Morphological Properties and Frictional Resistance of Zirconia Brackets According to Yttria Proportions

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Morphological Properties and Frictional Resistance of Zirconia Brackets According to Yttria Proportions

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2024 년 새해 첫날

저자 씀

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ABSTRACT

Morphological Properties and Frictional Resistance of Zirconia Brackets According to Yttria Proportions

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(Directed by professor Kee-Joon Lee, D.D.S., M.S.D, Ph.D)

This in vitro study evaluated zirconia brackets for their manufacturing accuracy, morphological characteristics, and frictional resistance with orthodontic wires. Three experimental groups of zirconia brackets were fabricated using yttria-stabilized zirconia (YSZ) materials with different yttria proportions–3 mol% yttria (3Y-YSZ), 4 mol% yttria (4Y-YSZ), and 5 mol% yttria (5Y-YSZ) (Tosoh Ceramic, Japan). A polycrystalline alumina ceramic bracket (3M™ Clarity™ Advanced, MBT 0.022-inch slot) was employed as the control group. Morphological properties, including slot surface structure and dimensions, were examined using scanning electron microscopy and surface profiler analysis. Manufacturing accuracy was assessed with root mean square calculations of trueness and precision**.** Frictional resistance with the orthodontic wire was also measured.

Zirconia brackets containing 3 to 5 mol% YSZ presented enhanced reliability in terms of dimensional accuracy. 3 mol% YSZ had the smoothest surface roughness the least frictional forces for all wire types tested. Therefore, it appears to have remarkable potential as an advanced material for fabricating orthodontic brackets.

Keywords: Orthodontic ceramic brackets, Yttria-stabilized zirconia, Zirconia brackets

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I. INTRODUCTION

Ceramic brackets emerged in the 1980s as a viable solution for orthodontic appliances, elevating the aesthetic aspect of traditional stainless-steel brackets while upholding the treatment efficiency and favorable outcomes, especially in addressing complex malocclusion - the limitation of clear aligner therapy (Kusy, 2002; Robertson et al., 2020). These brackets predominantly employ alumina, either in polycrystalline or monocrystalline form, depending on the manufacturing process. Despite offering aesthetic benefits, ceramic brackets present certain drawbacks, such as elevated friction resistance (FR) and diminished fracture toughness as compared to stainless-steel brackets (Cacciafesta et al., 2003; Johnson et al., 2005). These limitations often lead to challenges for orthodontists, including bracket wing fractures during clinical procedures. Such incidents can compromise enamel integrity and result in supplementary costs due to bracket replacement (Johnson et al., 2005). To address these limitations, various innovative approaches have been proposed to develop advanced orthodontic brackets, with zirconia emerging as a promising material for enhancing mechanical properties owing to its remarkable toughness (Namura et al., 2022; Polychronis et al., 2023).

Zirconia brackets have been the subject of orthodontic research since the 1990s (Springate & Winchester, 1991). However, during this period, they did not demonstrate substantial improvements over alumina brackets in aspects such as frictional characteristics and aesthetic performance (Keith et al., 1994). Recent advancements in zirconia materials have led to the development of several variants, influenced by factors such as powder selection, sintering additives, heat treatment, and other processing considerations (Kontonasaki et al., 2019). Pure zirconia is composed of three main phases: monoclinic at room temperature, tetragonal above 1,170°C, and cubic above 2,370°C (Zhang & Lawn, 2018). While the monoclinic phase itself lacks remarkable mechanical attributes, the incorporation of dopants into the starting powder can augment strength and fracture toughness. This is achieved by partially stabilizing the tetragonal phase within the microstructure at ambient temperature (Zhang & Lawn, 2018). Among the various dopants, yttria (Y_2O_3) stands out for its efficacy in providing a synergistic blend of robust strength and toughness, facilitating the stabilization of the tetragonal or cubic phase at room temperature (Denry & Kelly, 2008; Kelly & Denry, 2008). Furthermore, yttria-stabilized zirconia (YSZ) allows for efficient production through computer-assisted design and fabrication (CAD/CAM) technologies. This ensures the reproduction of intricate details and lowered manufacturing costs, all while maintaining superior physical characteristics. As a result, 3 mol% yttria-stabilized tetragonal zirconia (3Y-YSZ) polycrystals have gained popularity in dental ceramics, particularly for prosthetic restorations. Recently, high-translucency partially stabilized zirconia with greater quantities of the non-birefringent cubic phase—achieved by utilizing higher yttria contents such as 4 mol% (4Y-YSZ) or 5 mol% (5Y-YSZ)—has been engineered. These innovations have notably broadened their clinical applications in terms of aesthetics (Han et al., 2017). Consequently, zirconia's emerging prominence in research and the creation of orthodontic brackets has become evident (Maki et al., 2016; Namura et al., 2022; Panayi, 2022; Polychronis et al., 2023; Zang et al., 2023). However, existing literature has reported a direct correlation between yttria concentration, translucency, and mechanical strength in zirconia restorations. While an increase in yttria concentration can stabilize the cubic phase, resulting in greater translucency, it may concurrently diminish the mechanical strength (Pekkan et al., 2020; Tong et al., 2016). Therefore, to achieve a balance between mechanical properties and aesthetic demands in clinical applications, it becomes imperative to explore the performance and appropriateness of zirconia brackets with different yttria concentrations. To the best of our knowledge, the information available on this subject is scarce.

