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A tensomeric and planimetric evaluation of the durability of the bond between an orthodontic bracket and enamel

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The development of orthodontics has improved thanks to the introduction of adhesives which are physically and chemically akin to tooth enamel and brackets. These materials often fall short of the required durability standards. The objective was to evaluate the real strength of the adhesives and to introduce a proprietary device, generating multiple vectors of strength between dental brackets and the surface of enamel. 11 types of adhesive materials have been studied. 990 applications have been made using removed teeth, followed by a randomised creation of 11 groups containing 90 samples each. The threshold values of the strength needed to break the brackets off were determined in torsional, shear and tension strength tests. A comparison between tensometric and planimetric methods was made by means based on ARI index. Resistance was highest for torsional stress, weaker for shear stress and the weakest for tension stress. A correlation was found between tensometric results. The study attempted to systematise the methodology of direct tests.

Key words: *dental adhesives, dental brackets, tensometric testing of bond, planimetric testing of bond, ARI index*

1. Introduction

A vast amount of bite defects resulting in cosmetic, verbal [1] and chewing [2] dysfunctions have led to the rapid development of orthodontic technology in the direction of simplifying and optimising corrective techniques. Putting new developments into practice while ensuring cost-effectiveness has been made possible thanks to the implementation and dissemination of inventions in the fields of bioengineering and materials engineering [3]–[5]. Technological progress has provided new solutions for planning optimal trajectories of the working of elastic elements and their practical incorporation into the stomatognathic system of a patient [6]–[8]. The durable, physically and chemically based fixation of parts on tooth enamel [9], [10] directs the trajectories of the elastic forces of the corrective device in an opposite direction to the vectors of the locally divergent bite geometry. The most important condition for maintaining the proper value of corrective forces and their effective triangulation in an anatomically changed stomatognathic system is the durability of the connection between the brackets and tooth enamel, as well as the generation of forces characterised by precise strength and vector sense values. The planned change of the location of a tooth inside the gums depends on the angle in which force is applied to the surface of the enamel. This force then is carried down from the crown to the root in a lever system causing the tooth to change position around the dental arch. A prerequisite for the proper application of corrective force at the correct angle is the effective fixation of brackets mounted onto selected spherical surfaces of the enamel by means of fast-curing adhesive materials [11]–[14]. The orthodontic clinical effect is thus determined by two key factors: the proper determination of corrective force vectors [15] and the durability of the connection of brackets with the spherical surface

