Brazilian Dental Science

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"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
Campus de São José dos Campos

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ORIGINAL ARTICLE

DOI: https://doi.org/10.4322/bds.2022.e3000

Bond strength of different orthodontic brackets produced with different materials and fabrication methods

Resistência de união de bráquetes ortodônticos produzidos com diferentes materiais e métodos de fabricação

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ABSTRACT

Objective: The aim of this study was to evaluate the effects of material and processing methods on the bond strength of orthodontic brackets. **Material and Methods:** Five types of brackets were tested: Conventional metallic (CM), metallic sandblasted (SB), ceramic (C), polycarbonate (PC), and metallic fabricated by melting injection molding (MIM). Shear bond strength (SBS) was conducted to check bond strength of the brackets bonded to bovine teeth (n=10/group), and tensile bond strength (TBS) (20 brackets/group) to check bracket retention to bonding material (n=20/group). Both, SBS and TBS were conducted with 1mm/min crosshead speed in a universal testing machine. Bond strength was calculated in Megapascal (MPa) based on force (N) and bracket area (mm^2). Data normality was verified, and One-way ANOVA was the statistical test with Tukey post-hoc ($\alpha=0.05$). **Results:** SB and MIM presented higher SBS compared to C, PC, and CM ($p<0.05$). SB and MIM also presented significantly higher TBS compared to CM and PC ($p<0.05$). However, MIM was not different of C for TBS. **Conclusion:** The type of material and method of fabrication are determinant factors that affect bond strength of orthodontic brackets and melting injection molding (MIM) is a remarkable technology to improve brackets retention during the orthodontic treatment.

KEYWORDS

Bond strength; Orthodontic brackets; Melting injection molding.

RESUMO

Objetivo: O objetivo deste estudo foi avaliar os efeitos dos materiais e métodos de processamento na resistência de união de bráquetes ortodônticos. **Material e Métodos:** Cinco tipos de bráquetes foram testados: Convencionais metálicos (CM), metálicos jateados (SB), cerâmico (C), policarbonato (PC), e metálico fabricado por injeção de metal fundido em molde (MIM). A resistência de união ao cisalhamento (SBS) foi conduzida para verificar a resistência de união dos bráquetes aderidos a dentes bonivos (n=10/grupo) e a resistência à tração (TBS) (20 bráquetes/grupo) para verificar a retenção do bráquete ao material adesivo (n=20/grupo). SBS e TBS foram conduzidas com relação carga/velocidade de 1mm/min em uma máquina de ensaios universal. A resistência de união foi calculada em Megapascal (MPa) com base na força (N) pela área do bráquete (mm^2). A normalidade dos dados e a estatística foi realizada utilizando One-way ANOVA e Tukey post-hoc ($\alpha=0.05$). SB e MIM apresentaram os maiores valores de SBS comparados com C, PC e CM ($p<0.05$). **Resultados:** SB e MIM também apresentaram valores significativamente maiores de TBS comparados com CM e PC ($p<0.05$). Contudo, os valores de TBS para o grupo MIM não foram significativamente diferentes de C. **Conclusão:** O tipo de material e o método de fabricação são fatores determinantes que afetam a resistência de união de bráquetes ortodônticos e a injeção de metal fundido em molde (MIM) é uma tecnologia relevante para melhorar a retenção dos bráquetes durante o tratamento ortodôntico.

PALAVRAS-CHAVE

Resistência de união; Bráquetes ortodônticos; Injeção de metal fundido em molde.

INTRODUCTION

The fixed orthodontic method is the most common interceptive therapy to align teeth position and, depending on the condition and therapy, could require long term treatment [1]. In this sense, bonding retention between enamel and brackets is a determinant factor to successful orthodontic treatments, since bracket material and design must provide adequate orthodontic forces and masticatory loads [2]. Also, it should permit easy removal after finishing the treatment to maintain the enamel structure preserved [2,3].

Some studies have demonstrated that the bracket design is an important factor affecting shear bond strength on enamel [4-7]. This fact conduces to the development of novel technologies to improve the fabrication methods and brackets base geometry [3]. On the other hand, because metallic brackets have poor or none chemical interaction with a bonding material, manufacturers often develop mechanical retentions on the bracket base surface [8]. These retentions could be meshes soldered to the base or an integral structure obtained by laser or casting design [9]. Besides geometry modifications, it is common the use of surface treatment to improve the quality of metallic bracket bonding, including sandblasting, chemical etchants, and metal powder sintering [4].

Although the forces and the moment are capital requirements in orthodontic treatments, recent demand for esthetics has contributed to the use of different materials, like ceramic and plastics [10], apart from conventional metallic brackets, which implies in different retentive behavior in the mouth. Ceramic brackets have important advantages to sustain their use in orthodontic treatments, like; biocompatibility, resistance to chemical and temperature variations, and similar bond strength to enamel compared to metallic brackets [11]. However, according to bonding procedures and the type of retention, chemical or mechanical, ceramic brackets may cause enamel damage during their removal [11,12].

