Nanostructural Changes in Surface of Stainless Steel Archwires Combined with Orthodontic Conventional and Self-Ligating Brackets

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ABSTRACT

It is well-known that the frictional force between the archwire (AW) and the bracket reduces the efficiency of orthodontic treatment. It is affected not only by geometry of self-ligating brackets (SLBs) but also by physical changes between bracket slots and AW surfaces during sliding movement. This study observed the effect of SLBs on the surfaces of stainless steel (SS) AWs during sliding tooth movement *in vivo* utilizing atomic force microscope (AFM). From the first bicuspid extraction case, 0.019 × 0.025 inch SS-AWs with sliding movement were selected and four groups of SS-AWs were employed; with SS-SLBs and ceramic SLBs, conventional SS brackets and intact SS-AWs. The sections engaged with brackets of second bicuspids were cut and scanned in the air at resolution of 256 × 256 pixels, with scan speed of 1 line/sec using AFM. All the SS-AWs with sliding movement showed severe scratches caused by the fictional interaction between bracket slots and AWs. The SS-AWs interacted with SS-SLBs showed the smoothest surface roughness among the three brackets. Those interacted with conventional SS brackets showed the second smooth surface. The SS-AWs interacted with ceramic SLBs showed the roughest surface compared to the others. The findings suggest that the orthodontic treatment with SS-SLBs might be more effective than that with ceramic SLBs or conventional SS brackets.

Keywords: atomic force microscopy, self-ligating brackets, stainless steel archwire, surface roughness

1 INTRODUCTION

Orthodontic tooth movement is caused by the application of a mechanical force to the tooth. This mechanical force induces friction between the archwires (AWs) and brackets. Friction is the force resisting the motion of solid surfaces and/or motional elements sliding against each other. Therefore, tooth movement occurs as the applied force goes beyond the friction induced by an interaction between the AW and brackets. However, the increase in the frictional force between the AW and bracket is responsible for the decrease in actual bone application to the tooth. These negative correlations lead to a decrease in the efficiency of orthodontic treatment [1].

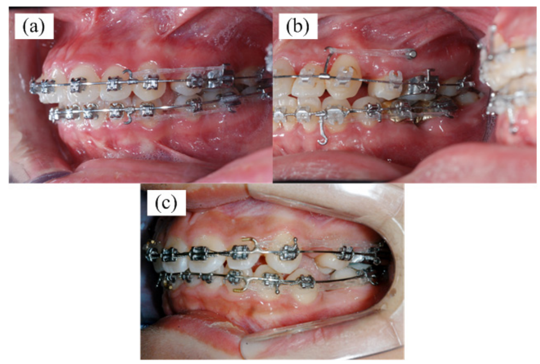

Figure 1: Representative bicuspid extraction treatments with the Damon 3MX® SS-SLBs (a), Clippy-C® ceramic SLBs (b) and Kosaka® SS brackets (c).

Several studies reported that this frictional force is related to a number of factors including the material, morphologic characteristics, interbracket distance, stiffness, roughness, ligating material/method, saliva, plaque and erosion of AW, bracket, biology and physiology. With these factors, the material of the bracket and AW is the main factors determining friction. Previous studies on the friction between the brackets and AW measured the surface roughness of the brackets and AWs using profilometer, scanning electron microscopy (SEM), or index scoring methods [2,3]. The fundamental method for measuring the surface roughness is surface profilometry, which scans the topography in a line at a preselected area. However, this profilometer only measures the defects of the surface adjacent to the scanning line, and might damage the surface of samples during scanning. On the other hand, SEM does not examine the real-time changes and does not provide quantitative and qualitative information of the sample surfaces. In contrast, atomic force microscopy (AFM) provides the 3D configuration with quantitative information regarding of the surface morphology with minimal sample preparation. With these advantages, many studies of the surface characteristics of orthodontic appliances using nanoindentation and AFM techniques have been reported [4]. Nevertheless, the changes in surface roughness of the brackets and AWs should be investigated *in vivo* because orthodontic tooth movement is affected by the dynamic changes based on mechanical and physiologic factors.

Recently, various types of self-ligating brackets (SLBs) have been used to attempt effective arch-guided tooth movement. This is a ligatureless bracket system with a mechanical device built into the bracket to close off the bracket slot. The SLB has many advantages. It creates a minimal friction environment for better sliding mechanics, and reduces the chair time due to faster placement and removal of the AW [5].