The objective of this in vitro study is to contribute to the existing knowledge base regarding the utilization of YSZ materials in the fabrication of advanced orthodontic brackets. The study involves a comprehensive examination and comparison of the morphological attributes and frictional resistance of zirconia brackets with those of commercial polycrystalline alumina brackets. The hypothesis was that there was no significant difference in the performance of zirconia brackets containing 3 to 5 mol% yttria proportions.

II. MATERIAL AND METHODS

Methods

Design and manufacture of zirconia brackets

The experimental groups were fabricated utilizing three distinct zirconia powders: 3Y-YSZ (Zpex; Tosoh Ceramic, Japan), 4Y-YSZ (Zpex4; Tosoh Ceramic, Japan), and 5Y-YSZ (ZpexSmile; Tosoh Ceramic, Japan). According to the manufacturing specifications, all these powders are highly translucent zirconia grades, containing less than 0.1 wt% alumina, with the primary distinction being the yttria content (Fonseca et al., 2019).

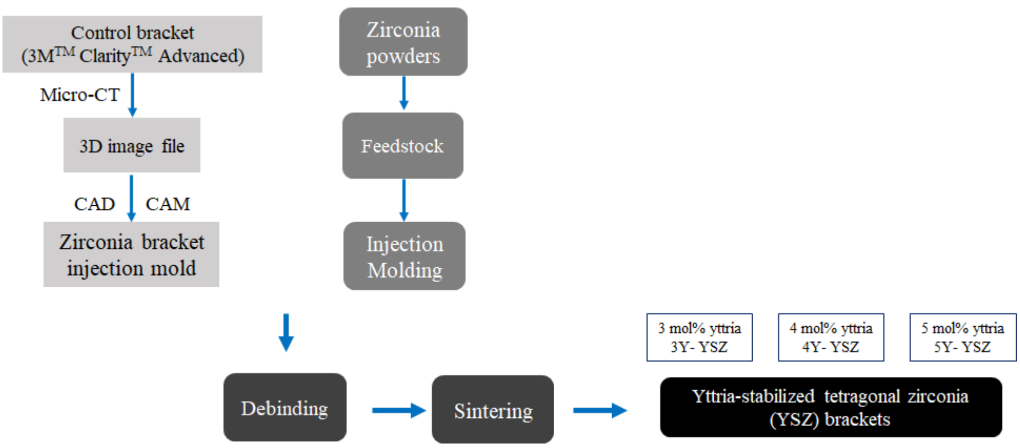

Figure 1. schematic diagram illustrating the ceramic injection molding method utilized for the production of zirconia specimens

All brackets were meticulously fabricated for the maxillary right central incisors, employing the reverse engineering process based on the morphology of an existing polycrystalline alumina ceramic bracket product (3M™ Clarity™ Advanced, MBT 0.022-inch slot) used as the control group. Figure 1 delineates the ceramic injection molding method employed for the production of the zirconia brackets. During this procedure, the mold was digitally conceptualized through three-dimensional (3D) software (Creo 5.0, PTC, USA)—referred to as *the digital reference design*—based on a 3D scanned image of the control group's morphology (micro-computed tomography scanner, SkyScan 1173, Bruker, USA). This design process took into consideration the linear shrinkage associated with zirconia materials.

Measurements

Morphological properties

Scanning electron microscopy (SEM) Analysis

For the SEM analysis, samples of 10 brackets were randomly selected from each group and studied using an SEM instrument (S-3000N, Hitachi, Tokyo, Japan). The focus of this analysis was to examine the dimensions and surface structure of the bracket slots. The specimens were secured on SEM stubs, subjected to drying in a freeze dryer (ES-2030, Hitachi, Tokyo, Japan), and then coated with platinum to a thickness of 100 nm using an ion coater (E-1010, Hitachi, Tokyo, Japan). Photomicrographs were captured from each bracket's face at an operating voltage of 15 kV. Low-magnification SEM images provided insights into the overall structure, while high-magnification SEM images revealed detailed microcosmic surface topography (Shin et al., 2021). The average grain size was investigated by the line intercepted method at the magnification of 10k in which five micrographs and five lines were used for each bracket group (Arellano Moncayo et al., 2023; Li et al., 2022).

