Optimization of Bracket Base Curvature Based on the Morphometric Analysis of Bonding Sites

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This Certifies that the Master's Thesis
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2025년 6월 저자 씀

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ABSTRACT

Optimization of Bracket Base Curvature Based on the Morphometric Analysis of bonding sites

Accurate bracket positioning is crucial for achieving precise tooth movement and optimal treatment outcomes. To ensure reliable and reproducible bracket positioning, the bracket base is designed and fabricated to maximize the adaptation with the tooth surface. This requires precise understanding of the morphological characteristics of the bonding surfaces.

Given that the buccal surface of the tooth is curved, the radius of curvature (R) can be used as to quantify its anatomical characteristics. The radius of curvature (R) is an essential parameter in engineering design that represents the morphological characteristics of curved structures and is similarly applied for designing the bracket base.

Therefore, the aim of this study was to evaluate the morphological characteristics of the bracket bonding surfaces by measuring the radius of curvature (R) of the whole dentition among Koreans and to apply the morphometric results to optimize bracket base design.

A total of 300 sets of digital casts from adult post-treatment orthodontic patients were utilized. The bracket bonding sites were determined based on the Facial Axis of the Clinical Crown (FACC) in a rectangular bonding size, and the radius of curvature(R) was measured at six specific sites including mesial, distal, incisal and gingival margins of the region of interest.

As a result of measuring the curvature of the teeth, the mean curvature and standard deviation across six sites per tooth were identified. It was found that the curvature in the horizontal direction was significantly smaller than that in the vertical direction, indicating that the horizontal sites exhibit a more pronounced convexity. Furthermore, statistical analysis using p-values revealed that among the three sites in each direction, only the horizontal sites of the maxillary canines showed similarity. In all other sites, the distributions were found to be significantly different from one another.

However, R values deviated from a typical normal distribution with discrepancies between the mode and mean values, suggesting that relying solely on mean values of R may not be clinically effective. Instead, an optimized adjustment value was derived to establish clinically applicable curvature data. Ultimately, this study aims to propose an optimized bracket base design specifically suited for Korean dentitions.

In the optimization process, through a comparative analysis of the curvature value between the bracket and the tooth surface, teeth with a curvature value greater than the average were considered to be included in the bracket application range corresponding to the average curvature and account for 50% of the total. The goal was to identify the adjusted curvature values that could cover higher proportions—specifically 70%, 80%, and 90%—and to propose these as the

optimized bracket curvatures.

Key words : **curvature, orthodontic bracket, bracket base**

1. Introduction

Accurate bracket placement is crucial for achieving ideal orthodontic treatment outcomes and facilitating effective tooth movement.[1] The bracket bonging site is typically determined and designed based on the Facial Axis of the Clinical Crown (FACC), which has been reported to hold high reproducibility.[2] [3] [4] Clinical training, various attachment devices, or indirect bonding techniques are applied to improve precise bracket positioning. [5] [6]

In addition, the compatibility between the tooth surface and the bracket surface—specifically, the similarity in shape between the bracket base and the tooth surface—can enhance bonding accuracy and ease.[7] [8] Therefore, when determining the bracket design including the base and the profile, anatomical characteristics of the tooth bonding surface are fully taken into consideration. However, given that each tooth has unique anatomical features with curved surfaces, defining buccal surface morphological characteristics with a single numerical value is challenging.

In previous studies, curvature of the buccal surface was estimated by measuring 20 points per millimeter on each tooth from 30 intraoral scans and fitting a second-degree polynomial equation ($ax^2 + bx + c = 0$), from which the coefficient was used as an index of curvature. [9] Although these values effectively represented anatomical characteristics, it did not directly correspond to the numerical value of curvature expressed as the radius of curvature (R). Curvature describes the degree of bending of a curve or surface and is defined as the reciprocal of the radius of curvature. The radius of curvature represents the radius of an arc that closely approximates the curve, providing a more intuitive and geometrically meaningful parameter. From an engineering perspective, the shape of the buccal surface of a tooth can be described using curvature.

The radius of curvature (R) is particularly valuable because it can be directly applied to engineering tasks such as bracket design. To design a bracket, 3D modeling software requires six curves (vertical and horizontal curves at both ends and the center of the bracket base) to defined shape the base surface. (Fig 1) These curves are defined using arc radius values, making the radius of curvature an essential parameter in the bracket design process. (Fig 2)

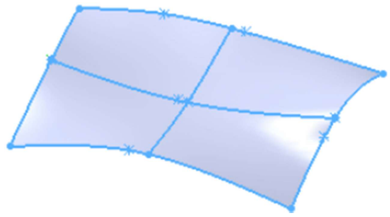


Figure1. Surface formation in Solidworks program with bidirectional tangency [10]

Figure2. Radius of curvature (R) of the arc applied to the curve in 3D CAD program

A smaller radius of curvature indicates a more convex surface, whereas a larger radius suggests a flatter surface. When applied to the tooth surface, a smaller radius corresponds to a more convex buccal surface, while a larger radius indicates a flatter surface. (Fig 3)

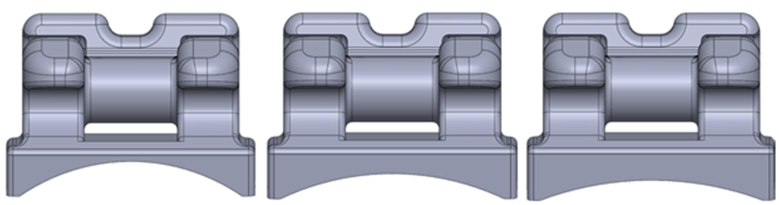


Figure3. Bracket design when bracket curvature R=3, R=4, R=5

It has been reported that bracket placement on canines and premolars can be less stable than others due to the pronounced convexity of these teeth leading to imbalance during orthodontic treatment[11)] which also influences the torque effect of bracket.[12)] Thus, understanding specific features of the curvature among the canines and premolars is especially necessary in the current clinical settings.