To the best of the authors' knowledge, there are no reports on the comparative changes in the surface roughness of AWs, along with clinical SLB treatment using AFM. Therefore, this study examined the effects of the ligating methods and bracket materials on the surface roughness of AWs with a bicuspid-extraction treatment resulting from intraoral exposure using AFM, with three hypotheses as follows; (H1) An orthodontic treatment increases the surface roughness of SS-AWs significantly. (H2) All SLBs lead to significantly lower changes in the surface roughness of 0.019 × 0.025 inch SS-AWs than conventional brackets. (H3) Orthodontic treatment with ceramic brackets leads to significantly higher changes in the surface roughness of 0.019 × 0.025 inch SS-AWs than that with SS brackets, regardless of the ligating method.

2 MATERLANS AND METHODS

2.1 AW Preparation

Orthodontic 0.019 × 0.025 inch SS-AWs (3M, Monrovia, CA., USA) after clinical use with the first bicuspid-extraction treatment were employed, Fig 1. The AWs were treated with the Damon 3MX® SS-SLBs (Ormco, USA, group 1), Clippy-C® ceramic SLBs (Tomy, Tokyo, Japan, group 2), and Kosaka® SS brackets (Tomy, Tokyo, Japan, group 3). The SS-AWs before clinical use were employed as the control group. These AWs (n = 22 for each type) were applied for four months in the retraction stage for to close the extraction space immediately after the leveling stage. Before removing the AWs, they were marked just mesial and on the distal side of the second bicuspid bracket position because the sites underwent a frictional interaction between brackets and AWs during sliding en masse retraction. Sections engaged with brackets of the second bicuspids were cut.

2.2 AFM Measurement

Non-contact mode AFM images were obtained using a NANOS N8 NEOS (Bruker, Herzogenrath, Germany) equipped with a 43 × 43 × 4 μm^3 XYZ scanner and two Zeiss optical microscopes (with Epiplan 200× and 500×, Carl Zeiss Inc. Standort Göttingen-Vertrieb, Germany). External noise was eliminated by placing the AFM machine on an active vibration isolation table inside a passive vibration isolation table. Data acquisition and image processing were performed with SPIP (Scanning Probe Image Processor Version 4.8, Image Metrology, Denmark). The AW surfaces of each group were scanned in air at a resolution of 256 × 256 pixels and a scan speed of 0.8 line/s. The images were scanned using an area size of approximately 43 × 43 μm^2. To identify the morphological changes in each group, two surface roughness parameters including the roughness average and root mean square (RMS) parameter were calculated using SPIP software.

2.3 SEM Measurement

After AFM imaging, SEM (Hitachi S-4700, Hitachi Co. Ltd., Tokyo, Japan) was used to observe the morphological changes in the AW surfaces of each group. Each AW was immobilized on a brass stub with double sided tape and vacuum-coated with a layer of carbon followed by gold. The slot surfaces of each sample were then examined at a beam voltage and magnification of 10 kV and 2,000×, respectively.

2.4 Statistics

The quantitative data was expressed as the mean ± standard deviation (SD). Statistical analyses were performed to compare the mean values obtained from each group using a two-tailed Student's t-test. One-way analysis of variance (ANOVA) was performed to compare the differences in surface roughness within each of the SS-AWs with respect to the control group. Additional post-hoc comparisons were performed with a Student-Newman-Keuls test where appropriate. P-values < 0.05 were considered significant.

3 RESULTS AND DISCUSSION

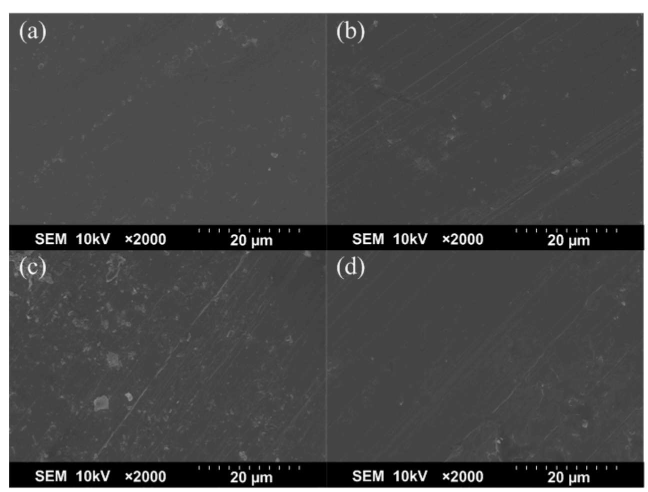

Figure 2: Representative SEM images of the AW surfaces before clinical use (a), and treated with the SS-SLBs (b), ceramic SLBs (c) and conventional SS brackets (d).