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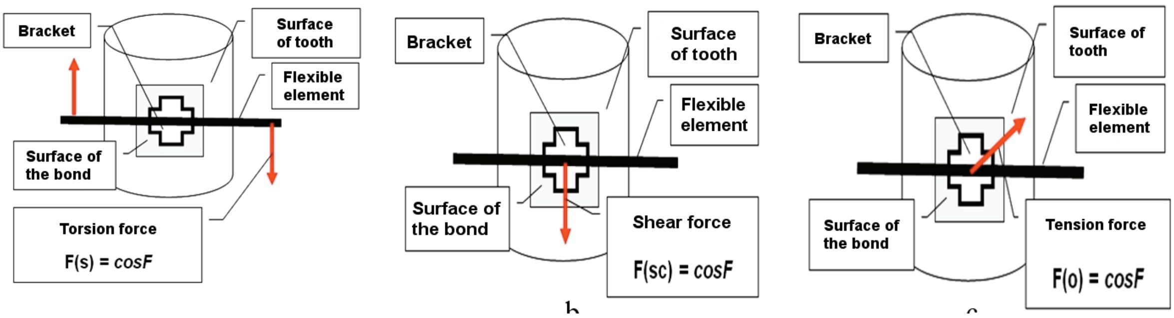
of the enamel. The force vector generated by an elastic component of the corrective device needs to be treated as a resultant of shear, torsional and tension forces, which, depending on the location where the bracket has been attached on the enamel, has different values [16]. It should also be made clear that the durability of the bond, which is measured in torque value, is not a homogeneous parameter. It is rather a time and phase determined function of the adhesion of the glue to the surface of the enamel and the bracket. When analysing the causes of a bond break, directional characteristics are taken into account by performing a semi-quantitative assessment of the amount of adhesive left on the surface of the enamel and bracket. This assessment results in the calculation of the so-called ARI indicator. Advanced work on the planimetric assessment of biological structures has provided a more precise set of figures than the 4 scale ARI indicator. This information may prove more useful in the evaluation of the causes of the break of the adhesive bond in a torque test by showing the precise location of the weaker part of the bond between the adhesive and bracket or between the adhesive and enamel. An adhesive bond which is too strong (over 10 MPa) may lead to the removal of enamel prisms when removing the bracket [17]–[19]. Laboratory tests made to determine a bond's strength between the bracket and tooth show that an adhesion of 5.8–7.8 MPa is enough to ensure proper fixture of a fixed appliance [10]. In addition, it was discovered that shear stress from 1 to 3 MPa which appears when chewing, should not lead to the breaking of orthodontic bonds [20], [21]. One interesting strategy in orthodontics is the use of high-durability adhesives (>10 Mpa), which are modified before the removal of brackets by thermoplastic treatment [12], [22]. The total balance of forces in a real clinical situation, represented by a spatial system of three vectors, has to take into account not only the aforementioned fixed values of corrective forces, but also the fluctuating values of dynamic constituents affecting these forces [23]. It should be remembered that these forces are directed at different angles to the surface of the enamel (cos α), and their vectors are a derivative of the standard utilisation of the teeth in mastication [24].

The durability values of a bond and its resistance to the forces (Fig. 1) depend not only on the relatively



(a) (b) (c)

Fig. 1. Trajectories of the main mastication forces: (a) torsional forces F(s), (b) shear forces F(sc), (c) tension forces F(o)

(a) (b) (c)

Fig. 2. RMO bracket: (a) general view, (b) contact surface after debonding and leaving a small amount of adhesive, (c) contact surface covered with adhesive with small delamination areas

stable characteristics of the biomaterials used, but to a large extent also on the physical and chemical properties of the metal and enamel, which are very individual for every clinical case [25], [26]. Summing up, the reason behind many failures in fixing brackets to the surface of the enamel or during the operation of the brackets in the oral cavity is their debonding caused by: the individual process of enamel erosion, errors made in the preparation process, resulting from bad pre-treatment of the surface of the enamel and metal before application of the adhesive material, varying adhesive properties of particular bracket designs, bite force, individual properties of various adhesive materials [27], [28]. RMO CR-Co-Ni alloy brackets with an etched bracket base were used in our study [29].

Durability, characteristics of the enamel [30], bracket base characteristics, measurement methods and method of bracket application onto the enamel [31], [32] all determine the success of tooth alignment treatment.

The clinical objective of the work is the continuation of research on the forecasting of possible failures in orthodontic treatment through acquiring knowledge on the real adhesive forces existing between the brackets and enamel bonded by commercially adhesive materials [33]. The technical objective was to construct an electronic device for durability testing in 3D [34] based on the authors' patent submission documentation. The prototype constructed made it possible to test the extracorporeal mechanical durability of orthodontic bracket adhesion to human tooth enamel performed shortly after extraction from the oral cavity. The proprietary diagnostic system was used to measure breaking forces along the trajectories of shear F(sc), torsional F(s) and tension F(o) force vectors present in mastication. Another objective was to make precise, quantitative measurements of the adhesive left on the surface of enamel and brackets to indicate and evaluate a weaker bond between the adhesive/enamel or adhesive/bracket. The measurements were performed based on standard ARI criteria and the authors' own planimetric method [35].

