ORIGINAL ARTICLE

# Esthetics of Orthodontic Appliances: Objective Evaluation by Spectrophotometry vs Subjective Evaluation Using the Visual Analog Scale Method

Naohiko Kawamura[1], Takashi Murakami[2], Kazuki Sobue[3], Shigemasa Kobayashi[4], Atsue Yamazaki[5], Yuya Nakao[6], Masahiro Iijima[7]

## Abstract

**Aim and objective:** In this study, we quantified the color of brackets and archwire appliances for an objective evaluation and investigated its relationship with subjective esthetic evaluation.

**Materials and methods:** Five types of commercially available brackets (ceramic brackets C1, C2, and C3; plastic brackets P1 and P2) and three types of archwires (coated nickel-titanium archwires W1, W2, and W3) were used. The reflectance (%) and color (lightness: $L^*$, hue: $a^*$, $b^*$) of each sample were quantified using a spectrophotometer ($n = 5$). Fifteen combinations of brackets and archwires were used. The esthetic evaluation was performed using the visual analog scale (VAS) method, and responses were obtained from 30 laypersons and 15 orthodontists. The mean VAS score was calculated, and the relationship between the reflectance and color of the bracket and archwire was discussed.

**Results:** The reflectance and $L^*$ of the brackets showed significantly higher values for C3 and C1 than for the others and lower values for P1 and P2. The reflectance and $L^*$ of the archwire showed significant differences among all samples. There was a high positive correlation between the reflectance and $L^*$. There were statistically significant positive correlations between the layperson and orthodontist groups, between the VAS score and reflectivity, and between VAS score and $L^*$.

**Conclusion:** Our results showed that as the lightness and reflectance of the brackets and archwires increased, the subjective evaluation concerning their esthetic value was higher.

**Clinical significance:** It is extremely difficult to evaluate esthetics despite the fact that patients' demands for esthetics have been increasing in recent years. If a method for evaluating esthetics is established, it should help in the development and selection of esthetic devices. The results of this study will facilitate the development of future study designs.

**Keywords:** Esthetics, Orthodontic appliances, Orthodontic archwire, Orthodontic bracket, Spectrophotometry.

*The Journal of Contemporary Dental Practice* (2021): 10.5005/jp-journals-10024-3210

## Introduction

Many materials traditionally used for orthodontic appliances are manufactured from metals, which generally have superior mechanical properties to other materials. However, metal orthodontic materials are considered inferior in terms of esthetics.[1] An increase in the number of adult patients seeking orthodontic treatment has been reported in recent years.[2] As a result, the demand for more esthetically pleasing orthodontic appliances has increased. This demand has led to the development of orthodontic appliances with esthetics acceptable to both patients and orthodontists.

Concerning bracket appliances, esthetic brackets have been commonly used since the 1980s.[3] Esthetic brackets have since been produced from ceramics and plastics and have been widely used in orthodontic practice.[4,5] The introduction of esthetic orthodontic brackets may have partially solved the esthetics issue facing multibracket devices worn on the labial surfaces of the teeth. During the 1990s, silicone-reinforced nylon-based archwires with silica cores became commercially available to improve esthetics and attracted attention. However, these appliances failed to demonstrate sufficient mechanical properties clinically, and metal archwires incorporating materials such as nickel-titanium and titanium-molybdenum alloys and stainless steel remain the most widespread products in use. Coated metal archwires and fiber-reinforced archwires have recently been introduced to resolve esthetic concerns associated with archwire appliances.[6] The most common coatings are plastic resins, such as epoxy, and synthetic resins, or rhodium.[7] Fiber-reinforced archwires are experimental and not a universal solution, but this technology holds promise for the future.[8]

[1,5–7]Division of Orthodontics and Dentofacial Orthopedics, Department of Oral Growth and Development, School of Dentistry, Health Sciences University of Hokkaido, Ishikari-Tobetsu, Hokkaido, Japan

[2,3]Analytical and Measuring Instruments Division, Global Application Development Center, Shimadzu Corporation, Chiyoda-ku, Tokyo, Japan

[4]Samu Orthodontic Clinic, Sapporo, Hokkaido, Japan

**Corresponding Author:** Naohiko Kawamura, Division of Orthodontics and Dentofacial Orthopedics, Department of Oral Growth and Development, School of Dentistry, Health Sciences University of Hokkaido, Ishikari-Tobetsu, Hokkaido, Japan, Phone: +81-133-23-3041, e-mail: kawamura@hoku-iryo-u.ac.jp

**How to cite this article:** Kawamura N, Murakami T, Sobue K, *et al.* Esthetics of Orthodontic Appliances: Objective Evaluation by Spectrophotometry vs Subjective Evaluation Using the Visual Analog Scale Method. J Contemp Dent Pract 2021;22(10):1160–1166.