Figs. 2 and 3 show representative SEM and AFM 3D images of the AW surfaces of the second bicuspid bracket position, before and after orthodontic treatment with the Damon 3MX® SS-SLBs, Clippy-C® ceramic SLBs, and Kosaka® SS brackets. Surface defects made from the manufacturing processes as well as a substantial amount of debris were observed in the SS-AWs before treatment. All the SS-AWs after orthodontic treatment showed severe scratches caused by the sliding movement of the interaction of an AW with the slots of an orthodontic bracket, compared to those before treatment. In particular, 0.019 × 0.025 inch SS-AWs treated with ceramic SLBS showed the highest surface roughness of the groups examined. The two roughness parameters were used to evaluate the surface topography of each group quantitatively. Surface defects made from the manufacturing processes as well as a substantial amount of debris were observed in the as-received SS-AWs, 24.66 ± 8.76 nm. Similar to the SEM findings, all the 0.019 × 0.025 inch SS-AWs contained severe scratches and significantly higher roughness, $p < 0.0001$, which were caused by sliding movement between the AWs and bracket slots. The mean surface roughness of the SS-AWs treated with conventional SS brackets, 270.30 ± 25.83 nm, were significantly higher than that of the SS-AWs treated with the SS-SLBs, 214.93 ± 78.35 nm ($p < 0.005$). The mean surface roughness of the AWs with ceramic SLBs, 339.55 ± 51.85 nm, was significantly higher than that with SS-SLBs, $p < 0.0001$ (Fig. 4). ANOVA revealed significant differences ($p < 0.001$) in the surface roughness of the SS-AWs with respect to orthodontic treatments, ligation methods and bracket materials, whereas post-hoc comparisons revealed the no significant difference in the ligation methods. In addition, the AFM 3D images provided details of the changes in the nanostructures of the SS-AW surfaces by the orthodontic treatment.

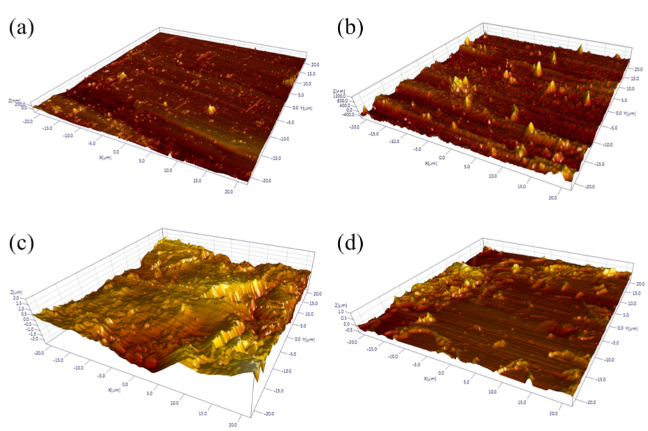

Figure 3: Representative AFM 3D images of the AW surfaces before clinical use (a), and treated with the SS-SLBs (b), ceramic SLBs (c) and conventional SS brackets (d).

This study first examined the effects of a SLB treatment on the morphology of 0.019 × 0.025 inch SS-AWs after clinical use using AFM and SEM. 0.019 × 0.025 inch SS-AWs taken from patients treated clinically with bicuspid extraction were used. Hence, this study might be more clinically applicable. In this study, it was hypothesized in the bicuspid extraction case that an orthodontic treatment would alter the surface roughness (H1). The AW surfaces with all SLB treatments showed fewer changes than those with conventional treatments (H2). Ceramic brackets lead to more morphological changes in 0.019 × 0.025 inch SS-AWs than SS brackets without regard to the ligating method (H3). These findings confirmed hypotheses 1 and 3 but disproved hypothesis 2.

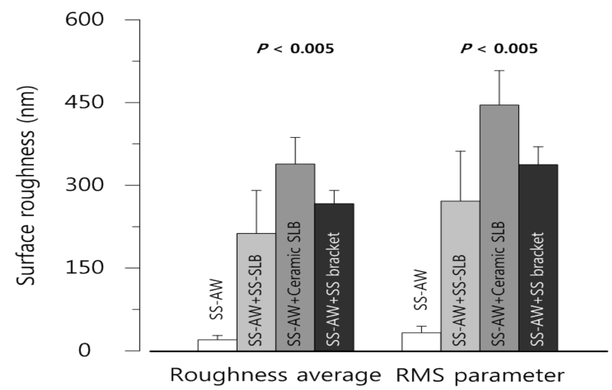

Figure 4: Changes in the roughness average and RMS parameter with respect to the group. Each point represents the mean ± SD.