Therefore, the objective of this study was to first analyze the anatomical features of the buccal bonding surfaces by measuring the radius of curvature among the canines and the premolars. In addition, the values of the radius of curvature were aimed for adjustment through optimization process and validated to improved surface adaptability among broader range of Korean population and to enhance the clinical efficiency of precise bracket positioning.

2. Materials and Methods

2.1. Subject of Study

Specifically, canines and premolars were specifically selected as the teeth of interest for measurement. The buccal surface in the anterior region is generally flatter than that of the canines and premolars, resulting in significantly larger curvature values and greater variability. This large variability increases measurement errors, reducing the validity of the results. When analyzing the measurement results of the maxillary central and lateral incisors and the mandibular anterior teeth, there were significant differences depending on the measurement point and there were many measurement errors. Therefore, the anterior teeth were excluded from the optimization of this study. Also, molars were also excluded from the analysis because the orthodontic attachments used on molars are typically tubes rather than brackets. Since tubes are usually made of metal, their design and fabrication are less sensitive to curvature, making curvature-based analysis less relevant for these teeth.

This study was approved by the IRB of Gangman Severance Hospital. (IRB no. 3-2025-0152)

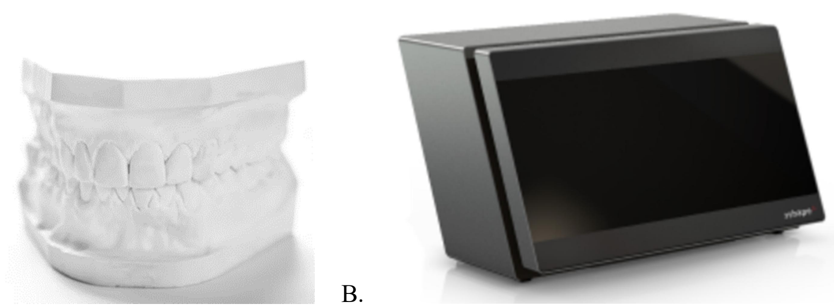
Post-orthodontic treatment digital models were analyzed for the measurement of tooth curvature of canines and premolars. The sample included patients aged 10 to 40 years with fully developed permanent dentition.

To represent the anatomical characteristics among Koreans, the sample size was determined by factors including population size, confidence level, and margin of error. When population size was defined as the population of South Korea (51 million) with confidence level and margin of error are set within the range of 90–95%, the appropriate sample size fell between 271 and 385 subjects. In this study, the sample size was set as 300.

$$\text{Sample Size} = \frac{\dfrac{z^2 \times p(1-p)}{e^2}}{1 + \dfrac{z^2 \times p(1-p) - e^2}{e^2 N}}$$

(N=population size, e=Sample proportion (usually assumed to be 0.5), z = z-score according to confidence level, p=allowable error, 0.5) [13) 14)]

Post-orthodontic models with clearly exposed buccal surfaces were selected for analysis. Well aligned teeth made it possible to accurately identify the FACC surfaces and FA points. Post-orthodontic plaster models, both maxilla and mandible, from 300 patients were scanned using an optical 3D scanner (3shape's R2000 3D, Denmark) to obtain three-dimensional virtual models in STL (Fig. 4). Using 300 pairs of scanned data, measurements were performed, and the process was considered complete once 300 representative data points—accounting for both left and right sides—had been collected.



A. B.

Figure4. Equipment and materials required for acquiring digital scan data (A. Dental cast, B. 3D scanner of 3shape used to scan dental casts)

2.2. Region of Interest

Facial axis (FA) points and their respective facial axes of the clinical crowns (FACC) were identified[2)] from the labial, occlusal, and lingual aspects for the canine and first and second premolars. Three points are selected to construct the FACC plane and the FA point, using the program, Geomagic Control X (3D SYSTEMS, USA) (fig. 5).

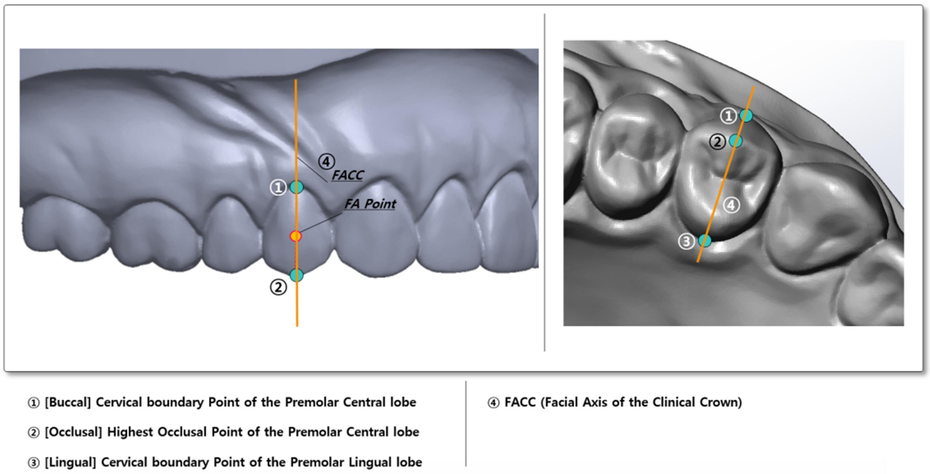
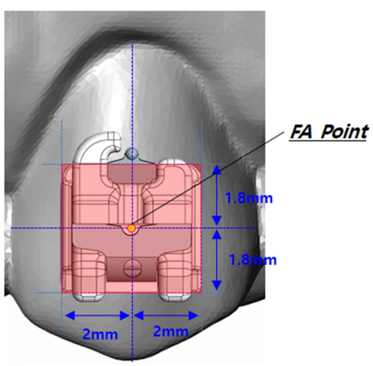


Figure5. Three points on the center of the tooth crown selected on the scanned tooth model to define the FACC, and the FACC plane constructed based on these points.

