic reasons	Tungsten carbide bur followed by rubber cup and Zircate	Optical measurement of the depth of a reference hole on silicone impressions	Average enamel loss was 55.6 μm

Although each of the indices allows for a classification of the destruction, they rely on descriptive categories, not on parameters from precise instrumental measurements.

It is believed that removal of external enamel layer leads to decreased enamel resistance (increased susceptibility to demineralization due to exposing enamel prism endings), since the most external enamel layer is harder and more mineralized than the deeper zones and should be protected. On the other hand, resin infiltration resulting from enamel etching may be up to 50 μm [43]. Thus, complete adhesive removal would require grinding a layer of the enamel. However, in the studies included, no method was used to measure the enamel remnant width or volume within the enamel.

Enamel roughening during adhesive removal may cause stain formation. Bollen et al. [44] reported that R_a of 0.2 μm is a threshold for bacterial adhesion – below this value, no further reduction in the pathogenicity of the adhering bacteria could be expected. Thus, efforts should be made to leave a smooth surface.

Studies reporting on enamel loss from instrumental measurements provide various amounts (depth or volume) of enamel loss. This fact is due to different methodology. Contact profilometry has a limitation from the stylus, and laser scanners cannot be used to scan shiny surfaces. The objects analyzed were human extracted teeth (predominantly premolars), plaster models, or epoxy replicas. In 2 studies [32,35] using laser 3D scanning, plaster models of extracted teeth were used to reduce light reflections. According to Fitzpatrick and Way [18],

the measurement error due to silicone impression inaccuracy ranges from $-2.5 \mu\text{m}$ to $+3.5 \mu\text{m}$. It can be supposed that model pouring causes a further increase of the measurement error.

In contrast, Alessandri Bonetti et al. [23] reported that the presence of saliva can affect the process of debonding, so studies on replicas are used to have an image of real teeth. Moreover, it is difficult to collect extracted intact teeth other than premolars for the purpose of scientific studies. It is of importance that enamel differs in its thickness and structure, both between tooth groups and between surfaces of the same tooth. Thus studies leaving a surface as control might not reflect real changes of the surface morphology.

Detailed quantitative analysis (e.g., volumetric assessment) of adhesive remnants as well as enamel damage with 3-dimensional techniques conducted on different teeth groups would bring the existing knowledge concerning iatrogenic enamel damage to a higher scientific level. The authors of this paper are of the opinion that in the era of magnification (microscopic) dentistry, the orthodontists should have a better insight into the exact depth of enamel loss, scratching, and faceting. Direct clinical methods of high accuracy should be invented to clinically assess adhesive remnants and enamel loss.

Conclusions

There is no doubt that fixed orthodontic treatment causes irreversible damage to dental enamel. Arkansas stones, green

stones, diamond burs, steel burs, and lasers should not be used for adhesive removal. Tungsten carbide burs are faster and more effective in adhesive removal than Sof-Lex discs, ultrasonic tools, hand instruments, rubbers, or composite burs. They remove a substantial layer of enamel and roughen its surface, and thus should be followed by multi-step Sof-Lex discs and pumice slurry, which is the most reliable method of polishing. Further efforts should be made to find tools and methods allowing complete removal of adhesive remnants to minimize enamel loss and to achieve a smooth surface after the completion of treatment with a fixed orthodontic appliance.

Addenda

Indices aiding visual enamel evaluation [3,20-27]:

Enamel surface index (ESI) by Zachrisson and Årthun [3], later used by Pont et al. [20], as well as by Sessa et al. [21]:

- 0 – perfect surface with no scratches and distinct intact perikymata,
- 1 – satisfactory surface with fine scratches and some perikymata,
- 2 – acceptable surface with several marked and some deeper scratches, no perikymata,
- 3 – imperfect surface with several distinct deep and coarse scratches, no perikymata,

- 4 – unacceptable surface with coarse scratches and deeply marked appearance.

Enamel Damage Index according to Schuler and van Vaes [22], later used by Alessandri Bonetti et al. [23] and Baumann et al. [24]:

- 1 – acceptable surface, fine scattered scratches,
- 2 – rough surface, numerous coarse scratches or slight grooves,
- 3 – surface with coarse scratches, wide grooves, and enamel damage visible with the naked eye.

Surface roughness index according to Howell and Weeks [25], later used by Hong and Lew [26]:

- 1 – acceptable surface, fine scattered scratches,
- 2 – mildly rough surface, denser fine scratches with some coarser scratches,
- 3 – rough surface, numerous coarse scratches over the entire surface,
- 4 – very rough, deep, very coarse scratches over the entire surface.

Enamel Surface Rating System according to Schiefelbein and Rowland [27]:

- 1 – major defects and/or roughness in entire enamel,
- 2 – major defects and/or roughness in some areas of enamel,
- 3 – few areas of defects and roughness in enamel,
- 4 – minimal roughness and no defects,
- 5 – smooth enamel with very minor defects,
- 6 – smooth, unaltered enamel surface,

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