2.Materials and methods

2.1. Research material

990 human premolars acquired from biological waste collected in a period of 30 months at the author's own dental clinic and from other dental practices, were qualified for the research. The main inclusion criterion was the quality of the enamel surface, where the bracket base was going to be applied, i.e., its uniformity, no fillings nor carries [37]. The evaluation was carried out using a CMOS 2.0 Mp digital microscope supported by MicroCapture software and a PC USB 2.0 interface. Qualification of the removed teeth, disinfected previously with propanol containing Incidin and stored in a 0.9% NaCl solution at 37 °C, was made every two weeks. Teeth were disinfected, the surface was cleaned and then dried in a stream of dry air at 40 °C, after which each tooth placed in a Heraeus chamber (temp. 22 °C) was fixed in a 2 cm × 2 cm × 2 cm metal mold filled with Plus 710 Novol polyester resin, where it cooled off in a standard position with 1/3 of the enamel exposed. It was made sure that the front part of the tooth remained exposed and free of resin. The enamel of the teeth in the molds was cleaned with a mixture of paste and pumice, then etched with a 37% solution of phosphoric acid, and finally rinsed with water and dried. The RMO Integra 0.22 brackets were degreased with ethyl alcohol and their contact surface was dried using compressed air. The bracket surfaces prepared this way were then covered with adhesive material (Transbond XT 3M, Medicept Light Cure Medicept Dental, Spofacryl Spofa Dental, Resilience Ortho Technology, Light Bond Reliance, Enlight Ormco, No-Mix Dentaurum, Tetric Flow Vivadent, GC Fuji ORTHO LC, ConTec Prime Dentaurum and Granitec Falcon). Polymerisation of each of the adhesives after attaching the bracket to the enamel surface was performed according to the producers' recommendations using a UV lamp with a Heraeus Kulzer, Translux Power Blue 1000 mW/cm^2 monochromatic diode.

2.2. Measurement system

The author's own measurement system (Fig. 3) allowed an extracorporeal evaluation of the forces leading to the debonding of the bracket from the enamel in shear, torsional and tension tests [36] to be made. The device is composed of: (1) a holder holding the mold with teeth, where the bracket is attached to the tooth using one of the adhesives, (2) a blade or clamp adjusted to the size of the bracket, connected to a reactive element and a tensometric converter, (3) a linear drive with a stepper motor controlled by PAL-PCV1.5 software, (4) measuring module.

The holder is a mechanical component of the measurement system, equipped with clamps and a load application system. It is used for quick and durable fixation of metal molds containing a tooth immersed in resin with a bracket attached to the enamel. The blade is made of H19 stainless steel and is precisely fitted into the central groove of the bracket. It allows shear and torsional forces to be applied on the bracket (Fig. 4a, b). The clamp forms a twin-blade system, and is attached to the bracket's tie point, allowing tension forces to be applied. The guide is a leverage system, which allows torsional and shear forces to be applied on the bracket through the blade and tension forces through the clamp (Fig. 4c).

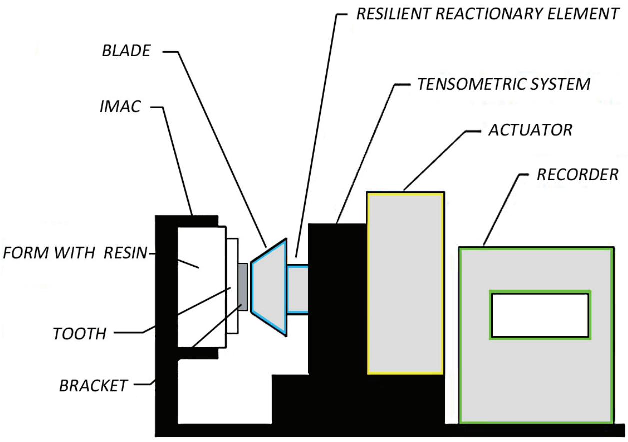
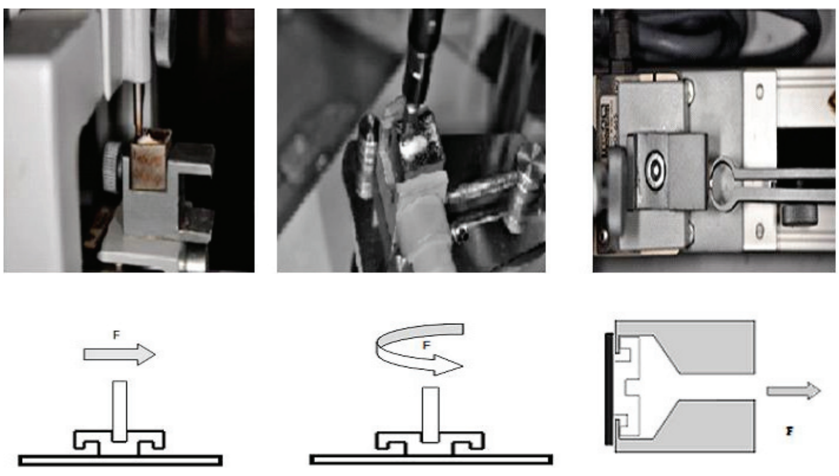