The region of interest (ROI) was based on the bracket dimension of a commercially available ceramic bracket (Table 1) and the placement site was set according to the FA point following the clinical guideline.[2)] (fig.6).

A. 

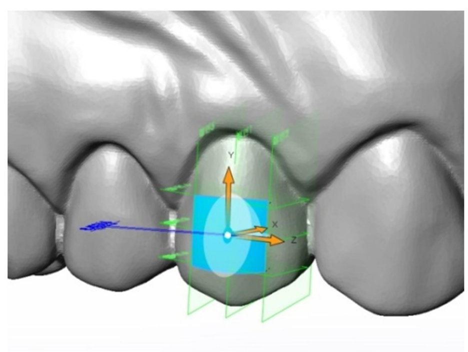
B. 

Figure6. Bracket bonding sites on the tooth (A. Bracket bonding size with FA point, B. Bracket bonding site in 3D)

The size of the region of interest was set to be the same as the base size of the ceramic bracket. Ceramic brackets are typically larger in size and the base curvature is generally less pronounced compared to metal brackets due to the inherent brittleness of ceramic materials, which limits its profile dimension and versatility in manufacturing. In fact, it can be observed that the base curvature of metal brackets tends to be more convex compared to that of ceramic brackets. (Fig. 7)

<Table 1> Bonding bracket size for canine and premolars

	Maxillary			Mandibular		
	Canine	1st premolar	2nd premolar	Canine	1st premolar	2nd premolar
M-D width	4.0 mm	4.0 mm	4.0 mm	4.0 mm	4.0 mm	4.0 mm
O-C width	3.6 mm	3.6 mm	3.6 mm	3.6 mm	3.6 mm	3.6 mm

A. B.

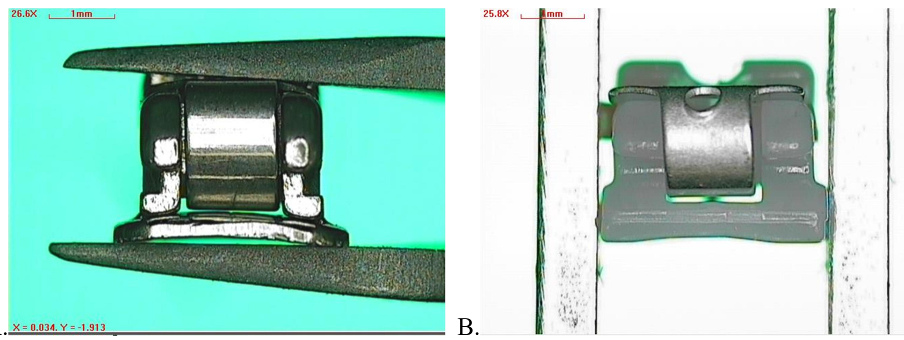


Figure7. Metal bracket (A) and ceramic bracket (B) in occlusal side

Upon designing curved surfaces, it is essential to consider the curvatures at both the occluso-cervical and mesio-distal margins as well as at the center. The mesial-distal direction parallel to the bracket slot was designated as the horizontal curve and the occlusal-gingival direction perpendicular to the bracket slot was designated as the vertical curve. The curvature was measured at the six margins in horizontal and vertical direction per tooth. For the horizontal curves, the middle passing through the FA point, cervical and occlusal margins were measured. For the vertical curves, the distal, mesial margins and the center, a curve passing through the FA point was measured (fig. 8, 9).