The slot dimensions in each bracket group were assessed in lateral views using a computer-based measuring tool (IMT i-Solution Inc., version 7.3; Coquitlam, BC, Canada). To mitigate any bias from the rounded nature of the slot angles, measurements were carried out at a distance of 100 μm from the base and wall of the slot. Subsequent measurements included the slot base width, slot angle (corresponding to the torque of the bracket prescription), and parallelism of the slot walls (Figure 2) (Shin et al., 2021).

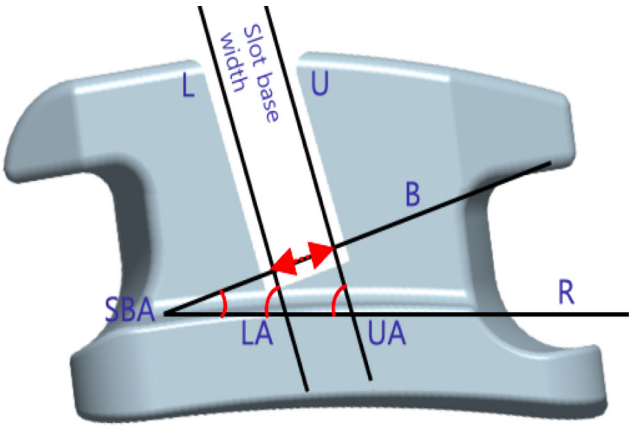

Figure 2. Detailed illustration of bracket slot measurements. R represents a horizontal reference line; B is a line parallel to the slot base, distanced 100 μm from it; U is a line parallel to the upper wall of the slot, positioned 100 μm from that wall; L is a line parallel to the lower wall of the slot, distanced 100 μm from it; slot angle (SBA) denotes the angle between R and B; upper angle (UA) signifies the angle between R and U; lower angle (LA) characterizes the angle between R and L.

The precision and trueness of the slot dimensions were evaluated to ascertain the dimensional accuracy of the brackets. Precision, defined as the agreement of repeated results, was calculated by comparing the differences among pairs within the 10 brackets of each group. Trueness, indicating the agreement of the slot dimension with a true value, was determined by contrasting the dimensions of the control group's 10 brackets with the manufacturers' specified nominal values, while in the experimental group, the dimensions were compared with the *digital reference design*. To compensate for the offset error due to positive and negative value deviations, root mean square (RMS) values were computed for both precision and trueness (Kim et al., 2018). A lower RMS value for precision or trueness is indicative of higher accuracy.

Surface profiler analysis

The examination of surface roughness in the bracket slots was conducted using a surface profiler (DektakXT Stylus Profiler, Bruker, USA), with a sample of 10 brackets per group. Each bracket was sectioned using a fine diamond disk. The profiler was operated with an inductive gauge that featured a 12.5-μm-radius diamond stylus, moving at a scanning speed of 5 m/s. Prior to the examination, all brackets were meticulously cleaned with 95% alcohol. The specimens were scanned to evaluate two key surface roughness parameters: the average roughness (Ra) and RMS roughness (Rq).

Friction resistance (FR) tests

A designated sample comprising 30 bracket–wire combinations was prepared for each group (refer to Table 1), wherein an elastic ligature (Ormco) was utilized to secure the archwire to the bracket, applied consistently by the same individual. To negate the effect of ligature force decay, the elastomeric rings were affixed immediately preceding each test. Both bracket and archwire specimens were meticulously cleaned with 95% alcohol prior to examination.

Table 1. Design of the frictional resistance test.

Wire alloys	**Wire sections**	**Control group**	**Experimental groups**		
			3Y-YSZ	4Y-YSZ	5Y-YSZ
Stainless steel	0.016-inch	10	10	10	10
	0.019 in × 0.025-inch	10	10	10	10
Beta-titanium	0.017 × 0.025-inch	10	10	10	10

The investigation of the FR was conducted in a dry state using a universal testing machine (Instron 5942; Instron Corp., USA) (Choi et al., 2014). The bracket slot and wire were positioned at an angulation of 0°, and the wire was drawn through the slot for a distance of 5 mm at a crosshead speed of 5 mm/min. The resulting static and kinetic friction forces were recorded. Specifically, the static frictional force was ascertained from the initial force peak, while the kinetic frictional force was computed as the average force subsequent to the peak until the conclusion of the test.

