

## Orthodontic Recycling at the Crossroads

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Thousands of orthodontic practitioners around the world currently recycle brackets, tubes, and bands.<sup>1</sup> Nearly all recyclers, whether commercial companies or private clinicians, use heat and electropolishing.

Heat is necessary not only to decontaminate and sterilize orthodontic attachments, but also to remove the adhesive's polymeric matrix. Heating stainless steel to between 350° and 800°C (650-1,600°F), the temperature range necessary for charring the adhesive, for more than 30 minutes leads to the alloy's sensitization--a segregation of chromium carbide at the boundaries of the grains. The depletion of structural chromium, along with the formation of a disrupting, acid-soluble film of carbides, renders the steel brittle and susceptible to intergranular corrosion, a condition considered "catastrophic" because it dramatically affects the alloy's strength.<sup>2</sup>

To remove the highly adherent dark layer of oxides and carbides that forms on the attachment surfaces after they have been subjected to heat,<sup>3</sup> and to restore the luster of the metal, recyclers use electropolishing. Even in professional shops, however, electropolishing of such small and complex-shaped parts is difficult and inconsistent at best.<sup>4</sup> Electropolishing tends to open the bracket slots, level the undercuts in the bases, and thin the power arms, the wings, and especially the mesh. In addition, the strong acids used in the electropolishing process can dissolve and weaken the brazing that keeps multipart attachments together. If a "nobler" brazing is used, the steel itself can be attacked (galvanism).

While one or two cycles of charring the adhesive and electropolishing may not have a significant impact on treatment, recent studies have shown that traditional recycling cannot meet the requirements of national and international organizations such as the U.S. Food and Drug Administration (FDA) and Centers for Disease Control (CDC), the International Standards Organization (ISO), and the European Union Council (Conformité Européene, or CE Mark).<sup>5,6</sup> The FDA standard is that the physical characteristics and quality of the device should not be adversely affected, so that the device remains safe and effective for its intended use. The CDC requires that devices may not be reprocessed or reused if their physical integrity and function are compromised in the cleaning, sterilization, or disinfection process, or if their overall safety and effectiveness are affected.

The present study was designed to measure the effects of three recycling methods on three different orthodontic attachments.

### Materials and Methods

Three types of attachments with 100-mesh bases (100 openings per inch) were evaluated: Twin Torque brackets, made of an American Iron and Steel Institute (AISI) type 304 stainless steel; Mini Diamond brackets, made of the AISI ferromagnetic steel type APH 17-4; and TruForm tubes with bands. Each of the new, randomly selected attachments was marked with a carbide tip to distinguish it from the others after recycling.

In the first method, described as "Thermal" (T), the attachments were subjected to three successive

cycles of adhesive smearing followed by charring and electropolishing, according to Esmadent' s instructions.<sup>7</sup> In the second method, described as "Dissolution-Flash Electropolishing" (DE), the attachments were subjected to three cycles of adhesive smearing followed by dissolution of the adhesive and flash electropolishing,<sup>8</sup> a proprietary process used for decades by Ortho-Cycle Company. In the third method, described as "Dissolution-Burnishing" (DB), the brackets were subjected to adhesive smearing and dissolution followed by burnishing with high-energy centrifugal tumbling. The tumbler, a BCI-10, was similar to those used routinely by orthodontic bracket manufacturers. A turret rotates at a high speed in one direction, while four drums attached to the outside of the turret rotate at a slower speed in the opposite direction. The drums are loaded with manufactured parts, water, a hard but smooth medium, and a surfactant.

*Dimensional changes.* Five new Twin Torque upper central incisor brackets were checked for possible manufacturing defects and then gauged before and after recycling with the methods T and DB. To assess thinning of the material at readily accessible points, 10 measurements were taken with an indicating micrometer that is accurate to within 5 microns, according to its manufacturer. The changes were also evaluated under a scanning electron microscope operated by the Biomaterials Center of the Polytechnic University, Bucharest, Romania. Several Mini Diamond brackets were also subjected to both the T and DB methods and SEM-examined. A TruForm band was randomly selected from the ones treated using method T and photographed at close range with a Nikon CoolPix 950 camera.