Fig. 3. Block diagram of the device for measuring bracket break force values

The tensometer used comprises a spring and tensometric gauges.

The spring is capable of repeated forced deformation and repeated return to exit parameters. Only the range well below the upper elastic limit of the spring was used. The elastic element used in torsional force tests comprised a Tohnichi FTD50CN2-S analogue torque screwdriver calibrated in cN*m in the range from 1–50, with a 0.01 cN*m measurement error. A Vishay 615 Tedea Huntleigh load cell for shear and tension force testing was used. An electromechanical linear drive was used in the measurement device, equipped with an ISEL stepping motor supplied with electricity from a standard IT 116G adapter and steered by PAL-PCV1,5 software. The software is operated from a graphical interface written in Delphi Professional 7.0 and allows for the control of the creep speed of the clamp or blade, automatic stop after receiving a signal from the load cell (simulating bracket detachment) or positioning of the blade or clamp after attachment of another sample. The measurement system, which measures the bend value of an elastic element, is composed of 4 load cells connected in a classical bridge circuit, the advantage of which is a strong output value and effective thermal compensation. The system is made up of 4 TF-2/350 load cells made of constantan with the following parameters: R = 350.3 Ω, maximum measurement current $I \leq 40$ mA, max. deformation ≤ 4%, and a deformation sensitivity factor k: 2.1–2.2, factor error k = 0.5%, fatigue strength n > 107 for ε = 1‰ and a thermal resistance variability factor of $\alpha = 0.04 \times 10^{-3}$/°C. A VT 100 module was used to condition the signal from the load cell converters, which allows the load cells to be supplied with a stabilised voltage of 3 V to 5 V and the potential signals, resulting from the geometric deformation of the load cell's reactive element, to be amplified. It has an in-built system for compensating temperature and resetting the load cell bridge circuit. The system output load should be >10 kΩ and 100 pF. The whole system is supplied by a 12 V/100 mA mains adapter. The module, apart from a graphic display, also has a USB 2.0 port, allowing the peak load cell values to be recorded in txt files in the recording module of the software,



(a) (b) (c)

Fig. 4. System for transferring force from the guide to the bracket: (a), (b) blade, (c) clamp

where the values are presented graphically and in numbers.

2.3. Measurement procedures

Direct tests were performed in the Laboratory of Biotechnology in Cieszyn on a testing machine (Figs. 3, 4) which allowed the borderline torsional, shear and tension forces to be measured in the available measurement range from 100 G to 500 kG with an error under 1% (for 500 kG). The tests were conducted at 22 °C an hour after mounting the bracket to the enamel, hence the impact of the conditions within the oral cavity on the mechanical properties of the polymers tested was avoided. The data was sent by the analogue digital converter to the PC and displayed graphically as a diagram presenting the maximum value of the strength needed to break the bond. The device, which was graduated in (N) (PCA certificate), performed measurements moving at a creep speed of 5 mm/min. Following dynamic tests, photos of the surface of the enamel and bracket in each sample were taken using a digital video channel optical miscroscope set to 20× magnification and the images were recorded in BMP format. The objective of taking images of the surface of the broken bond was to evaluate the amount of the adhesive left on the surface of the enamel and classify it according to the ARI index (Adhesive Remnant Index).