Statistical analysis

The measurement repeatability and intra-observer variability were evaluated by computing the intraclass correlation coefficient between two assessments taken at 2-week intervals by a single inspector. The ensuing intraclass correlation coefficient (ICC) between the measurement pairs denoted high reliability (ICC > 0.97).

To verify the data distribution's normality, the Shapiro-Wilk test was administered. One-way ANOVA and post-hoc Tukey's multiple comparison tests were employed to analyze the intergroup variations in morphological characteristics and frictional resistance. A one-sample T-test analysis was utilized to examine intragroup disparities in trueness. All statistical evaluations were conducted with SPSS 24.0 Statistical Software (SPSS, Armonk, NY, USA), applying a significance threshold of 0.05.

III. RESULTS

Morphological characteristics

To quantify the slot dimensional measurement error, the Dahlberg error was computed,(Kim, 2013) confirming that the linear measurement error was 5.58 μm, while the angulation measurements ranged from 0.10° to 0.27°.

Each group's bracket dimensions were measured and presented in Table 2. No disparities were observed in any dimensional parameters between the experimental groups; however, significant differences emerged between the control and experimental groups. The experimental groups manifested a greater slot base width (mean difference, 31.2 to 34.1 μm) and a reduced slot base angle (mean difference, 1.83° to 2.42°). Furthermore, although essentially parallel slot walls were verified in all groups, the experimental groups exhibited a lesser divergence of slot walls, attributable to an approximately 1° inward tilt of the upper angle relative to the control group.

Table 2. Slot dimensions of the experimental and control groups.

Parameters	Control group	Experimental groups			Sig.
		3Y-YSZ	4Y-YSZ	5Y-YSZ	
Slot base width	420.40 ± 4.05^{a}	453.60 ± 3.25^{b}	454.50 ± 3.26^{b}	452.70 ± 3.97^{b}	0.000*
LA	74.12 ± 0.56^{a}	74.51 ± 0.53^{a}	74.61 ± 0.59^{a}	74.48 ± 0.43^{a}	0.194
UA	75.16 ± 0.62^{b}	73.77 ± 0.68^{a}	73.95 ± 0.58^{a}	73.75 ± 0.57^{a}	0.000*
SBA	20.39 ± 0.57^{b}	18.35 ± 0.75^{a}	18.35 ± 0.61^{a}	17.97 ± 0.58^{a}	0.000*

Data are shown as mean ± standard deviation (linear: μm, angular: °)
UA, upper angle; LA, lower angle; SBA, slot angle
Sig values were calculated from one-way ANOVA between the control and experimental groups.
The same upper superscript letters indicate no significant differences between groups (Tukey's multiple comparison test).
* Statistically significant at $p < 0.01$

The trueness and precision of all morphological parameters were assessed across all groups, with the findings summarized in Tables 3 and 4.

Table 3. RMS trueness values in the experimental and control groups.

	Parameters	**Group**	**Mean ± SD**	***p*-value**	**Sig.**
Trueness	Slot base width	Control	61.6 ± 4.05^{a}	0.000^{**}	0.000^{*}
		3Y-YSZ	117.40 ± 3.25^{b}	0.000^{**}	
		4Y-YSZ	115.50 ± 3.26^{b}	0.000^{**}	
		5Y-YSZ	117.30 ± 3.78^{b}	0.000^{**}	
	SBA	Control	3.39 ± 0.57^{b}	0.000^{**}	0.000^{*}
		3Y-YSZ	0.57 ± 0.59^{a}	0.170	
		4Y-YSZ	0.59 ± 0.34^{a}	0.097	
		5Y-YSZ	0.50 ± 0.23^{a}	0.870	

Data are shown as mean ± standard deviation of root means square values calculated for trueness (linear: μm; angular: °)
SBA, the slot angle
p values were calculated from a one-sample T-test for each group to examine intragroup disparities in trueness. ($p < 0.01$ means that the measured value is different from the nominal value.)
Sig. values were calculated from one-way ANOVA between the control and experimental groups.
The same upper superscript letters indicate no significant differences between groups (Tukey's multiple comparison test).
* Statistically significant at $p < 0.01$

