Dental Research Journal

Original Article

Assessment of the hardness of different orthodontic wires and brackets produced by metal injection molding and conventional methods

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ABSTRACT

Background: This study was conducted to assess the hardness of orthodontic brackets produced by metal injection molding (MIM) and conventional methods and different orthodontic wires (stainless steel, nickel-titanium [Ni-Ti], and beta-titanium alloys) for better clinical results.

Materials and Methods: A total of 15 specimens from each brand of orthodontic brackets and wires were examined. The brackets (Elite Opti-Mim which is produced by MIM process and Ultratrimm which is produced by conventional brazing method) and the wires (stainless steel, Ni-Ti, and beta-titanium) were embedded in epoxy resin, followed by grinding, polishing, and coating. Then, X-ray energy dispersive spectroscopy (EDS) microanalysis was applied to assess their elemental composition. The same specimen surfaces were repolished and used for Vickers microhardness assessment. Hardness was statistically analyzed with Kruskal–Wallis test, followed by Mann–Whitney test at the 0.05 level of significance.

Results: The X-ray EDS analysis revealed different ferrous or co-based alloys in each bracket. The maximum mean hardness values of the wires were achieved for stainless steel (SS) (529.85 Vickers hardness [VHN]) versus the minimum values for beta-titanium (334.65 VHN). Among the brackets, Elite Opti-Mim exhibited significantly higher VHN values (262.66 VHN) compared to Ultratrimm (206.59 VHN). VHN values of wire alloys were significantly higher than those of the brackets.

Conclusion: MIM orthodontic brackets exhibited hardness values much lower than those of SS orthodontic archwires and were more compatible with NiTi and beta-titanium archwires. A wide range of microhardness values has been reported for conventional orthodontic brackets and it should be considered that the manufacturing method might be only one of the factors affecting the mechanical properties of orthodontic brackets including hardness.

Key Words: Casting technique, dental, hardness, metals, orthodontic brackets, orthodontic wires

Received: January 2017
Accepted: May 2017

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INTRODUCTION

In orthodontic treatment, forces are applied to teeth through activated archwires inserted into the slots of the brackets bonded to tooth enamel surfaces. Three different methods are used to manufacture metallic brackets: milling, casting, and metal injection molding (MIM). Combined brackets are manufactured

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How to cite this article: Alavi S, Kachuie M. Assessment of the hardness of different orthodontic wires and brackets produced by metal injection molding and conventional methods. Dent Res J 2017;14:282-7.

by soldering with brazing alloys to connect the base and wings of the brackets or by direct laser welding the wings to the base.[1,2]

The MIM technique is more recent than the other three methods and was developed in the United States in the early 1980s.[3] It is an inexpensive manufacturing process compared to other methods and is used to manufacture large quantities of complex and intricate parts. MIM makes it possible useing different alloys to manufacture orthodontic brackets, which is not always possible with the other manufacturing methods.[4-6] Single-unit MIM brackets exhibit uniform elemental distribution with no brazing components, without intra-bracket galvanic corrosion; however, they have increased porosity, increasing the risk of pitting corrosion.[5,7,8] In comparison to conventional brackets, MIM brackets exhibited a lower rate of nickel ion releasing into saliva.[9]

The method of production might seriously affect the mechanical performance of orthodontic brackets in the clinic, and despite a large number of studies compared corrosive potential between MIM and conventional metal brackets, only a limited number of studies have compared the mechanical properties of these appliances.[5,7-11]

This study was undertaken to assess the hardness of orthodontic brackets produced by MIM and conventional methods and also different orthodontic wires (stainless steel, nickel-titanium [Ni-Ti], and beta-titanium alloys) to determine which wire is more compatible with each bracket to decrease the consequences of bracket and wire hardness mismatch.