Regarding plastic brackets, they initially presented low mechanical properties and poor stability in the mouth. Nevertheless, this scenario has changed and some improvements in the mechanical properties of plastic brackets were reached [13]. This progress is related to fiber-reinforcement and incorporation of metallic slots in plastic brackets [13]. Despite this, some evidence reported that plastic brackets are more susceptible to bacterial colonization compared to metallic and ceramic brackets [14].

Recently, a new different bracket is available, with modifications in retaining pins configuration and fabricated by metal injection molding (MIM) technology. MIM technology is commonly used in customized brackets fabrication [15]. However, neither wide information about the mechanical properties of MIM fabricated brackets are published yet [16] nor regarding the efficacy of this system in a standard configuration to an industrial scale.

Therefore, it is necessary to compare the properties of this novel MIM brackets with other retention systems and materials. Thus, this study was purposed to evaluate the shear bond strength of the bracket fabricated by MIM, with novel pin configuration, compared to four distinct brackets. The main hypothesis is that MIM fabricated bracket has higher bond strength than brackets fabricated by traditional methods.

MATERIAL AND METHODS

Groups' distribution

Five different brackets were tested in this study as described in Table I. Brackets were divided according to material and fabrication method: Sandblasted metallic bracket (SB), MIM bracket, ceramic (C), polycarbonate (PC), and conventional metallic bracket (CM). Thirty brackets of each type were used (10 for shear bond strength analysis and 20 for the tensile test).

Shear bond strength test (SBS)

The SBS test was done using bovine teeth. Fifty bovine incisors without cracks or surface

Table I - Brackets used in the experiments, type of bracket, manufacturers, and group acronym

Bracket	Manufacturer	Type of bracket	Group Acronym
Metallic Light standard Roth 022	Morelli Ortodontia, Sorocaba, SP, BRA	Metallic with meshed sandblasted base	SB
Advanced Series Roth 022	Orthometric, Marilia, SP, BRA	MIM bracket with novel pin configuration	MIM
Ceramic Roth 022	Morelli Ortodontia, Sorocaba, SP, BRA	Ceramic with pin base	C
Compósito Roth 022	Morelli Ortodontia, Sorocaba, SP, BRA	Polycarbonate with meshed base	PC
Metallic Standard Roth 022	Morelli Ortodontia, Sorocaba, SP, BRA	Conventional Metallic with pin base	CM

defects were obtained and cleaned using a rotative brush and prophylactic paste. After cleaning, the teeth were inserted into PVC tubes and embedded in self-cure acrylic resin (Clássico Produtos Odontológicos, São Paulo, SP, Brazil) in a vertical position. After acrylic resin polymerization, the teeth were randomly distributed into five groups (n=10), according to each bracket used in this study, as presented in Table I. The teeth were etched with 37% phosphoric acid for 30 seconds and rinsed for 1 minute. The brackets were positioned at 2 mm apically of the cement-enamel junction in the central region of the buccal face. Bonding procedure was done with Transbond XT orthodontic adhesive (3M ESPE, St. Paul USA) as manufacturer recommendation, and the light activation was conducted with Valo Cordless light-curing unit (Ultradent, Inc. South Jordan, UT, USA) at 1200mW/cm^2 of irradiance.

After bonding, the specimens were stored at 37 °C in 100% relative humidity for 24 h. Then, the specimens were submitted to the SBS test in a universal testing machine (Model 4411; Instron, Canton, MA, USA) as previously described elsewhere [17]. Briefly, an occlusogingival load was applied at the bracket using a knife-edged rod with a crosshead speed of 1mm/min, until failure. SBS values were recorded in Newton (N) and converted to megapascal (MPa) considering the area and the configuration of each bracket type. Subsequently, the debonding procedure, the failure mode was characterized in a stereomicroscope (Olympus Corp, Tokyo, Japan) with 10x magnification and classified as adhesive, mixed (involving enamel/resin cement/bracket) and cohesive in resin cement.

Tensile bond strength test (TBS)

This method was done using a bracket-bracket bonding. Through this method, we isolated the influence of the retentive forces involved with the adhesion of the resin to the tooth, and solely compared the retentive ability related to the brackets' structure. Twenty brackets of each group analyzed in this study were used and bonded together in pairs on the basis. There was no type of etching or cleaning on the internal surface of the brackets and they were bonded using the Transbond XT orthodontic adhesive (3M ESPE) in a way to guarantee a layer of 0.8 mm thickness between the two brackets. After bonding procedure, a 0.7 mm orthodontic wire was bent around the slots of the brackets in up and down position for all the specimens and the sets were stored at 37 °C in 100% relative humidity for 24 h. Elapsed the time, the sets were put in a tensile test device on a universal testing machine (Instron, USA). The TBS was made at a cross-head speed of 1mm/min.