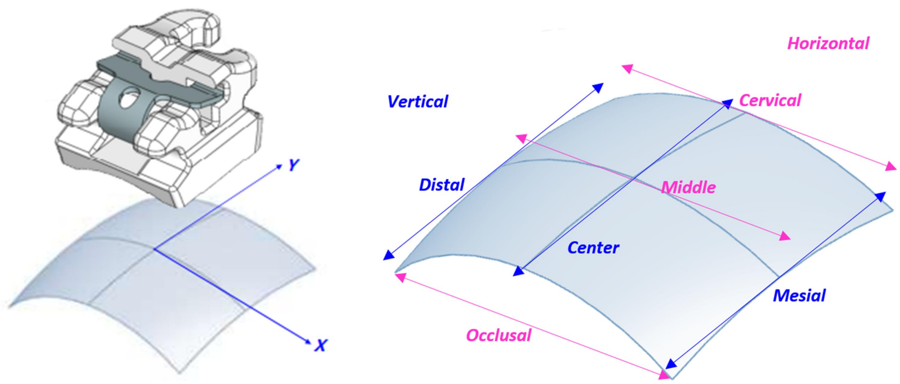


Figure8. The 6 directions of curvature in bracket bonding site

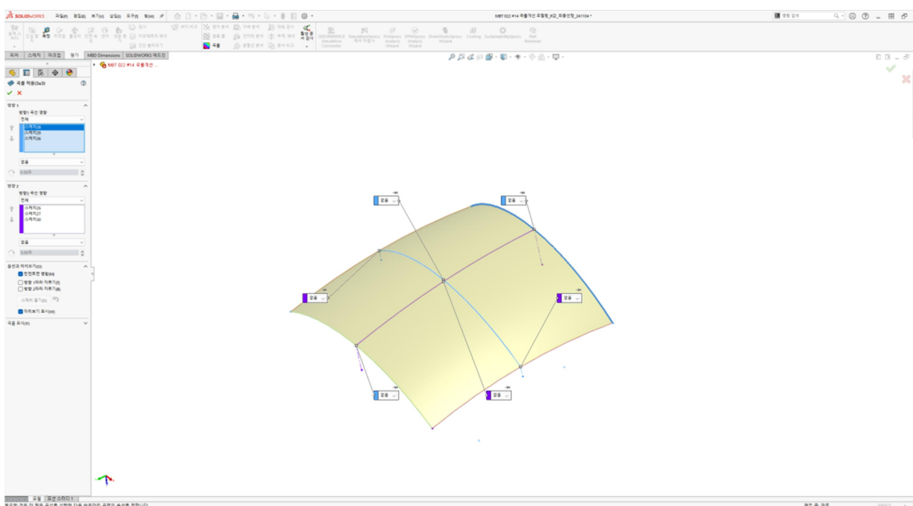


Figure9. Screenshot of the program interface during surface modeling in SolidWorks

2.3. Curvature Measurement Method

Using the tooth scan data, cross-sections in the 6 sites were identified. The corresponding curvature values were measured using Geomagic Control X (3D SYSTEMS, USA) (Fig. 11). The curvature of radius was equated from the curvature value.

In brief, the cross-section of the designated FACC surface was examined. From the crosssectional image of the of the FACC surface, radius of curvature can be measured by selecting the "radius measurement" () icon. The measured curvature at this point corresponds to the center of the vertical direction. Subsequently, the distal and mesial surfaces, as well as at the cervical, middle, and occlusal regions along the horizontal axis can be measured.

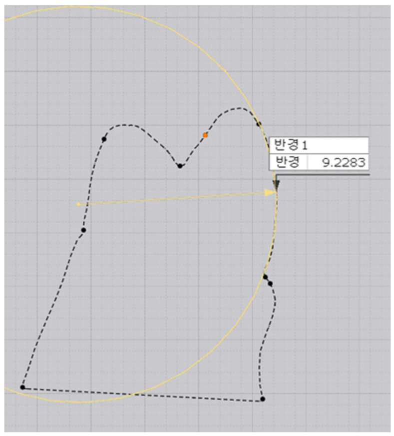


Figure10. The measurement of curvature radius

When a perfect arc radius cannot be defined from the tooth cross-section, a larger fitting arc that sufficiently encompasses the buccal surface was used for curvature measurement. Tooth involving dental restorations or dental prosthetics were excluded from the analysis.

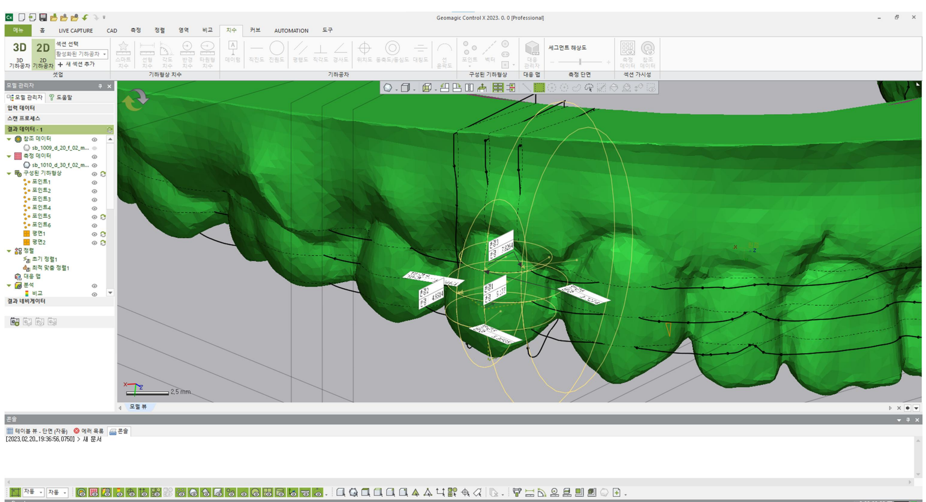


Figure11. Program interface displayed after completing curvature measurement (Geomagic Control X)

2.4. Orthodontic Bracket Base Curvature Measurement Method

To investigate the correlation between the tooth surface and the bracket base, we measured the base curvature of currently used brackets. Three types of active ceramic self-ligating brackets commonly used in Korea, OSSTEM MAJESTY-SLC, TOMY Clippy-C, American Orthodontics Empower Clear, were selected for the analysis. Measurements were conducted on brackets designed for use on canines and premolars. OSSTEM MAJESTY-SLC and American Orthodontics Empower Clear provided one universal design for the maxillary first and second premolars.

A conventional microscope can measure curvature in a limited 2D perspective, but it is extremely difficult to assess the curvature inside the base. To overcome this limitation, a laser microscope capable of measuring surface roughness was used to evaluate the curvature of the base. The bracket base was scanned and measured using a laser microscope (OLYMPUS's OLS5000, Japan) to identify height variations. After confirming the height profile of the base, the curvature was analyzed by selecting both ends and the center of the product.