Because electropolishing can also affect the slot, and a previous study has shown that the gap between the archwire and the slot wall can entrap an elastomeric module,<sup>9</sup> a separate experiment was designed to determine whether elastomeric particles could influence friction. A chain Superelastic was gently rubbed on both nickel titanium and stainless steel archwires and subjected to Atomic Force Microscopy (AFM), which provides both a direct measurement and an evaluation of friction. The tests were made at Nanotech-21 Laboratories in Bucharest using a Multimode Atomic Force Microscope.

*Metal removed.* The liquids remaining after processing were tested for any loss in integrity of the attachments (metal dissolved) as well as for environmental pollution with ions such as Ni<sup>++</sup> and Cr<sup>++</sup>. Only the iron ions were semi-quantitatively evaluated because in single-phase alloys, the same ratio between the elements is maintained when the metal is dissolved.

Batches of 500 Mini Diamond brackets were subjected in parallel to three cycles of each recycling process, and the resulting liquids were separated and analyzed. Samples of the solutions were subjected to a .1% solution of potassium ferrocyanide (a reagent that turns blue in the presence of Fe<sup>++</sup> ions) and examined for color intensity. In addition, the gray liquid obtained from the DB process was left to settle, and the separated solids were dried and subjected to a common magnet.

## Results

*Dimensional changes.* All three methods reduced the average dimensions of the Twin Torque brackets (Fig. 1). The thinning of protuberances such as power arms was sometimes apparent even to the naked eye.

SEM photographs of the mesh exposed to methods T and DB showed more subtle differences. Method T tended to level the mesh pad borders and corners of the Twin Torque brackets, so that in some instances only the wire' s welding points were left (Fig. 2). With the Mini Diamond brackets,

method T produced a noticeable thinning of the mesh, but method DB showed a good finish without the pad area being significantly affected (Fig. 3). The thinning effect of method T was also evident on the TruForm band (Fig. 4).

Rubbing with elastomeric material increased friction by three to seven times, depending on the metal of the archwire, as measured by AFM (Fig. 5).

*Metal removed.* The electrolyte solution obtained from method T was green and turbid; that of method DE was clear and only faintly green. In contrast, the liquid separated from method DB was foamy, slightly turbid, and gray. Adding the potassium ferrocyanide solution to the electrolytes obtained from the T and DE methods resulted in an intense and an appreciably less intense blue color, respectively. Applying the same test to liquid resulting from the DB method, after the sedimentation of the solids, showed only a faint blue shade. The dried and separated solids formed a powder that was not attracted by magnets.

## Discussion

In this study, unlike others that compared groups of new brackets to different groups of recycled brackets, the same, distinctively marked brackets were evaluated before and after processing. Orthodontic attachments are made in large series or batches by either human labor or automatic machines. Both can commit errors in fabrication, and the usual random inspection (10-100 brackets per 1,000) is not foolproof.<sup>10,11</sup> Significant deviations in the slot widths of new brackets have also been shown in a thesis supported by a manufacturer' s grant to demonstrate the harmful effects of recycling.<sup>12</sup>

*Dimensional changes.* All three of the tested recycling methods caused a reduction in attachment size (although inconsistent and in some cases too small to be accurately measured), with T producing the greatest effect and DB the least. The measurements were similar between methods DE and DB because in method DE, only the brackets are subjected to electropolishing, while the bases are protected.

Significant dimensional changes can affect the proper functioning of attachments by thinning the power arms, hooks, and wings (ligation, Lewis, and especially Lang). At the same time, the edges and corners of the bracket bases become sharp and thus cease to contribute to the strength of the bond. Bands lose strength as they become thinner, and sometimes become sharp enough to cut soft tissue (electropolishing is widely used to sharpen razor blades).

The bottom of the slot was not significantly altered by either the T or the DB method. In contrast, the widening of the insertion area of the slot by method T was enough to be visible under 3× magnification. This not only reduced the slot' s depth,<sup>9</sup> but increased friction. When individual elastomeric modules are used, the widening of the slot' s insertion area drags the module into the gap between bracket and archwire, generating friction and tearing the module (Fig. 6). The detached elastomeric particles act as a wedge between the archwire and the bracket, further increasing friction (Fig. 5). This makes it difficult to correlate friction with the bracket design,<sup>9</sup> causing random jumps instead of predictable curves.<sup>13</sup>

*Metal removed.* The semi-quantitative reaction with a reagent that changes color in proportion with the concentration of Fe<sup>++</sup> ions showed that the methods using electropolishing (T and DE) released metal ions in proportion to their changes in dimensional measurements. The DB method did not

lead to metal dissolution, but rather to the removal of insoluble, non-magnetic impurities (including oxides). The resulting waste liquid contained a lesser amount not only of heavy metals, but of environmentally harmful substances.