Previous studies [6,7] examined the frictional force with respect to the bracket types and SLB method. They reported that the passive SLB showed lower frictional resistance than the active SLB. Some studies [8] demonstrated no significant differences in the frictional force between conventional and SLBs when loosened steel ligatures are used. However, most studies reported that SLBs result in significant decreases in frictional force compared to conventional brackets. This result is consistent with the findings of this study in that 0.019 × 0.025 inch SS-AWs treated clinically with SS-SLBs showed significantly lower surface roughness than those treated clinically with SS conventional brackets. This suggests that SLBs lead to lower frictional resistance than conventional brackets, which may reduce the orthodontic treatment time.

SS brackets, which have properties closer to the ideal, are used most frequently for orthodontic treatment [1]. Michelberger et al. [9] compared the surface roughness and friction with respect to the materials. The surface roughness rated from the lowest to the highest was SS, Co-Cr, TMA and NiTi. The frictional resistance rated from the lowest to highest was SS, Co-Cr, NiTi and TMA. SS showed the lowest surface roughness and friction compared to the other materials. Angolkar et al. [10] showed that a mono-crystalline alumina (MCA) bracket had a smooth surface, but greater frictional resistance than the SS brackets. Lee et al. [11] examined the slots of SS and ceramic brackets using an *in vitro* experimental sliding test. They reported that Crystalline V polycrystalline alumina (PCA) brackets and Perfect MCA brackets have a rougher surface than Succes SS brackets, Inspire Ice MCA brackets and Invu PCA brackets. They concluded that the surface roughness of AWs showed more changes than the bracket slots. After the sliding test, the surface roughness of the SS brackets, SS- and TMA-AWs increased, whereas that of the ceramic brackets decreased. In addition, SS and ceramic brackets showed no significant changes in surface roughness after the sliding test of the SS-AWs. This finding is consistent with the result of this study in that 0.019 × 0.025 inch SS-AWs treated with ceramic SLBs showed higher morphological changes than those treated with SS-SLBs. This suggests that, in a frictional interaction between the AWs and brackets, most of the frictional resistance is delivered to the AWs rather than the brackets. Therefore, this friction may reduce the efficiency of orthodontic treatment.

4 CONCLUSIONS

This study examined quantitatively the changes in the surface roughness of 0.019 × 0.025 inch SS-AWs treated with SLBs exposed to an intraoral environment for four months of the retraction stage by sliding mechanics using AFM. Three types of brackets, SS-SLBs, ceramic SLBs, and conventional brackets, were used. This study showed that all 0.019 × 0.025 inch SS-AWs showed severe scratches caused by the sliding movement of the interaction between the AW and the slots of an orthodontic bracket. The 0.019 × 0.025 inch SS-AWs treated with SS-SLBs showed the smoothest surface compared to the other three brackets followed in order by the conventional SS brackets and ceramic SLBs. Further studies will be needed to examine the relationship between the surface roughness and frictional force using lateral force microscopy, which is a useful tool for examining the friction of a material. It will be also necessary to examine the surface roughness with respect to the combinations of AW types, such as round or rectangular, and AW materials including NiTi or TMA, in each stage of the orthodontic treatment. This can help determine the relevant clinical implications of these findings[1].

REFERENCES

[1] S. Choi, K.-H. Park, Y. Cheong, H.-K. Kim, Y.-G. Park, H.-K. Park. Scanning, 33, 25, 2011.

[2] I.S. Marques, A.M. Araujo, J.A. Gurgel, D. Normando. Angle Orthod. 80, 521, 2010.

[3] S. Zinelis, T. Eliades, G. Eliades, M. Makou, N. Silikas. Dent. Mater. 21, 890, 2005.

[4] K.H. Park, H.J. Yoon, S.J. Kim, G.J. Lee, H.K. Park, Y.G. Park. Korean J. Orthod. 40, 294, 2010.

[5] J.L. Berger. Semin. Orthod. 14, 54, 2008.

[6] S. Budd, J. Daskalogiannakis, B.D. Tompson. Eur. J. Orthod. 30, 645, 2008.

[7] T.K. Kim, K.D. Kim, S.H. Baek. Am. J. Orthod. Dentofacial Orthop. 133, 187.e15, 2008.

[8] L. Franchi, T. Baccetti, M. Camporesi, E. Barbato. Am. J. Orthod. Dentofacial Orthop. 133, 87, 2008.

[9] D.J. Michelberger, R.L. Eadie, M.G. Faulker, K.E. Glover, N.G. Prasad, P.W. Major. Am. J. Orthod. Dentofacial Orthop. 118, 662, 2000.

[10] P.V. Angolkar, S. Kapila, M.G. Duncanson Jr., R.S. Nanda. Am. J. Orthod. Dentofacial Orthop. 98, 499, 1990.

[11] T.H. Lee, K.H. Park, J.Y. Jeon, S.J. Kim, H.K. Park, Y.G. Park. Korean J. Orthod. 40. 156. 2010.

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