MATERIALS AND METHODS

The brackets in this experimental study consisted of injection-molded (Elite Opti-Mim, Ortho Organizers, USA) and conventional brazed (Ultratrimm, Dentaurum, Germany) orthodontic brackets. The two types of brackets were edgewise brackets with a slot size of 0.018” for the upper left canine. The wires were made of stainless steel (SS) (Remanium, Dentaurum, Germany), nickel titanium (NiTi, Ortho Technology, USA), and beta-titanium (TMA, Ortho Technology, USA). All the archwires had the same rectangular cross-sectional configurations (0.017” × 0.025”) and were cut into 15-mm segments. Fifteen specimens from each bracket and wire brand were evaluated. To this end, the wires were embedded in epoxy resin, and to expose the wing area for hardness assessment, the brackets positioned in a horizontal direction. The specimens were then ground with water-cooled 220–2000-grit Silicon carbide papers and polished up to 0.05-mm alumina slurry (Buehler, Lake Bluff, Il, USA). Then, the specimens were cleaned in an ultrasonic bath for 5 min, and three specimens from each study group were vacuum coated with a thin layer of gold to determine the elemental composition by X-ray energy dispersive spectroscopy (EDS) microanalysis. A scanning electron microscope (Seron AIS 2300, Seron, Korea) connected to an EDS unit equipped with a super-ultra-thin beryllium window was used. These specimens were repolished and the exposed surfaces of all the fifteen specimens from each experimental group underwent a VHN (HV_{200}) test, using a microhardness tester (Micromet 5101, Buehler, Tokyo, Japan) that applied a 200-g load for 15 s. The hardness of the external surfaces of the brackets and wires was measured, with only the wing component of the brackets being assessed. Three readings were recorded from the center of each specimen, and the mean value was calculated to represent the specimen. The micrographs of the representative Vickers indentations were obtained at ×200 through an optical microscope (Metallux, Leitz, Germany) equipped with a digital color camera. Since data did not exhibit normal distribution, the hardness test data were statistically analyzed with Kruskal–Wallis test, followed by Mann–Whitney test.

RESULTS

Figure 1 illustrates representative X-ray EDS spectra obtained from the surfaces of tested brackets and wires. The elemental compositions of the brackets and wires as determined by EDS analysis are presented in Tables 1 and 2, respectively. In relation to brackets,

Table 1: Chemical compositions of Elite Opti-Mim and Ultratrimm brackets (wt%)

Bracket	Fe	Co	Cr	Ni	Mo
Elite Opti-Mim		60.06	28.17		11.76
Ultratrimm	70.06		17.77	12.16	

Table 2: Chemical compositions of the stainless steel, nickel-titanium and beta-titanium wires (wt%)

Wire	Fe	Ti	Ni	Cr	Mo	Zr	Sn
Stainless steel	70.84		11.16	17.99			
Ni-Ti		42.12	57.87				
Beta-titanium		62.74			16.94	10.39	9.93