Statistical analysis

Data of SBS and TBS were submitted to the data distribution test Shapiro-Wilk. SBS data presented non-normal distribution and were submitted to the Kruskal-Wallis test ($\alpha=0.01$) while TBS data exhibited normal distribution and were submitted to One-way ANOVA and Tukey *posthoc* test ($\alpha=0.01$).

RESULTS

Shear bond strength

The SBS results are presented in Figure 1. Sandblasted and MIM groups exhibited the higher SBS mean values, 15.5 MPa, and 15.3 MPa respectively, and a statistical difference was found ($p < 0.001$) when comparing both to C (9.0 MPa), PC (8.0 MPa) and, CM (8.5 MPa). No statistical difference was evidenced between C, PC, and CM.

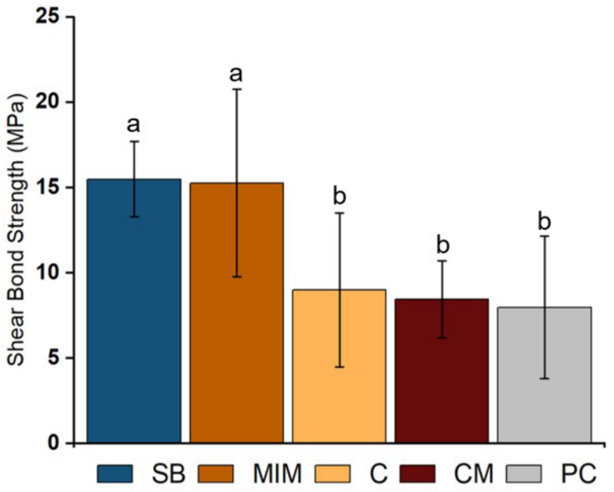

Figure 1 - Mean values and standard deviation of SBS (MPa) to the five brackets analyzed in this study. Different lower-case letters represent statistical differences between groups (p<0.001).

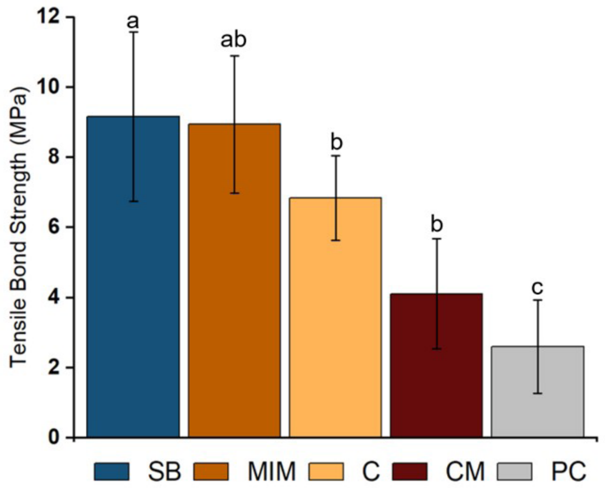

Figure 2 - Mean values and standard deviation of TBS (MPa) of the brackets analyzed in this study. Different lower-case letters represent statistical differences between groups (p<0.001).

Regarding the failure mode, 100% of Sandblasted and Advanced showed mixed failures. Ceramic brackets showed 50% of adhesive, 20% of mixed, and 30% of cohesive failures in the bracket slot. Polycarbonate brackets showed 80% of adhesive and 20% of mixed failure, while CM brackets presented 50% of mixed failures and 50% of adhesive.

Tensile bond strength

Sandblasted (9.2 MPa) and MIM bracket (8.9 MPa) presented higher TBS mean values and did not present statistical differences between them. Sandblasted brackets were superior (p<0.001) to ceramic (6.8 MPa), polycarbonate (2.6 MPa), and conventional metallic brackets (4.1 MPa). However, ceramic brackets were statistically similar to MIM brackets and both exhibited better results (p<0.001) compared to polycarbonate and conventional metallic system. The values of the tensile test are shown in Figure 2.

DISCUSSION

The retention of brackets to enamel contributes to the quality of orthodontic treatment [3] and brackets design should be an adjunct to bonding stability [4,5]. Thus, esthetical, geometrical, and material improvements to the brackets were reached in the last years, which require constant researches. In this study, metallic modified brackets (SB and MIM) presented higher SBS mean values when compared to C, PC, and CM brackets. The same scenario was observed in the TBS test. In this sense, our hypothesis was partially proved, once the bracket synthesized by MIM presented better mechanical retention except when compared to the sandblasted bracket.