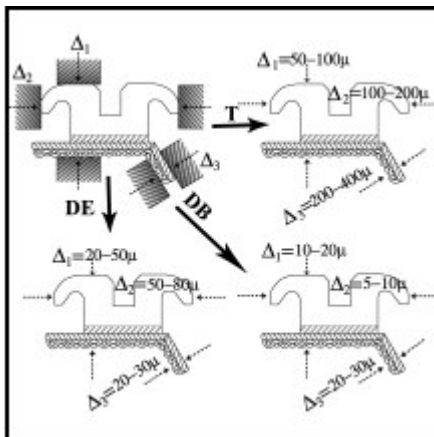
## Conclusion

Among the three attachment-renewal methods examined, only the dissolution of the adhesive followed by burnishing of the metal (DB) produced both a minimal dimensional change and an environmentally acceptable waste. Whereas electropolishing removes metal, high-energy centrifugal tumbling compresses it, actually hardening the metal surface.<sup>14,15</sup> According to NASA, a compressed external layer resists crack initiation and propagation and is more resistant to corrosion and fatigue.<sup>16</sup> The authoritative *Metals Handbook* reports that burnishing' s "smooth action achieve consistent and reproducible results. Very high tolerances are maintained even with fragile parts, and very high quality surfaces are achieved."<sup>17</sup> This process is used by both orthodontic manufacturers and jewelers to brighten metals without material loss, and has allowed one recycler to be certified both ISO-2000 and CE.

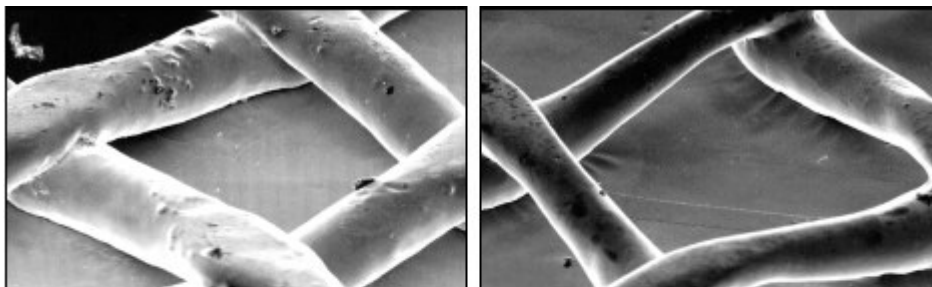
Although only three cycles of each method were used in this study, the effects of electropolishing would presumably accumulate over multiple cycles. With governmental and multinational organizations now demanding that the physical characteristics and performance quality of devices not be adversely affected, orthodontic recycling must adapt to remain financially justified and environmentally responsible.

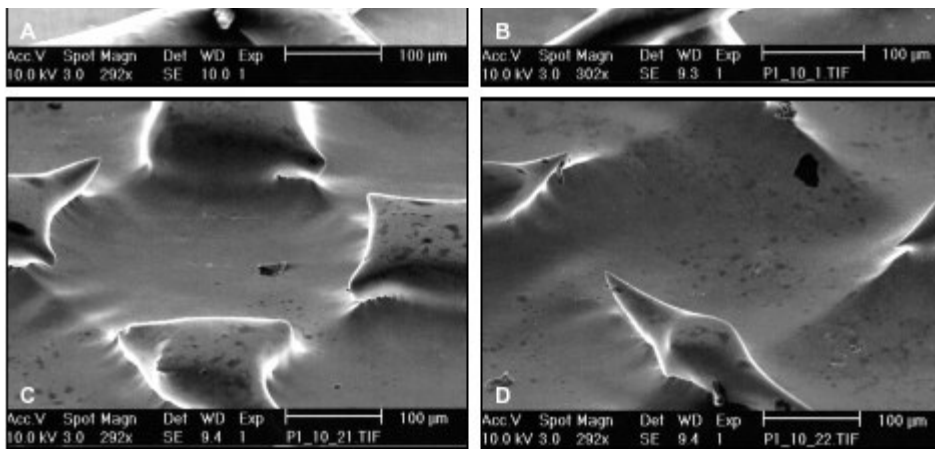
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## FIGURES