In the statistical analysis, the mean value and standard deviation for each of the forces was calculated for all 11 adhesives. The Shapiro–Wilk test was used to evaluate the agreement of the variables distribution with the normal distribution in each of the data groups. ANOVA single factor variance analysis and Tukey's post-hoc test were used to compare the results of the resistance tests. Uniform result groups were determined using Tukey's post-hoc tests. ARI results were compared using the nonparametric Kruskal–Wallis variance analysis supported by multiple mean rank comparison tests. A value of $p < 0.05$ was accepted to be significant.

3. Results

Mean values, including the maximum and minimum group values of breaking forces in the tension force tests are presented in Table 1, in the shear force tests in Table 2, and in the torsional force tests in Table 3.

Table 1. Mean break stress values in tension tests for particular adhesives (MPa)

Bond	Number (*N*)	Mean	SD	min	max
Tetric flow Vivadent	30	1.76	±0.28	1.22	2.03
Medicept LightCure Dental	30	4.84	±1.86	2.81	7.2
Light Bond Reliance	30	3.25	±0.77	2.20	4.44
Spofacryl Spofa Dental	30	3.69	±1.75	1.6	5.80
Enlight ORMCO	30	3.52	±0.96	2.54	5.05
Transbond XT 3M	30	3.20	±1.48	1.84	5.4
No Mix Dentaurum	30	1.99	±0.85	1.2	3.21
Resilience Ortho Technology	30	1.96	±0.75	1.29	3.21
Gc Fuji ORTHO LC	30	3.65	±1.20	2.13	5.74
ConTec Prime Dentaurum	30	3.12	±1.04	1.55	4.90
Granitec Falcon	30	2.98	±1.21	1.58	5.29

Table 2. Average break stress values in shear tests for particular adhesives (MPa)

Bond	Number (*N*)	Mean	SD	min	max
Tetric flow Vivadent	30	4.44	±1.47	2.34	7.13
Medicept LightCure Dental	30	6.59	±2.00	3.01	8.3
Light Bond Reliance	30	5.97	±1.83	3.58	8.25
Spofacryl Spofa Dental	30	6.84	±3.58	2.71	9.7
Enlight ORMCO	30	5.64	±2.20	2.57	9.50
Transbond XT 3M	30	9.31	±2.86	5.94	10.9
No Mix Dentaurum	30	3.11	±2.25	1.8	5.2
Resilience Ortho Technology	30	4.55	±3.41	1.92	7.3
Gc Fuji ORTHO LC	30	3.62	±0.32	3.11	4.09
ConTec Prime Dentaurum	30	4.54	±0.72	3.29	5.36
Granitec Falcon	30	3.50	±1.11	2.05	5.36

Table 3. Average break stress values in torsion tests for particular adhesives (MPa)

Bond	Number (*N*)	Mean	SD	min	max
Tetric flow Vivadent	30	2.29	±0.603	1.43	3.3
Medicept LightCure Dental	30	2.78	±0.390	1.89	3.8
Light Bond Reliance	30	3.3	±0.511	2.35	4.36
Spofacryl Spofa Dental	30	2.65	±0.461	2.02	3.64
Enlight ORMCO	30	2.73	±0.424	2.06	3.46
Transbond XT 3M	30	3.17	±0.348	2.37	3.8
No Mix Dentaurum	30	1.71	±0.449	1.04	2.63
Resilience Ortho Technology	30	2.71	±0.645	1.52	3.74
Gc Fuji ORTHO LC	30	2.33	±0.293	1.74	2.86
ConTec Prime Dentaurum	30	2.72	±0.292	2.18	3.24
Granitec Falcon	30	1.096	± 0.215	0.75	1.37