Concerning SBS mean values, SB and MIM groups showed superior results when compared to the other groups. Sandblasting, as reported before, is an effective alternative to achieve retention in metallic brackets [4]. Notwithstanding, when sandblasting is done by the clinician, this method is not capable to reduce the number of lost brackets during one year of clinical evaluation [18]. Probably, these differences are related to the fact that the sandblasting process, during the fabrication, generates homogeneity in micro retentions, while in clinical practice, the distribution of aluminum oxide aggregated on the basis of the bracket is not enough to improve bonding stability.

Regarding the MIM group, this bracket showed similar SBS and TBS mean values to sandblasted brackets. These brackets are fabricated by MIM processing, a method frequently used to customize brackets [15]. Customized brackets by the MIM process have resulted in higher or similar bond strength compared to conventional fabrication methods [15]. However, sparse analyses of mechanical properties and bonding characteristics of this method are available [16]. Some studies reinforce that MIM makes it possible to combine different alloys with a homogeneous distribution of the components in microstructure [19] which can contribute to improving mechanical resistance. Thereby, the results of MIM are according to the expectations of this processing method, being superior to C, PC and, CM, like the SB group.

Even though the proven efficacy of different metallic brackets, the recent demand for esthetics has resulted in alternative material to bracket fabrication [20]. Nowadays, ceramic brackets are commonly used with this purpose and have demonstrated good retention forces, mainly when chemically bonded by a silanization process [11]. In contrast, this chemical retention can induce more damage to enamel during brackets removal [11,12]. Besides, due to ceramic brittleness, this kind of bracket is more prone to fracture during removal [20]. In this study, only mechanical retention was analyzed, and the results evidenced ceramic brackets have inferior SBS mean values compared to sandblasted and MIM brackets. Still, 30% of ceramic brackets fractured during the SBS test and this fact probably is related to the high brittleness of ceramic materials, which corroborates with the literature [20]. Nonetheless, in the TBS test, ceramic-based brackets presented statistical similarity to MIM brackets and higher values than PC and CM. This could be associated with the changes in stress-induced forces during different mechanical tests. For instance, in the SBS test the tension is applied on the interface, while for the TBS test the force was applied through the metallic wires and transferred to the brackets and, consequently, the resin layer.

Regardless of the test, CM and PC exhibited lower resistance values, and polycarbonate-based brackets presented 80% of adhesive failures between bracket and bonding material, which means inadequate chemical and mechanical interaction. Even the retentive forces to plastic brackets have been improved in fiber-reinforced systems [13], it was evidenced a distinct scenario, once polycarbonate brackets used in this research did not have fiber-reinforcement. In contrast, the metallic systems presented mainly mixed failure which is associated with the base conformation, surface area, and pin or meshes configuration in that brackets [7,9].

Dealing with conventional metallic brackets it is well understood that this system has no chemical interaction [8] and the retention is very dependent on the geometry and brackets basis [3]. Moreover, there are aspects related to the base processing method and the surface area that influence the retentive forces of the bracket [9]. These conditions contributed to the low SBS mean values for this type of bracket when compared to other metallic brackets analyzed in this study. It is important to highlight that although lower values to CM, SBS results of 8 MPa are acceptable to orthodontic brackets retention [21], which represents that all brackets tested here are in accordance with this parameter.

Metallic brackets remain as the most common material used in fixed orthodontic treatments because of durability and high strength [13]. In this study, we found that brackets made by the MIM process have marked SBS results, quite similar to SB and more effective than C, PC, and CM. It is also important to remark that MIM technology is more economic than normal fabrication processes and does not include a binding step of the parts of the bracket. Despite being an *in vitro* study, these results could contribute to guiding *in vivo* studies comparing the effectiveness and costs of each bracket in clinical practice.

CONCLUSION

In conclusion, brackets made by metal injection molding (MIM) presented high SBS and TBS mean values than ceramic, polycarbonate, and conventional metallic brackets and similar mean values to metallic sandblasted brackets.

Acknowledgments

The authors thank to CAPES foundation – Brazil, for the financial support through AUX/PROEX/CAPES 0878/2018.

Author Contributions

IJSA: Conceptualization, Data collection and analysis, Drafting and Reviewing the manuscript. MMZ: Conceptualization, Data collection, Drafting and Reviewing the manuscript. JF: Conceptualization, Data collection, Drafting and Reviewing the manuscript. RMPR: Data analysis, Drafting and Reviewing the manuscript. ABC: Conceptualization, Data analysis, Drafting and Reviewing the manuscript. MACS: Conceptualization and Supervision, Experimental design, Data analysis, Drafting and Reviewing the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Funding

CAPES foundation – Brazil - AUX/ PROEX/ CAPES 0878/2018.

Regulatory Statement

The study was conducted *in vitro* and did not involve any human or animal subjects. Therefore, the authors declare that the study does not require ethics committee approval.

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Date submitted: 2021 Apr 27
Accept submission: 2021 Sep 19