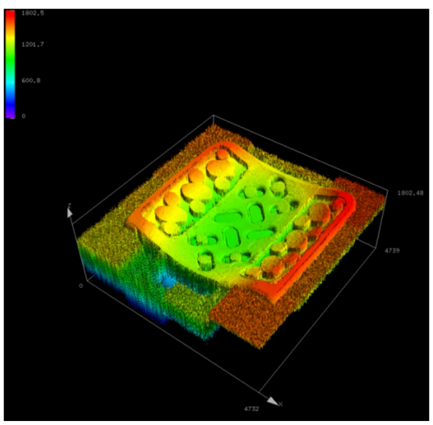


Figure12. Scanning the bracket base through a laser microscope

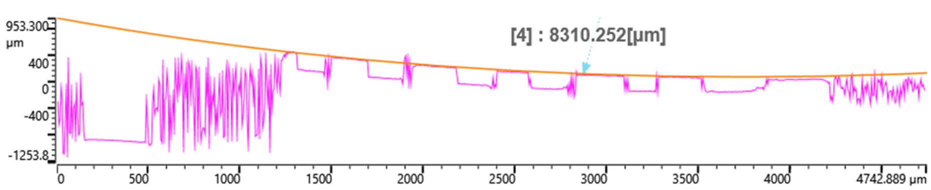


Figure13. Checking the curvature of the selected area

2.5. Optimization Process: Basic Concepts

When the bracket curvature is flatter than the tooth surface, residual adhesive resin can be displayed laterally, causing the bracket to slide or create gaps at both ends (Fig.15A). Conversely, when the bracket curvature is more convex than the tooth curvature, the ends of the bracket contact with the tooth surface, possibly minimizing the risk of adhesive resin loss or bracket swinging. (Fig 15B) Therefore, conventional brackets are intentionally designed with slightly lower curvature radius, i.e. more convex than the tooth surfaces to ensure proper bracket positioning and adhesion.

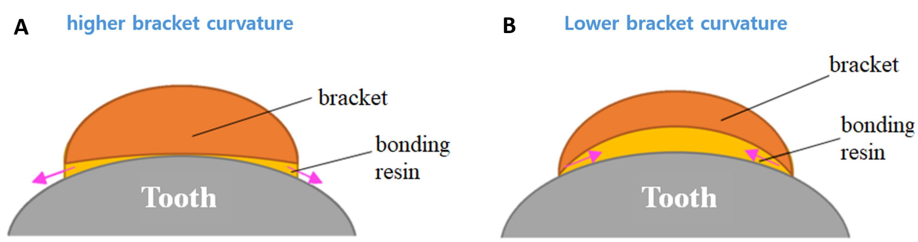


Figure14. Bracket curvature relative to the tooth curvature.(A. Higher curvature bracket, B. Lower curvature bracket)

To visualize the distribution as well as the range and variability of the curvature of each tooth type, the measurements were converted into histograms with overlaying normal distribution curves. The statistical distributions for each of the six curvature sites were derived based on the measured results for each tooth type. The fitted curve represents the probability density function (PDF) based on a normal distribution, which is defined as follows.

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}, \mu: average\ , \sigma: standard\ deviation, x: data$$

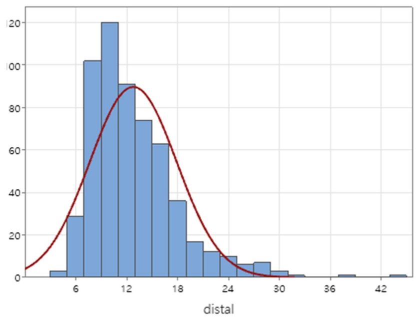


Figure15. Histogram of distal curvature of the maxillary canine with normal distribution

The mean curvature value illustrates the tooth surface characteristics. However, from a commercial standpoint, bracket curvature should be convex enough to cover a wider range of variations.

By the application of the average R, the bracket base would be convex enough to cover around 50% of the total subjects (Fig. 16 A) but may not represent the remaining 50% with more convex tooth curvature. Thus, the measurement values were adjusted to cover a wider range of surface variations by increasing the convexity, i.e. decreasing the curvature of radius. The measurement values were adjusted and optimized for production to include 70%, 80%, and 90% range of the total subjects using distribution histograms. (Fig. 16 B)

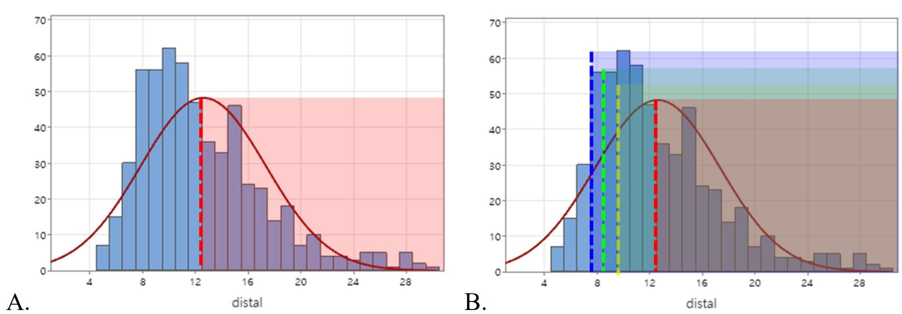


Figure16. Mean value and adjusted values based on coverable range shown in the histogram (red: mean (50%), yellow: 70%, green: 80%, blue: 90%)

2.6. Validation of Adjustment Curvature values (adusted R)

To validate the adjusted curvature values and its cover range, curvatures of canines and premolars were measured for additional 10 sets of pre-treatment diagnostics digital casts separate from the original measurement models. The ratio of curvature values that fit into the adjusted value range (curvature equal or higher than the 70, 80, 90% adjusted value) per tooth type were calculated and scored as validation rate.