Table 4. Mean adhesive remnant values (acc. to ARI) after debonding in tension tests for particular adhesives

Bond	Number (*N*)	Mean	SD	min	max
Tetric flow Vivadent	30	1.80	0.63	1.00	3.00
Medicept Light Cure Dental	30	1.40	0.52	1.00	2.00
Light Bond Reliance	30	1.40	0.52	1.00	2.00
Spofacryl Spofa Dental	30	1.20	0.42	1.00	2.00
Enlight ORMCO	30	1.80	0.42	1.00	2.00
Transbond XT 3M	30	1.60	0.52	1.00	2.00
No Mix Dentaurum	30	2.30	0.48	2.00	3.00
Resilience Ortho Technology	30	2.00	0.47	1.00	3.00
Gc Fuji ORTHO LC	30	2.00	0.47	1.00	3.00
ConTec Prime Dentaurum	30	1.70	0.48	1.00	2.00
Granitec Falcon	30	1.90	0.74	1.00	3.00

Table 5. Mean adhesive remnant values (acc. to ARI) after debonding in shear force tests for particular adhesives

Bond	Number (*N*)	Mean	SD	min	max
Tetric flow Vivadent	30	1.90	0.32	1.00	2.00
Medicept LightCure Dental	30	1.40	0.70	1.00	3.00
Light Bond Reliance	30	1.40	0.52	1.00	2.00
Spofacryl Spofa Dental	30	1.40	0.84	1.00	3.00
Enlight ORMCO	30	1.80	0.42	1.00	2.00
Transbond XT 3M	30	1.60	0.52	1.00	2.00
No Mix Dentaurum	30	2.30	0.48	2.00	3.00
Resilience Ortho Technology	30	1.90	0.57	1.00	3.00
Gc Fuji ORTHO LC	30	1.90	0.32	1.00	2.00
ConTec Prime Dentaurum	30	1.70	0.48	1.00	2.00
Granitec Falcon	30	1.70	0.48	1.00	2.00

Table 6. Mean adhesive remnant values (acc. to ARI) after debonding in torsion tests for particular adhesives

Bond	Number (*N*)	Mean	SD	min	max
Tetric flow Vivadent	30	1.80	0.42	1.00	2.00
Medicept LightCure Dental	30	1.30	0.48	1.00	2.00
Light Bond Reliance	30	1.40	0.52	1.00	2.00
Spofacryl Spofa Dental	30	1.30	0.48	1.00	2.00
Enlight ORMCO	30	1.70	0.48	1.00	2.00
Transbond XT 3M	30	1.60	0.52	1.00	2.00
No Mix Dentaurum	30	2.40	0.52	2.00	3.00
Resilience Ortho Technology	30	2.10	0.57	1.00	3.00
Gc Fuji ORTHO LC	30	1.80	0.42	1.00	2.00
ConTec Prime Dentaurum	30	1.70	0.48	1.00	2.00
Granitec Falcon	30	2.00	0.67	1.00	3.00

The results of the conventional estimations of the adhesive remnants on the teeth as per ARI criteria, are presented in Table 4 for tension forces, in Table 5 for shear forces, and in Table 6 for torsional forces.

Medicept LightCure achieved the highest mean breaking stress values the tension force tests, whereas Tetric flow the lowest (Table 1). Transbond XT achieved the highest mean breaking stress values in the shear force tests, whereas No-Mix Dentaurum the lowest (Table 2). Light Bond Reliance achieved the highest mean breaking stress values in the torsional force tests, while Granitec Falcon the lowest (Table 3).

ARI index values in adhesive groups tested for tension, shear and torsion, fluctuated around 1 and 2. A mean value of over 2 in the torsional force test was recorded in the case of No-Mix Dentaurum and Resilience Ortho Technology, which indicates that most of the adhesive was left on the enamel (Table 6). In the shear force test, mean values of over 2 were recorded in the case of No-Mix Dentaurum (Table 5), while in the tension force test mean values of over 2 were recorded in the case of No-Mix Dentaurum, GC Fuji ORTHO LC and Resilience Ortho Technology (Table 4).