Ni-Ti: Nickel-titanium

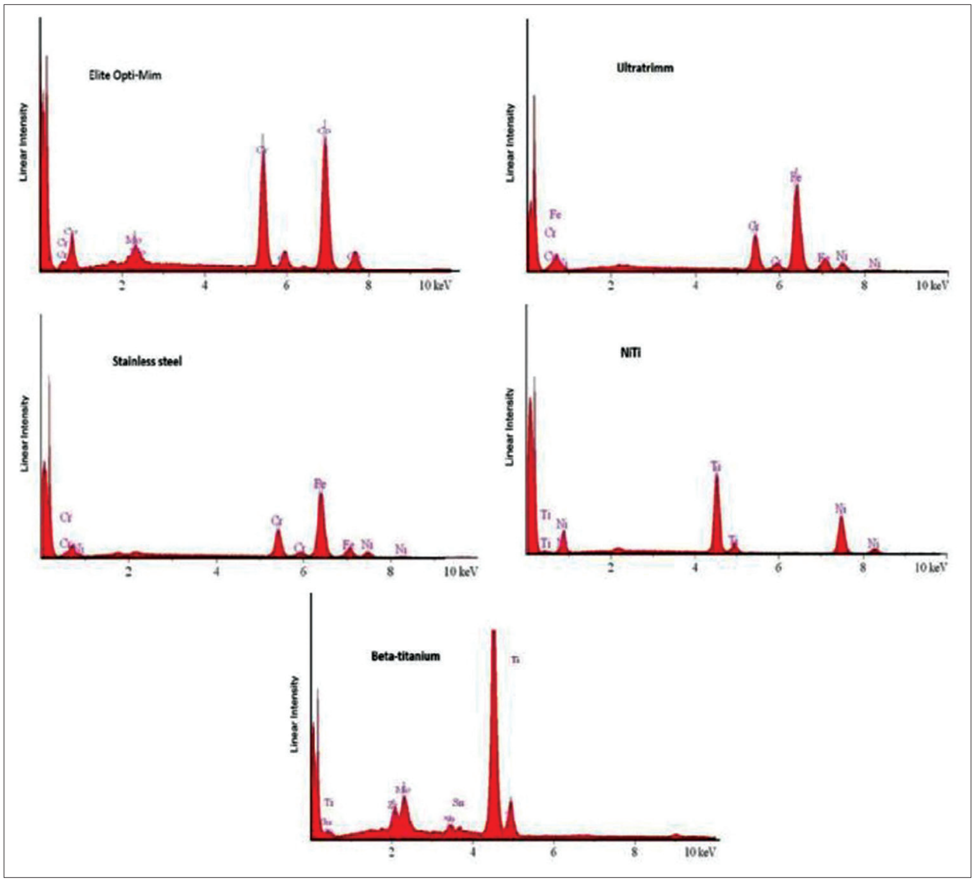

Figure 1: Spectra obtained from X-ray energy dispersive spectroscopy microanalysis of orthodontic brackets Elite Opti-Mim and Ultratrimm and orthodontic wires stainless steel, nickel-titanium, and beta-titanium.

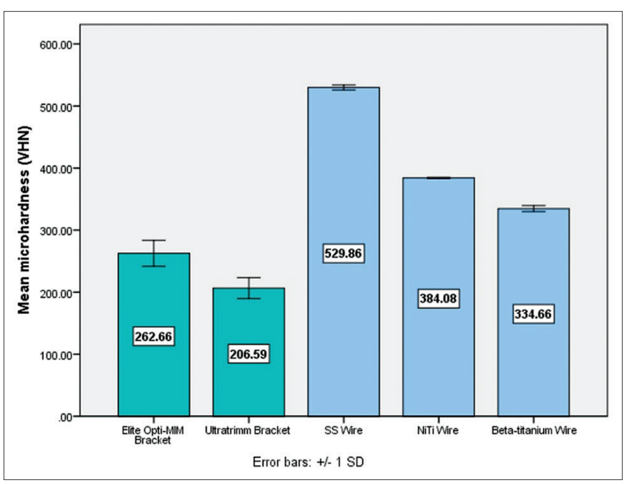

Figure 2: The result of microhardness test.

based on the X-ray EDS analysis, Elite Opti-Mim is composed of Co, Cr, and Mo, whereas Ultratrimm contains Fe, Cr, and Ni [Figure 1].

The results of Vickers hardness (VHN) measurements are presented in Figure 2 and Table 3. Micrographs of the representative Vickers indentations, obtained through the optical microscope, are shown in Figure 3. The maximum mean hardness values of the wires were obtained with SS wires, with the minimum values being recorded with beta-titanium wires. Among the brackets tested, Elite Opti-Mim demonstrated significantly higher VHN values. VHN values of wire alloys were significantly higher than those of the brackets studied**.** Comparisons of microhardness data among the five experimental groups were carried out with Kruskal–Wallis test, which revealed a significant difference between the groups ($P < 0.001$). Mann–Whitney tests were also employed for pair-wise comparisons and demonstrated significant differences among the study groups ($P < 0.001$ for all the comparisons).