2.7. Statistical evaluation

To measure the reproducibility of coordinates of the FACC plane and the FA point, the same examiner remeasured the values with a two-month interval for ten randomly selected models. The intraclass correlation coefficient (ICC) for FACC plane and FA point were 0.996 and 0.753, respectively indicating moderate to excellent reliability. The differences in curvature were evaluated between regions for each tooth type using a permutation test based on the coordinates and normal vectors. Statistical significance was set at $P<0.05$. For the FACC plane, the resulting p-value was 0.0626, indicating no statistically significant difference. Similarly, p-values for the FA point coordinates before and after treatment were 0.6141, 0.3321, and 0.9090 along the X, Y, and Z axes, respectively, confirming that there were no significant differences along any of the three coordinate axes.

3. Results

3.1. Morphometric evaluation of the teeth curvature

Overall, the curvature values were higher for the vertical curvatures than the horizontal curvatures. For the vertical curvatures, the center indicated the highest values than the mesial and distal curvatures ($p<0.05$), indicating the center is less curved and flat while it becomes more convex toward both mesio-distal ends. For the horizontal curvatures, values progressively increased from cervical toward the occlusal regions ($p<0.05$), except for the maxillary canine.

The mean and standard deviation of curvature at the six sites on the maxillary and mandibular canines and premolars are shown on Table 2.

<Table 2> The curvature for the ROI on the buccal surface (mm)

	Mesio-distal (vertical) curvature(R) Mean ± standard deviation			sig	Occluso-cervical(horizontal) curvature (R) Mean ± standard deviation			sig
	distal	center	mesial		cervical	middle	occlusal	
Upper canine (N=576)	12.79±5.12	17.63±5.52	11.97±4.59	*	4.36±1.19	5.31±1.31	5.08±2.15	
Upper 1st premolar (N=304)	8.77±4.65	12.61±5.25	9.34±4.25	*	3.00±0.60	3.75±0.50	4.01±0.52	*
Upper 2nd premolar (N=318)	6.74±3.28	10.37±4.03	6.03±3.53	*	2.62±0.87	3.47±0.61	3.98±0.62	*
Lower canine (N=583)	12.76±5.97	19.08±6.83	14.15±4.86	*	3.93±0.70	4.34±0.76	4.56±0.81	*
Lower 1st premolar (N=302)	8.26±3.50	11.86±4.90	11.55±5.68	*	3.28±0.60	3.93±0.53	4.30±0.51	*
Lower 2nd premolar (N=311)	6.58±2.27	8.21±2.97	6.27±3.46	*	2.82±0.76	3.60±0.61	4.23±0.72	*

* indicates values with p-value less than 0.05.

3.2. Curvature of the commercially available bracket base in use

In general, the curvature values of the commercially available brackets indicated lower values than those of the teeth curvatures. (Table 3)

<Table 3> The curvature of commercially available bracket

			Vertical			Horizontal		
			Distal	Center	Mesial	Cervical	Middle	Occlusal
OSSTEM MAJESTY-SLC	Maxillary	Canine	6.99	6.30	9.28	3.16	3.30	3.52
		1st premolar	0.00	0.00	0.00	2.93	3.32	2.95
		2nd premolar						
	Mandibular	Canine	11.43	34.82	18.51	2.93	2.91	3.06
		1st premolar	4.61	4.17	4.49	3.50	4.19	3.75
		2nd premolar	4.53	4.28	4.49	3.45	4.11	3.86
TOMY Clippy-C	Maxillary	Canine	6.38	7.53	13.94	3.49	3.24	3.40
		1st premolar	7.48	7.07	8.15	2.93	3.32	2.71
		2nd premolar	7.24	7.24	7.02	2.67	2.71	2.60
	Mandibular	Canine	9.02	6.13	10.99	3.60	3.38	3.46
		1st premolar	4.23	3.70	3.50	4.53	4.58	5.09
		2nd premolar	4.42	3.77	3.51	4.30	4.47	4.45
American Orthodontics Empower Clear	Maxillary	Canine	11.04	9.95	10.07	3.67	3.56	3.61
		1st premolar	5.53	5.95	5.61	3.04	3.00	2.82
		2nd premolar						
	Mandibular	Canine	10.22	10.11	11.32	3.75	3.59	3.63
		1st premolar	5.99	5.89	6.00	3.07	2.93	2.88
		2nd premolar	5.42	5.81	6.02	3.75	3.00	2.87

3.3. Adjustment of Curvature values

To monitor the pattern of the curvature, the curvature values were converted into histograms with overlaying normal distribution curves. Adjusted R margin values covering the 70, 80 and 90% of the total distribution were calculated (Fig. 17, Table 4).

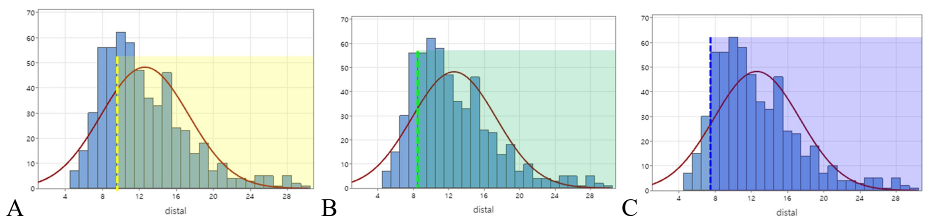


Figure17. The distribution histogram and normal distribution curve of curvature values

The adjusted R margin value in yellow (A), green (B) and purple(C) represent the 70, 80 and 90% adjusted values, respectively.