In the control group, the bracket slot width exceeded the nominal values defined by the manufacturers by approximately 61.6 μm (11.02%; $p < 0.05$), and the slot base angle was larger by approximately 3.39° (slot width, 558.8 μm; slot base angle, 17°; $p < 0.05$). Conversely, in the experimental groups, the bracket slot width was less than their *digital reference* design's value (slot width, 770 μm). The mean disparities for the 3Y-YSZ, 4Y-YSZ, and 5Y-YSZ groups were 117.40 μm (15.25%), 115.50 μm (15.00%), and 117.30 μm (15.26%), respectively ($p < 0.05$). These measurements underscore the linear shrinkage of the YSZ material during sintering, a phenomenon anticipated through detailed observation to regulate the experimental groups' slot dimensions. As a result, a higher RMS value for the slot base width was corroborated in the experimental group ($p < 0.05$). However, the slot base angle in the experimental groups did not differ significantly from the reference design (slot base angle, 18°) (Table 3), resulting in the better trueness value (lower RMS value) in the experimental groups relative to the control group ($p < 0.05$) (Table 3). Moreover, the precision of any morphological parameter did not vary among the groups (Table 4).

Table 4. RMS values of precision in the experimental and control groups.

	Parameters	Group	Mean ± SD	Sig.
Precision	Slot base width	Control	4.82 ± 3.13	0.200
		3Y-YSZ	3.84 ± 2.54	
		4Y-YSZ	3.83 ±2.62	
		5Y-YSZ	4.69 ± 3.13	
	UA	Control	0.72 ± 0.50	0.891
		3Y-YSZ	0.76 ± 0.59	
		4Y-YSZ	0.68 ± 0.47	
		5Y-YSZ	0.69 ± 0.44	
	LA	Control	0.63 ± 0.48	0.191
		3Y-YSZ	0.64 ± 0.41	
		4Y-YSZ	0.69 ± 0.48	
		5Y-YSZ	0.50 ± 0.36	
	SBA	Control	0.65 ± 0.49	0.202
		3Y-YSZ	0.87 ± 0.63	
		4Y-YSZ	0.69 ± 0.51	
		5Y-YSZ	0.68 ± 0.46	

Data are shown as mean ± standard deviation of root means square values calculated for precision (linear: µm; angular: °)
UA, upper angle; LA, lower angle; SBA, slot angle
Intergroup comparisons were performed using one-way ANOVA.
* Statistically significant at $p < 0.01$

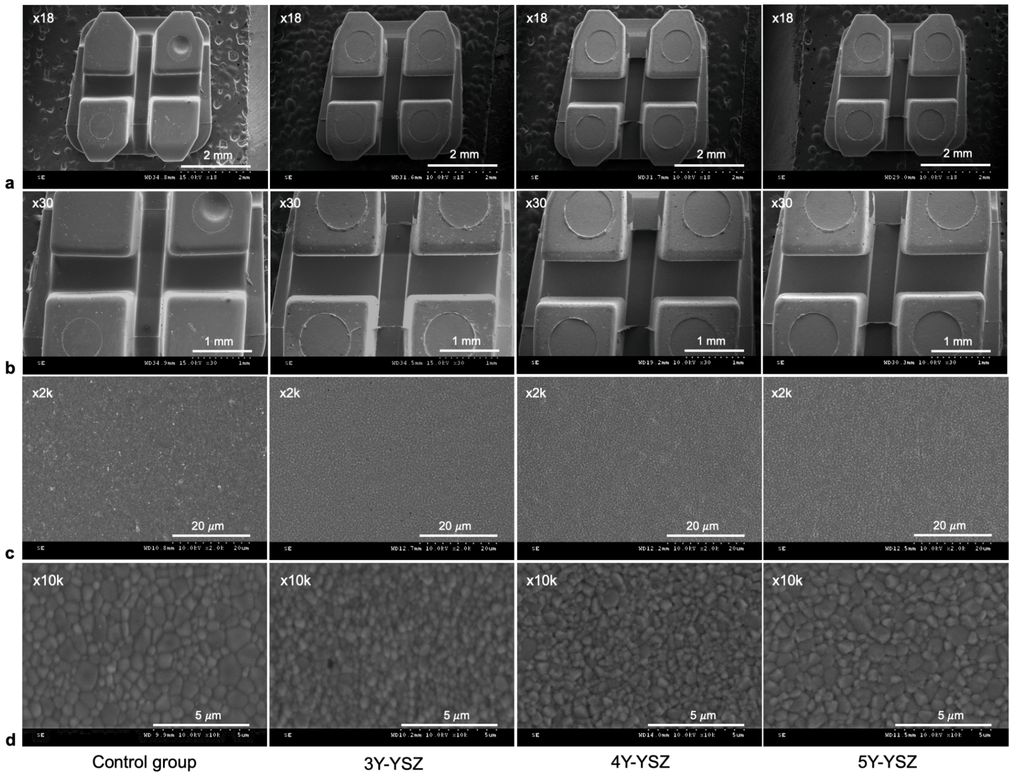

Figure 3. Comprehensive representation of the experimental and control group structures at various magnifications. A) ×18, B) ×30, C) ×2k, and D) ×10k.