4. Discussion

One way of determining the durability of a material is measuring its reaction to external force. The tension created in a test affects the material used and is defined as a ratio between the force F(N) and the surface area it impacts (m^2). In the case of a three-layered bracket-adhesive-enamel bond, after the application of an external force leading to debonding, a defined vector maximum threshold tension value, which comprises the ratio between the force threshold value (F) and the surface area of the base of the bracket, can be determined. Currently, binder-containing acrylate resins are used as adhesives for brackets (Bis GMA formulation), which are available in many variations and differ in terms of content and whether they are cured chemically or using light (2). The durability of a bond between the bracket and enamel depends on the physical and chemical properties of the enamel and its vulnerability to the etching agent, etching time, adhesive polimerisation time, the distance from the source of the light to the adhesive, the physical and geometrical characteristics of the bracket base, oral cavity environment and the skills of the clinician ([12]). Using the right adhesive and the optimum procedure is the key to success and provides for maximum comfort for the patient as well as prevents tooth decay after removal of braces (4). Bond evaluation, from a physical point of view, seems to be quite simple, since the tensions that occur when removing the brackets can be broken down into three dominating constituent vectors: torsion, tension and shear [19]. The breaking force values for torsional, tension and shear forces were measured. Based on the results, the highest mean threshold values for shear force were achieved with Transbond XT (9.31 MPa), whereas the lowest with No-Mix Dentaurum (3.11 MPa) (Table 2). The highest mean threshold value for tension force was demonstrated by Medicept Light Cure (4.84 MPa), whereas the lowest value was achieved by Tetric flow (1.76 MPa) (Table 1). The highest mean threshold values for torsional force were achieved by Light Bond Reliance (3.3 MPa), whereas the lowest by Granitec Falcon (1.096 MPa) (Table 3). It should also be mentioned that tensometric test results show that there is least difference between the adhesives in maximum resistance to torsional force, greater variance in maximum resistance to shear force and the greatest variance in maximum resistance to tension force (Tables 1, 2, 3). Careful attention should also be paid not only to the mean values but the fluctuation scale, which to a large degree depends on the individual, physical and chemical variables characterising enamel.

Despite the clarity of the results achieved, it is difficult to compare them to the results achieved by other researchers due to the variety of the laboratory procedures used. As far as the research methodology and equipment used in tests performed by other researchers are concerned, there seems to be no methodological compatibility, especially in terms of extracorporeal tooth preparation, curing and application of external forces on the bond, leading to results which not only are different but also incomparable [34]. When evaluating adhesives, it is important not to conclude with the absolute empirical values of the results achieved, but focus more on comparing the values produced by the research method used. By comparing the mean and minimum resistance of Granitec Falcon, No-Mix Dentaurum, No-Mix Dentaurum and Resilience to shear force, the conclusion is that their mechanical values are comparable. Furthermore, the low resistance values demonstrated by some of the samples tested indicate the unsuitability of the adhesive used to maintain orthodontic braces in place, resulting in frequent detachment of brackets and complications during treatment. The significant difference between the minimum and maximum resistance test results was also found to exist with Tetric flow, which could also lead to frequent detachment of brackets. Even though the brackets were applied with great care to avoid mistakes, the minimum bonding strength of the adhesives listed was lower than the strength needed to ensure that the braces stay in place. This shows that there is a greater possibility of making errors when fixing the appliance in clinical conditions with the use of the aforementioned materials. The higher resistance of Tetric flow as compared to No Mix, which has not been designed for orthodontic applications, but which many orthodontists use, may come as a surprise. Just as demonstrated by Valetta and Prisco [19], it follows from our work that Transbond XT showed higher statistically significant breaking forces in shear, torsion and tension tests than was the case with Fuji GC. However, the mean values achieved differed, most probably due to the different application procedures and bracket types used in the tests. The work proves that debonding begins with the detachment of the bracket from the adhesive. One should note that the structure of the base surface structure, especially its molecular structure and geometric features, is specific to each bracket, hence the adhesion of the glue itself is completely different for different bracket types [28].