<Table 4> The adjustment R values that covers the 70, 80 and 90% distribution

		Vertical			Horizontal		
		Distal	Center	Mesial	Cervical	Middle	Occlusal
Maxillary Canine	70%	9.66	14.225	9.38	3.666	4.64	4.49
	80%	8.58	13.25	8.758	3.46	4.417	4.25
	90%	7.61	11.40	7.77	3.134	4.085	3.84
Maxillary 1st premolar	70%	6.53	10.20	7.30	2.8199	3.47	3.79
	80%	5.88	9.553	6.49	2.692	3.33	3.61
	90%	5.21	8.50	5.43	2.428	3.18	3.36
Maxillary 2nd premolar	70%	4.65	8.27	4.133	2.199	3.10	3.64
	80%	4.14	7.24	3.72	1.996	3.00	3.488
	90%	3.62	6.51	3.16	1.82	2.84	3.24
Mandibular Canine	70%	9.54	15.26	11.50	3.558	3.999	4.169
	80%	8.84	13.974	10.40	3.416	3.8495	3.935
	90%	7.627	11.88	9.046	3.095	3.652	3.695
Mandibular 1st premolar	70%	6.619	9.17	8.262	2.96	3.659	4.08
	80%	5.99	8.32	7.16	2.82	3.537	3.88
	90%	5.29	7.28	6.30	2.62	3.399	3.708
Mandibular 2nd premolar	70%	5.25	6.988	4.69	2.49	3.354	3.957
	80%	4.897	6.486	4.14	2.357	3.195	3.828
	90%	4.24	5.89	3.61	2.207	2.96	3.61

3.4. Validation of adjusted R

Among the maxillary teeth, the second premolar indicated the lower validation rate than canine and first premolar. Specifically, the validation rate of the Distal and Occlusal adjusted R did not reach all 70, 80, and 90% range.

The mandibular second premolar also indicated the lower validation rate that canine and first premolar. Specifically, the validation rate of the Occlusal adjusted R did not reach all 70,80, and 90%% range, and the middle did not reach the 70 and 80% range.

<Table 5> The validation rate of adjusted R (Maxillary teeth)

		Vertical(N=20)			Horizontal(N=20)		
		Distal	Center	Mesial	Cervical	Middle	Occlusal
Maxillary Canine	70%	70% 14/20	85% 17/20	80% 16/20	90% 18/20	75% 15/20	90% 18/20
	80%	75% 15/20	90% 18/20	85% 17/20	100% 20/20	80% 16/20	95% 19/20
	90%	95% 19/20	100% 20/20	95% 19/20	100% 20/20	85% 17/20	100% 20/20
Maxillary 1st premolar	70%	70% 14/20	85% 17/20	55% 11/20	80% 16/20	75% 15/20	75% 15/20
	80%	85% 17/20	85% 17/20	80% 16/20	85% 17/20	80% 16/20	80% 16/20
	90%	90% 18/20	85% 17/20	100% 20/20	100% 20/20	95% 19/20	95% 19/20
Maxillary 2nd premolar	70%	60% 12/20	70% 14/20	90% 18/20	70% 14/20	85% 17/20	40% 8/20
	80%	70% 14/20	80% 16/20	95% 19/20	95% 19/20	90% 18/20	50% 10/20
	90%	75% 15/20	90% 18/20	100% 20/20	100% 20/20	90% 18/20	70% 14/20

<Table 6> The validation rate of adjusted R (Mandibular teeth)

		Vertical(N=20)			Horizontal(N=20)		
		Distal	Center	Mesial	Cervical	Middle	Occlusal
Mandibular	70%	70%	90%	75%	90%	75%	65%

Canine		14/20	19/20	15/20	18/20	15/20	13/20
	80%	75%	100%	80%	95%	85%	75%
		15/20	20/20	16/20	19/20	17/20	15/20
	90%	95%	100%	95%	100%	90%	85%
		19/20	20/20	19/20	20/20	18/20	17/20
Mandibular 1st premolar	70%	75%	65%	75%	90%	70%	70%
		15/20	13/20	15/20	18/20	14/20	14/20
	80%	75%	85%	80%	100%	95%	80%
		15/20	17/20	16/20	20/20	19/20	16/20
	90%	85%	100%	85%	100%	100%	100%
		17/20	20/20	17/20	20/20	20/20	20/20
Mandibular 2nd premolar	70%	70%	80%	70%	85%	65%	50%
		14/20	16/20	14/20	17/20	13/20	10/20
	80%	80%	85%	80%	90%	75%	55%
		16/20	17/20	16/20	18/20	15/20	11/20
	90%	95%	85%	85%	100%	90%	80%
		19/20	17/20	17/20	20/20	18/20	16/20

4. Discussion

The morphologic characteristics of tooth curvature were measured, optimized and validated using large-scale Korean samples. The radius of curvature values of the bracket bonding sites measured in this study represents the anatomic characteristics of tooth buccal surface but can also be directly applied during bracket designing proving efficiency for production.

Based on the analysis, variations in the curvature values were noted among regions and among different tooth types. From a manufacturing standpoint, bracket base is designed slightly more convex (lower curvature radius) than the tooth bonding surface to allow accurate placement without wobbling. While the mean values represent the distinct curvature of the tooth, it may not represent the most frequent curvature nor cover the variations among others. Theoretically, 50% of subjects may indicate a lower curvature than the mean value. Therefore, for the optimization process, the R margin was adjusted to be convex enough to cover approximately 70–90% of the total subjects. The adjusted values were further validated through measurement of additional samples from pre-orthodontic intraoral scans with high agreement except for the second premolar occlusal curvature.