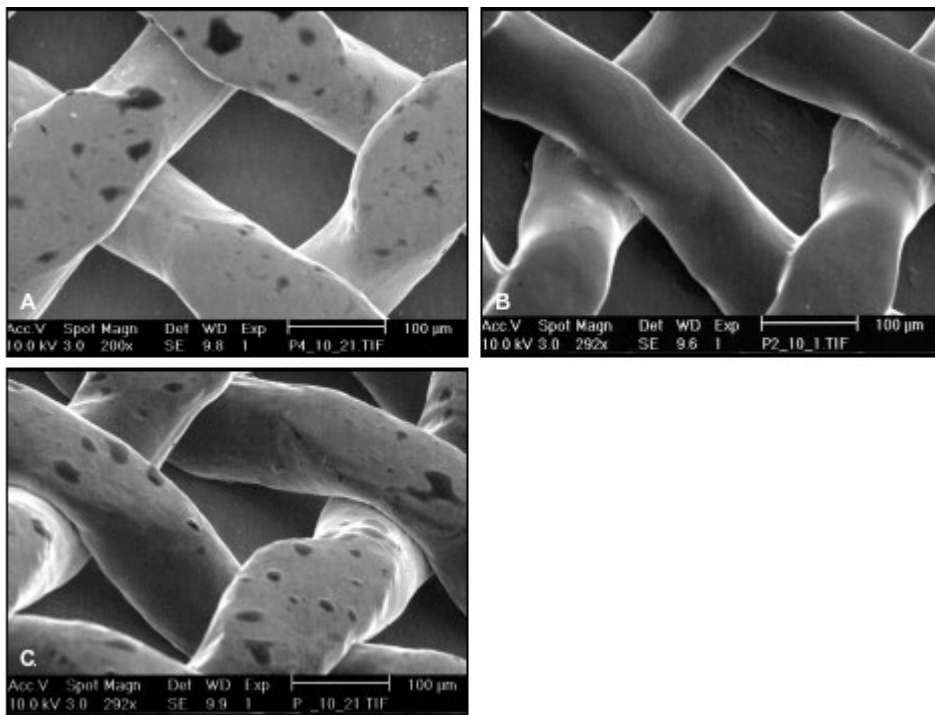


**Fig. 1** Average dimensional changes of Twin Torque upper central incisor bracket after three cycles of each recycling method: thermal (T), dissolution-flash electropolishing (DE), and dissolution-burnishing (DB).

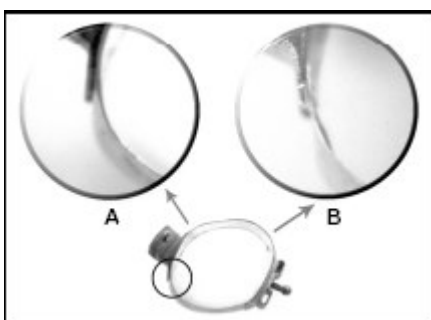




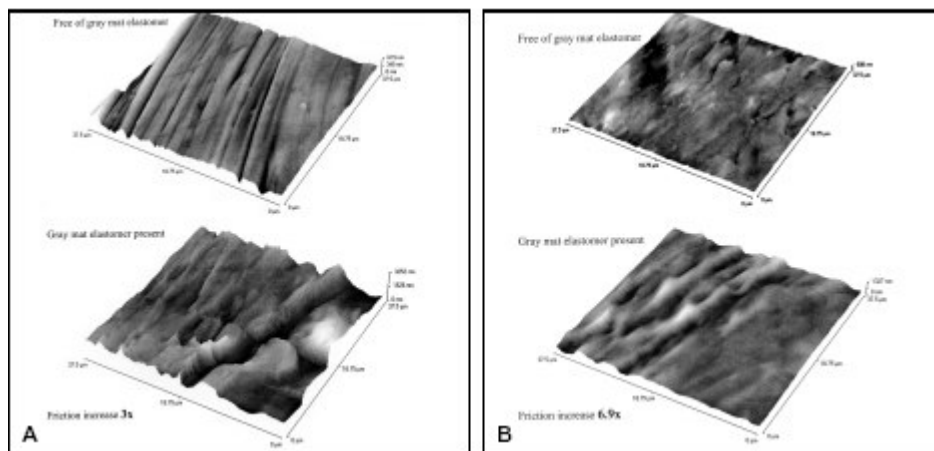
**Fig. 2** SEM photographs of Twin Torque bracket mesh base. A. New bracket. B. Middle of base after three cycles of method T. C. Edge of base after three cycles of method T. D. Corner of base after three cycles of method T.