Figure 3 illustrates the general structures of the bracket groups. The bracket slot surfaces displayed no apparent defects and were characterized by a smooth polycrystalline surface with uniform grains. The mean average grain size increased with the increase of yttria content. No significant difference in the average grain size was observed between the control, 4Y-YSZ, and 5Y-YSZ groups (Table 5).

Table 5. The average grain size in the experimental and control groups.

Group	Grain size	Sig.
Control	0.639 ± 0.073[a]	0.000*
3Y-YSZ	0.374 ± 0.063[b]	
4Y-YSZ	0.580 ± 0.021[a]	
5Y-YSZ	0.682 ± 0.102[a]	

Data are shown as mean ± standard deviation (nm)
Intergroup comparisons were performed using one-way ANOVA.
The same superscript letters indicate no significant differences between groups (Tukey's multiple comparison test).
* Statistically significant at $p < 0.01$

The surface roughness of the bracket slot was subsequently assessed using surface profiler analysis, affirming the lowest surface roughness parameters for 3Y-YSZ (Ra = 45.61; Rq = 56.76; $p < 0.05$). No marked differences in surface roughness were identified between the 3Y-YSZ and 4Y-YSZ groups or the control and 5Y-YSZ groups (Table 6).

Table 6. Surface roughness values of experimental and control groups.

Group	Ra	p	Rq	p
Control	57.02 ± 7.44[a]	0.000*	71.57 ± 8.67[c]	0.000*
3Y-YSZ	45.63 ±6.61[b]		56.76 ± 8.76[d]	
4Y-YSZ	50.87 ± 5.39[a,b]		64.70 ± 7.68[c,d]	
5Y-YSZ	60.72 ± 5.63[a]		76.44 ± 7.08[c]	

Data are shown as mean ± standard deviation (μm)
Ra, Roughness average
Rq, Root mean square
Intergroup comparisons were performed using one-way ANOVA.
The same superscript letters indicate no significant differences between groups (Tukey's multiple comparison test).
* Statistically significant at $p < 0.01$

Frictional resistance

The static and kinetic FR values varied significantly among the groups, displaying a consistent pattern. Within the groups, the 3Y-YSZ group demonstrated the least frictional forces for all wire types tested. The control group recorded the highest friction forces, although no considerable differences were found between the control, 4Y-YSZ, and 5Y-YSZ groups (Figure 4).