DISCUSSION

Regarding the important role of hardness in clinical performance of orthodontic appliance, this study was done to assess the hardness of MIM and conventional orthodontic brackets and different orthodontic wires to determine which combination leads to better clinical results.

Table 3: Vickers microhardness values of Elite Opti-Mim and Ultratrimm brackets and stainless steel, nickel-titanium and beta-titanium wires

Orthodontic bracket/wire	*n*	Mean	SD	SE	95%CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
Elite Opti-Mim bracket	15	262.6580	21.09187	5.44590	250.9777	274.3383	236.56	311.46
Ultratrimm bracket	15	206.5873	16.84605	4.34963	197.2583	215.9164	193.06	234.30
SS wire	15	529.8580	4.01212	1.03592	527.6362	532.0798	523.33	535.66
Ni-Ti wire	15	384.0827	0.81584	0.21065	383.6309	384.5345	382.63	385.36
Beta-titanium wire	15	334.6567	4.85123	1.25258	331.9701	337.3432	323.43	340.80
Total	75	343.5685	112.51363	12.99196	317.6815	369.4556	193.06	535.66

VHN: Vickers hardness; SD: Standard deviation; SE: Standard error; CI: Confidence interval; Ni-Ti: Nickel-titanium; SS: Stainless steel

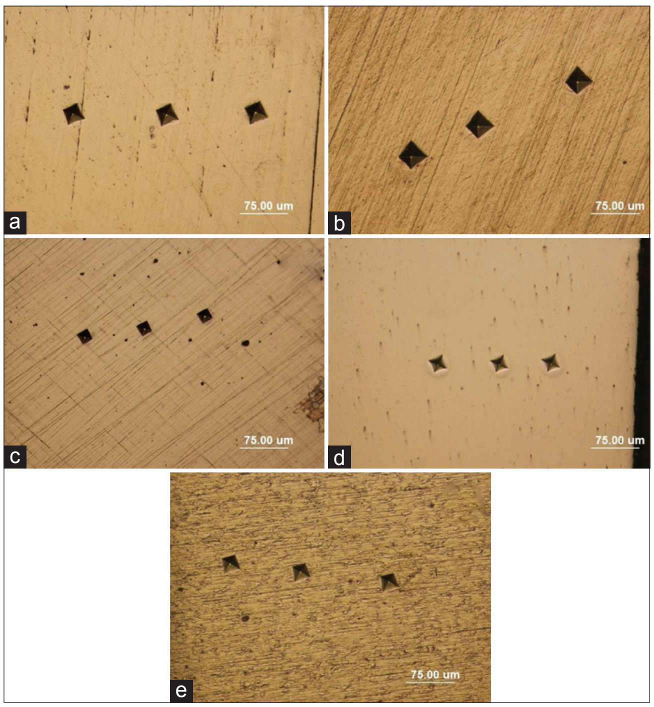

Figure 3: Optical micrograph of Vickers indentations in bracket and wire surfaces.(a) Elite Opti-Mim; (b) Ultratrimm; (c) stainless steel; (d) nickel-titanium; and (e) beta-titanium (original magnification ×200). Note the size of indentation for each alloy; the mean microhardness increased with a decrease in indentation depth. The curved sides in (d) indicate elastic rebound of nickel-titanium alloy around the tip.