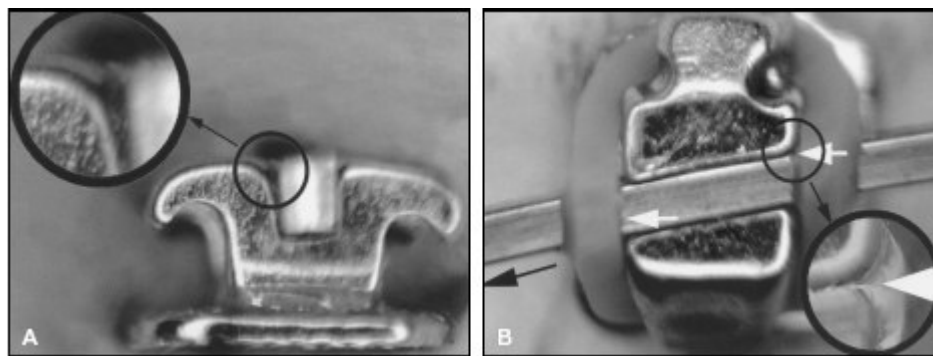
**Fig. 3** SEM photographs of Mini Diamond bracket base. A. New bracket. B. Middle of base after three cycles of method T. C. Corner of base after three cycles of method DB.



**Fig. 4** Close-up photographs of TruForm band. A. New. B. After three cycles of method T.



**Fig. 5** A. AFM images of nickel titanium wire before and after rubbing with elastomer (white indicates rubbed areas). B. AFM images of stainless steel wire before and after rubbing with elastomer (white indicates rubbed areas).



**Fig. 6** A. Elastomeric module dragged into space between widened bracket slot and archwire. B. Entrapped elastomer particles act as wedge between archwire and bracket, increasing friction.

## REFERENCES

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Holland, IL, 1980.

**8** Zachrisson, B.: Bonding in orthodontics, in Orthodontics, Current Principles and Techniques, ed. T.M. Graber, B.F. Swain, 2nd ed., C.V. Mosby, St. Louis, 1985, p. 513.

**9** Matasa, C.G.: Weighing . . . friction, Orthod. Mater. Insider, 13:1-8, 2001.

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**12** Fisher, T.: An in vitro comparative study of new and recycled brackets, thesis, University of Iowa, 1995.

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**14** Diffraction notes 26:10-25, 2000, Lambda Research, Cincinnati.

**15** [www.alpha-supply.com/241.htm](http://www.alpha-supply.com/241.htm), Alpha Supply, Inc., Seattle.

**16** [www.nasatech.com/Briefs/Aug02/LEW17188.html](http://www.nasatech.com/Briefs/Aug02/LEW17188.html).

**17** Mechanical finishing, in ASM Metals Handbook, vol. 5, 9th ed., American Society for Metals, Materials Park, OH, 1982, p. 133.

## **FOOTNOTES**

**1** Twin Torque brackets: 3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016.

**2** Mini Diamond brackets: Ormco/"A" Company, 1717 W. Collins Ave., Orange, CA 92867.

**3** TruForm tubes: TruForm, RMO Inc., P.O. Box 17085, Denver, CO 80217.

**4** Esmadent, a division of Esma Chemical, Highland Park, IL.

**5** Ortho-Cycle Company, 2026 Scott St., Hollywood, FL 33020.

**6** BCI-10 tumbler: Blue Crest Industries, Opa Locka, FL.

**7** Indicating micrometer: Model 2333 1521, Rutland Tool & Supply, Greenville, SC.

**8** Scanning electron microscope: Phillips XL-30-ESEM, TMP, Eindhoven, Netherlands.

**9** Superelastic chain: Ortho Arch Co., 1185 Tower Road, Schaumburg, IL 60173.

**10** Multimode Atomic Force Microscope: Digital Instruments, Santa Barbara, CA.