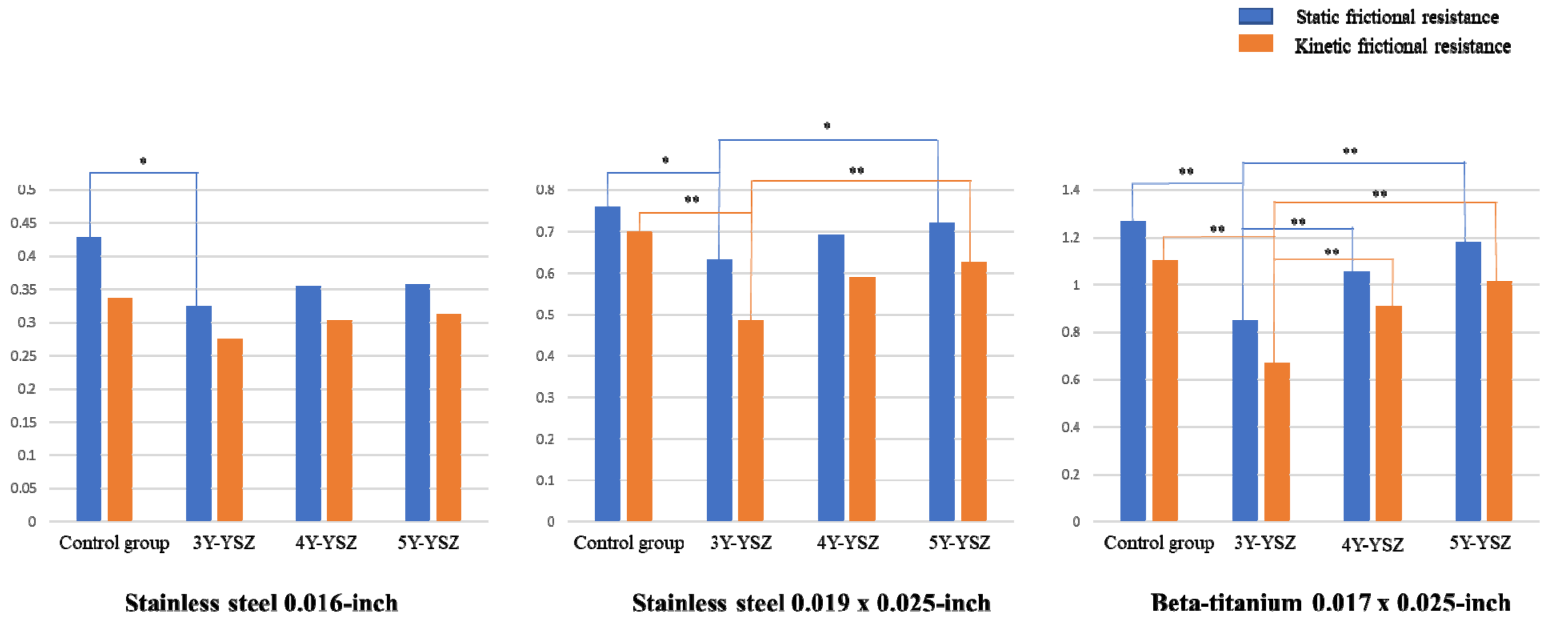

Figure 4. Graphical display of static and kinetic friction values for both the experimental and control groups

IV. DISCUSSION

Recent advancements in the composition, structure, and fabrication techniques of zirconia material have substantially enhanced its mechanical properties and aesthetic features, particularly within dental prosthodontics (Kontonasaki et al., 2019). This evolution has fueled an increasing interest in employing zirconia in the manufacture of orthodontic brackets, surpassing the constraints of conventional alumina ceramic brackets (Maki et al., 2016; Namura et al., 2022; Panayi, 2022; Polychronis et al., 2023; Zang et al., 2023). However, the performance of orthodontic appliances fabricated by these novel zirconia variants remained unclear. Our study serves as a pioneering effort to bridge this gap by offering crucial insights into the performance of zirconia brackets. The study spans an exploration of varying yttria proportions and their implications for developing advanced orthodontic brackets. The findings emphasize that zirconia brackets, containing 3 to 5 mol% YSZ, demonstrate superior reliability in dimensional accuracy compared to the control group.

To mitigate confounding factors in the experimental results, the zirconia brackets utilized in this study were digitally designed using the reverse engineering process, adhering to the morphology of the control group. Despite the absence of any significant disparity in slot dimension among the zirconia groups, they exhibited a more substantial slot base width (mean difference, 31.2 to 34.1 μm), a diminished slot base angle (mean difference, 1.83° to 2.42°), and reduced divergence of slot walls relative to the control group (Table 2). These variations can be attributed to slight discrepancies in the digital design of the zirconia brackets when compared with the morphology of the control group. To a certain extent, such differences appear unavoidable because of errors encountered during the fabrication processes (Figure 1).

In this study, the precision and trueness of the fabrication process were assessed by calculating the RMS values. According to these trueness measurements, the control group's dimensions were larger by approximately 61.6 µm in slot width (11.02%) and approximately 3.39° in slot base angle compared to the nominal values, with a significance level of $p < 0.05$ (Table 3). These findings align with previous studies (Cash et al., 2004). For instance, Lefebvre et al. (Lefebvre et al., 2019) examined the accuracy of several commercial brackets and concluded that over 90% of slot width measurements deviated by up to 24% from the values stated by the manufacturers, along with inconsistent slot inclination angles. Within the field of orthodontics, achieving precise slot dimensions is critical, as it directly influences the effectiveness of the torque exerted on the teeth. To create an efficient pre-adjusted bracket and reduce compensatory bending, manufacturers must focus on precision, especially with regard to slot dimensions (Erduran et al., 2016). Of all ceramic materials, zirconia is known for its exceptional fracture toughness, rendering it suitable for meticulous shaping and thereby potentially enhancing accuracy and reproducibility in finer details (Keith et al., 1994; Kusy, 2002; Namura et al., 2022). In fact, the trueness values for the slot base angle in the experimental groups showed no significant deviation from the *digital reference design* values (Table 3), reflecting the higher level of accuracy attained during the manufacturing process across all yttria proportions. Furthermore, the precision values for all slot dimension parameters in the experimental groups were found to be consistent and reproducible. Adhering to the ISO 27020 standard (ISO 27020, 2010), with tolerances of ±0.01 mm in slot width, ±1° in torque, and $\pm 1^0$ in slot wall parallelism,(27020, 2010) the slot dimensional accuracy in the experimental groups was confirmed with elevated reliability (Tables 3 and 4).