According to the finding of this study, the results of EDS analysis for the two bracket groups showed that each bracket had been manufactured from a different alloy. In case of Elite Opti-Mim bracket, Klimek and Palatynska-Ulatowska[12] reported it as an Fe-Cr alloy; however, our findings suggested that it consisted of a Co-based alloy. Based on the results of the present study, the elemental composition of Ultratrimm falls within the range of austenitic American Iron and Steel Institute (AISI) type 305 SS alloy which is used for manufacturing metallic brackets (with 17%–19% of chromium and 11%–13% of nickel with a small amount of manganese and silicon, and a low carbon content, typically <0.06%). However, EDS cannot be used to quantify light elements such as carbon; therefore, the results should be interpreted with caution.[13,14]

Based on the findings in relation to the hardness of wires, Vickers microhardness of SS wire (529.85 VHN) was significantly higher than that of NiTi wire (384.08 VHN). Beta-titanium wire exhibited the lowest hardness value (334.65 VHN). These findings are consistent with previous findings with the SS wires that exhibited the highest hardness (468–601 hardness values)[15-19] compared to other two alloys. Ni-Ti (240–438 hardness values)[16-18,20-22] and TMA (292–378 hardness values)[15-18,20,23,24] exhibited lower values with overlapping ranges.

In relation to bracket hardness, Zinelis *et al*.[5] reported that the Vickers microhardness of MIM brackets varied from 154 to 287 VHN, these results are consistent with the results of the present study. In our study, Elite Opti-Mim exhibited a hardness value of 262.66 VHN, significantly higher than that of Ultratrimm (206.59 VHN), probably due to the presence of Co-Cr alloy rather than a ferrous alloy in Ultratrimm bracket.

Surface properties are important factors in sliding technique for orthodontic space closure.[25] An increased hardness facilitates surface integrity of orthodontic brackets, preventing wire binding and impingement on the bracket slot walls, which might impede movement during displacement of bracket along the archwire. Moreover, low-hardness wing components might complicate the transfer of torque from an activated archwire to the bracket since it might prevent full engagement of the wire with the slot wall and possible plastic deformation of the wings.[17,22,23]

Ultratrimm is a conventional SS orthodontic bracket manufactured by soldering the base and wing parts.[26] Previous studies have suggested that the VHN of one-piece brackets produced by MIM technology (154–287 VHN) is much lower than the hardness (400 VHN) of the wing components of conventional SS brackets;[5,27] however, in the present study, the hardness value of conventional brackets was much lower than that of the MIM brackets.

Such a difference might be justified by the fact that the manufacturing technique might not be the only factor affecting the mechanical properties of orthodontic brackets; other factors might include the type of alloy used for bracket manufacturing, its microstructure, thermal treatments used after bracket fabrication, and other manufacturing process factors. For instance, the bracket tested in the study mentioned[27] was Mini Diamond (Ormco, Glendora, CA, USA). The composition of SS alloy used for manufacturing this bracket wing material is very close to that of the S17400 precipitation-hardening alloy (type 17–4 PH SS, with nominal composition of [wt%]: 0.07 C, 0.70 Mn, 1.00 Si, 1-17.5 Cr, 3.0–5.0 Ni, 3.0–5.0 Cu, 0.04 P, 0.04S, and 0.15–0.45 Ta and Nb),[27,28] which yields high strength and hardness through heat treatment and therefore has a higher mechanical property than austenitic 305 SS type used in Ultratrimm.[5,14,27,28]

As mentioned previously, the hardness of orthodontic brackets and wires should be similar and the results of this study are consistent with previous studies, suggesting that MIM brackets are more compatible with NiTi archwires, considering the decrease in the consequences of hardness mismatch.[5,13,29] However, it should be pointed out that the fabricating method might be only one of the factors affecting the mechanical properties of orthodontic brackets, including hardness, and further studies assessing these factors are needed.

CONCLUSION

The results of this study suggested that MIM orthodontic brackets exhibited hardness values much lower than SS orthodontic archwires, with greater compatibility with NiTi and beta-titanium archwires. In relation to conventional orthodontic brackets, a wide range of microhardness values has been reported and it should be pointed out that the manufacturing method might be only one of the factors affecting the mechanical properties of orthodontic brackets.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors of this manuscript declared that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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