Another mistake made by some researchers is conducting tests at different times after application of a bracket, i.e., at different times after initiation of adhesive polimerisation. According to Wendl and Droschl, the resistance of a bond between the bracket and enamel increases within the first 24 hours [24]. The measurements presented in the paper were conducted 1 hour after bracket application, which most certainly provides for a weaker bond, but standardises the results. Another factor which standardised the conditions in which the brackets were applied was the temperature and photopolymerisation, which as a result produced more uniform results, but lower values compared to those achieved by the authors cited. Higher mean values of the breaking forces registered by Valetta and Prisco [19], were probably caused by longer adhesive polymerisation times applied before the bracket broke. According to Majer and Smith [7], errors made during the application of brackets [7] have a significant impact on detachment of the enamel from the adhesive. In reality, as claimed by Valletta and Prisco [19] error free bracket application produces adhesion, which is sufficient enough to damage enamel when removing the bracket. In the course of the research, enamel prisms were damaged twice during shear resistance tests using Spofacryl as the adhesive. Regan and Van Noort's results also showed that tangential stress appearing in shear resistance tests has higher values than in tension stress tests, which results in a higher enamel damage risk hazard [38]. In reference to research by Valletta and Prisco [19], the mean values achieved to determine the torsional torque showed higher statistically significant differences in the case of Transbond XT and lower in the case of Fuji GC. In cases when brackets came loose during orthodontic treatment, it was often clinically concluded that a print of the bracket structure was left in the layer of adhesive, which adhered to the enamel, which is indicative of a weaker connection between the bracket and adhesive than between the enamel and adhesive [6]. Supporting polymerisation of the adhesive by use of the radiant energy of a glow coil (to a smaller extent of an LED) lowers the risk of detachment [39]. Mean values achieved in breaking tests for shear, tension and torsion forces, ensures that the brackets stay in place on the teeth during treatment. During our research, most of the commercially available adhesives were compared to improve the comparative reliability of results using a single research method.

Connecting a metal bracket to a tooth enamel using a biomaterial (adhesive), which demonstrates double-sided adhesion, leads to the formation of a composite bond with variable mechanical resistance, which is dependent on the direction of force, the individual physical, chemical and geometrical features of the enamel surface [26], [37], properties of the surface of the bracket and is dependent on the adhesive itself and the adhesive properties of the bond [24]. Based on literature findings, the main fluctuating factor which seems to have an impact on the resistance of the bond, are the physical, chemical and structural properties of the enamel, which are inherently specific for each tooth and which can vary the adhesion strength within the same adhesive product type significantly. It needs to be added that fluctuations in the surface area values of remnant adhesive left on the enamel of different teeth (belonging to different patients) were much higher than fluctuations of remnant adhesive left on bracket base surfaces. This confirms the hypothesis that the inherently specific enamel properties of each tooth significantly contribute to a greater distribution of individual characteristics of the broken bond in group tests.

5. Conclusions

1. The highest mean threshold values for shear force were achieved with Transbond XT, whereas the lowest with No-Mix Dentaurum.

2. The highest mean threshold values for tensile force were achieved with Medicept Light Cure, whereas the lowest with Tetric flow.

3. The highest mean threshold values for torsional force were achieved with Light Bond Reliance, whereas the lowest with Granitec Falcon.

4. The results of tensometric tests indicate that due to an increase in the force used more adhesive is left on the enamel.

5. In the case of all the adhesives used, there was 60–70% less adhesive left on the enamel than on the brackets, which is indicative of the fact that the debonding process is initiated on the bracket/adhesive connection.

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