In the field of orthodontics, it is crucial to comprehend the force necessary to overcome friction at the bracket–archwire interface, as this understanding aids in producing optimal biological tooth movement (Cacciafesta et al., 2003). Our findings indicated that both FR values and the surface roughness of the zirconia brackets are influenced by the yttria proportion; specifically, the 3Y-YSZ group exhibited the smoothest surface and the lowest static and kinetic friction values under all tested conditions (Tables 6 and Figure 4) (Alao et al., 2017; Alfrisany & De Souza, 2022; Jum'ah et al., 2020). These variations among the zirconia bracket groups became particularly pronounced when larger sizes of rectangular archwires were employed or when archwires made of alloys with rougher surfaces, such as TMA archwires, were utilized (Cacciafesta et al., 2003; Yang et al., 2019). Compared to the control group, zirconia brackets demonstrated reduced FR values; however, the significant differences were solely observed with the 3Y-YSZ group (Figure 4).

This study revealed that the fabrication process of YSZ brackets consistently demonstrated high accuracy and reproducibility across various yttria proportions, underscoring their potential for achieving predictable orthodontic tooth movement. Moreover, the YSZ material holds promise for fabricating self-ligating brackets, a category that places particular emphasis on intricate manufacturing details. Among the zirconia bracket categories, the 3Y-YSZ brackets stood out for their superior mechanical performance, marked by reduced FR forces and enhanced surface integrity in response to fracture loads. Such attributes offer advantages in optimizing orthodontic treatment.

This in vitro study has some limitations. Firstly, it must be noted that the results obtained in this study may not wholly represent the clinical scenario, owing to limitations inherent in laboratory conditions, despite measures taken to control for confounding variables (Lopes Filho et al., 2012). Additional clinical investigations are warranted to investigate the effects of these material properties in daily orthodontic practice. Secondly, the bonding strength of zirconia brackets was not included within the scope of this study since it is not only related to the material itself but also the design of the bracket base, surface treatment, and adhesive materials (Algera et al., 2008; Wang et al., 2004). Therefore, the bonding strength of these novel zirconia brackets and the enamel surface integrity after debonding should be investigated in the future.

V. CONCLUSION

In this study, the morphological characteristics, manufacturing consistency, and friction resistance of zirconia brackets were revealed as follows.

1. Zirconia brackets could be manufactured with the same level of precision as the control group, and the trueness value of angle-related values was statistically significantly better in the experimental group than in the control group.
2. 3Y-YSZ had the smoothest surface roughness the least frictional forces for all wire types tested.

Zirconia brackets, especially 3Y-YSZ, appear to have remarkable potential as an advanced material for fabricating orthodontic brackets.

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ABSTRACT (KOREAN)

지르코니아로 제작된 교정용 브라켓에서 Yttria 함량에 따른 형태적 특성 및 마찰 저항성 평가

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박 창 범

이 연구에서는 지르코니아 브라켓의 제조상 정확도, 형태학적 특성 및 교정 와이어와의 마찰 저항을 평가하였다. 지르코니아 브라켓의 세 가지 실험 그룹은 서로 다른 이트리아 비율 (3 mol% 이트리아(3Y-YSZ), 4 mol% 이트리아(4Y-YSZ) 및 5 mol% 이트리아(5Y-YSZ))을 갖는 이트리아 안정화 지르코니아(YSZ) 재료를 사용하여 제작되었으며 (Tosoh Ceramic, 일본), 대조군으로는 다결정 알루미나 세라믹 브라켓 (3M™ Clarity™ Advanced, MBT 0.022인치 슬롯) 이 사용되었다. 슬롯 표면 구조 및 치수를 포함한 형태학적 특성은 주사 전자 현미경 및 표면 프로파일러 분석을 사용하여 조사되었다. 제조상 정확도는 진실성과 정밀도의 평균 제곱근 계산을 통해 평가하였다. 교정용 와이어의 마찰 저항도 측정하였다.

3~5mol% YSZ를 함유한 지르코니아 브라켓은 치수 정확도 측면에서 향상된

진실성을 나타냈다. 그 중 3mol% YSZ는 테스트된 모든 와이어 유형에 대해 가장 매끄러운 표면 거칠기와 가장 적은 마찰력을 가졌다. 따라서 3mol% YSZ는 치아교정용 브라켓 제작을 위한 첨단소재로서 놀라운 잠재력을 가지고 있는 것으로 보인다.

핵심 되는 말: 세라믹 브라켓, 이트리아 안정화 지르코니아, 지르코니아 브라켓