As a single value cannot comprehensively accommodate all clinical or manufacturing scenarios, the adjusted curvature options were categorized into 70%, 80%, and 90% levels. The data has been calibrated accordingly, enabling practitioners and manufacturers to select appropriate values based on their specific needs and technical capabilities. While the 90% adjusted curvature value may provide optimal adaptation across a wide range of tooth surfaces, from a manufacturing standpoint, as the convexity increases, both the edges and the center of the bracket base may become thinner. This would increase the risk of bracket fracture, especially for ceramic brackets which are more susceptible due to its brittle nature. A reduced radius of curvature, intended to enhance bracket-to-tooth fit, may inadvertently increase the risk of fracture in ceramic brackets, potentially necessitating a thicker bracket design to maintain structural integrity. However, increased bracket thickness can lead to patient discomfort and interfere with desired tooth movement. Therefore, the final curvature to be applied should be carefully selected from the designer's perspective, considering the delicate balance between material properties, structural durability, and clinical performance to optimize both functionality and patient comfort.

The overall process presents that the adjusted curvature values can be applied for future bracket designing as well. The curvature values can be flexibly adapted depending on various design parameters such as the material properties and structural design of the brackets. Although the ROI was based on conventional ceramic brackets, the curvatures of the central regions—specifically the center and middle, which are derived from the FACC and FA point—may remain stable regardless of the bracket dimension. However, these values can be flexibly adapted depending on various design parameters such as the material properties and structural design of the brackets. In cases where the overall size is modified, the curvatures of the central regions—specifically the center and middle, which are derived from the FACC and FA point—may remain applicable. Nevertheless, the curvature at the outer edges could vary and should be applied with caution. Particularly, due to the higher variability observed in the distal and mesial regions, it may be necessary to re-measure their curvature values to ensure accuracy.

Conventional brackets often employ the same design for the maxillary first and second premolars. However, based on our results, the first and second premolars exhibit distinct characteristics, which suggest separate bracket base design for optimum fit. But when uniform design is necessary for clinical efficacy, applying the curvature of the maxillary second premolar may be a more suitable approach since the second premolars generally exhibits a smaller curvature. However, it is noteworthy that the second molar exhibits a lower validation rate especially in the occlusal curvature, indicating greater morphological variation for the region.

This study offers a valuable foundation for advancing next-generation orthodontic solutions, particularly in guiding the development of bracket bases that more accurately conform to the complex buccal surfaces of teeth. With the shift from conventional dental casts to fully digital workflows, surface curvature analysis can now be performed with increased precision and efficiency. Furthermore, the integration of digital modeling with additive manufacturing technologies such as 3D printing opens new possibilities for producing highly customized brackets.

These advancements may provide truly patient-specific “just-fit” bracket bases that align seamlessly with individual anatomical variations.

5. Conclusion

Morphometric characteristics of the bracket bonding site of the buccal tooth surfaces of the canines and the premolars were represented by the radius of curvature R. The curvature values were further adjusted to cover a wider range of tooth curvature variations. The optimized values can be selected to support bracket base designs tailored to the Korean dentitions.

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Abstract in Korean

치아 접착 부위의 형태 분석을 기반으로 한 교정용 브라켓 베이스 곡률 최적화

정확한 브라켓 포지셔닝은 정확한 치아 이동과 효과적인 치료 결과를 달성하기 위해 매우 중요하다. 따라서, 임상적으로는 브라켓 베이스는 부착 재현성과 부착 용이성을 확보할 수 있도록 부착되는 치면의 형태학적 특징을 정확하게 파악하고 최대한 치면과 접합되도록 설계, 제작되는 것이 유리하다.

치아의 협측면은 곡면을 이루고 있으며, 이 곡면의 해부학적으로 구부러진 정도를 재는 척도로 곡률 반경 값(R)을 사용할 수 있다. 곡률 반경(R)은 실제로 곡면 형태를 공학적으로 설계 시 그 형태학적 특징을 나타내기 위해 대입되는 값으로, 브라켓의 베이스를 디자인할 때 사용되는 값에 해당된다.

본 연구에서는 대규모 한국인 디지털 치아 모형을 이용하여 치아의 협측면 브라켓 부착 부위의 치아 곡률 반경 R 값을 계측하고 개별 치아의 형태학적 특징을 평가하고자 하였고, 이 결과를 최적의 브라켓 베이스 설계에 응용하고자 하였다.

교정 치료가 완료된 성인 디지털 치아 모형(300 쌍)을 이용하여 FACC(Facial Axis of the clinical crown)를 기준으로 브라켓 부착 부위의 영역을 설정하고 각 치아 당 부착부위의 근원심과 절단연, 치은연 경계를 포함하는 총 6 부위에서의 곡률 반경을 계측하였다.

각 치아의 수평 방향 곡률은 수직 방향 곡률보다 작은 더 볼록한 형태를 나타냈으며 개별치아 및 각 부위의 곡률은 유의한 차이가 있었다. 다만, 계측치의 통계 분석과 히스토그램을 통해 최빈값과 평균값은 일치하지 않고, 일반적인 정규 분포를 따르지 않는 점을 확인하였다. 평균 곡률 값으로는 이보다 큰 곡률을 가진 전체 약 50%의 치아에 유효할 수 있지만, 평균보다 작은 곡률을 보이는 나머지 50%에는 적용하기 어려울 것으로 판단하였다. 따라서 70%, 80%, 90%의 대상 치아를 포함할 수 있는 조정 곡률치(adjustment value)를 도출하고 검증하였으며 이를 최적화된 브라켓 곡률 값으로 제안하고자 한다.

핵심 되는 말 : 곡률, 교정용브라켓, 브라켓 베이스