**Source of support:** Nil

**Conflict of interest:** None

However, the assessment of esthetic value is based on human sensibilities. It is difficult to evaluate esthetics directly and quantitatively as this quality depends largely on the evaluator's subjective preferences. The visual analog scale (VAS) is a tool used to measure subjective characteristics and attitudes that cannot be measured directly. Although it can be used to evaluate the esthetics of orthodontic appliances, it does not reveal which factors influence the esthetic perception of brackets and archwires. Therefore, this study focused on the color of bracket and archwire appliances; from an esthetic point of view, the color of the archwire should ideally match the color of the tooth and bracket. One of the three tools, a spectrophotometer, a colorimeter, digital photographic analysis, or a combination of these tools, is commonly used to examine the color.[9] Color analysis in dentistry is generally defined by the CIELAB color space proposed by the Commission Internationale de l'Eclairage.[10] This system is one of the most common and universally used systems in dentistry, and many authors have used it to assess the perceptibility of color differences.[11,12] If a relationship is found between the evaluation of color using this color space and the subjective evaluation of esthetics using the VAS method, this relationship is likely to have value in informing the future development of esthetic orthodontic appliances.

No previous study has investigated the effect of a combination of esthetic bracket and archwire products on the esthetic value. The purpose of this study is to investigate the esthetic changes of various esthetic bracket and archwire combinations to examine the subjective assessments of esthetics using the VAS method and the relationship between the quantified bracket and archwire colors.

## Materials and Methods

### Samples

Five types of commercially available esthetic brackets and three archwires were used as target appliances (Table 1). The brackets included three ceramic bracket products (C1: Inspire ICE, Ormco, Brea, California, USA; C2: Avex CX, Opal Orthodontics, South Jordan, Utah, USA; C3: Clarity ADVANCED, 3M Unitek, St. Paul, Minnesota, USA) and two plastic bracket products (P1: Elation MB, Dentsply Sirona, Charlotte, North Carolina, USA; P2: Spirit MB, Ormco, Brea, California, USA). The archwire products selected for evaluation included three commercially available esthetic archwires (W1: BioForce Sentalloy White, Dentsply Sirona, Charlotte, North Carolina, USA; W2: Reflex, TP Orthodontics Inc, La Porte, Indiana, USA; W3: VIA Wires Ni-Ti SE Pearl White, Ormco, Brea, California, USA).

### Color Measurements (Objective Evaluation by Spectrophotometer)

The color of each sample product was measured using a UV–visible spectrophotometer (UV-2600, Shimadzu Corporation, Kyoto, Japan) and an integrating sphere (ISR-2600 Plus, Shimadzu Corporation, Kyoto, Japan). The powder sample holder of the integrating sphere was filled with barium sulfate, and the sample was placed in the center of the holder for measurement. Diffuse reflectance was measured in 1 nm steps over a wavelength range of 350–800 nm, and the average value in the visible light range (450–750 nm) was used in subsequent comparisons. Colors were measured according to the CIELAB color system[13] with a lightness scale ($L^*$) and two opposing color axes ($a^*$ and $b^*$) ($n = 5$). Reddish and greenish tones are represented by $a^*$ values, whereas yellow and blue tones are represented by $b^*$ values.

### Survey (Subjective Evaluation by VAS Method)

Each bracket was bonded to the anterior teeth (16th from the upper right canine to the upper left canine) of an epoxy jaw model (D16FE-500A; Nissin Dental Products Inc., Kyoto, Japan). Ortho Solo (Ormco, Brea, California, USA) and BeautiOrtho Bond II Flowable Paste (Shofu Inc., Kyoto, Japan) were used for bonding according to the clinical bonding process. Each archwire was ligated with a transparent elastomeric ligature (Elastic Ligature Tie Clear, Shofu Inc., Kyoto, Japan) and photographed (D7000 + AF-S Micro NIKKOR 85 mm 1:3.5G ED, Nikon Corporation, Tokyo, Japan). The imaging parameters, ambient light, and lighting remained constant. There were 15 bracket and archwire combinations (Fig. 1). The photographs were randomly presented to the evaluators that a total of 30 laypersons and 15 orthodontists, and the esthetic evaluation using the VAS method was performed using an iPad (Apple, Cupertino, California, USA) with the VasQ Clinical application for iPad (BottleCube, Tokyo, Japan). Each image was displayed for 10 seconds, followed by a 5-second evaluation period, after which the system automatically proceeded to the following image. The scale for evaluation ranged from "not good at all" to "extremely good" on a scoring scale of 0–10.

### Statistical Analysis

IBM SPSS Statistics 26 (IBM, Chicago, Illinois, USA) was used for all statistical analyses. A one-way analysis of variance and Tukey's test ($p < 0.05$) were used to compare the VAS scores within the layperson and orthodontist groups. The *t*-test ($p < 0.05$) was used to compare the VAS scores between the layperson and orthodontist groups. Pearson's product–moment correlation coefficient was used to examine potential correlations between all parameters used in this study. As the VAS score was assessed by the combination of the

**Table 1:** Commercially available esthetic brackets and wires used in this study

| *Material* | *Sample* | *Composition* |
|---|---|---|
| Ceramic bracket (0.022 inch slot) | C1 | Aluminum oxide (monocrystalline alumina), Zirconium oxide |
| | C2 | Aluminum oxide (polycrystalline alumina) |
| | C3 | Aluminum oxide (polycrystalline alumina) |
| Plastic bracket (0.022 inch slot) | P1 | Composite (polycarbonate, polyethylene terephthalate), Slot: Stainless steel |
| | P2 | Composite (polycarbonate), Slot: Stainless steel |
| Nickel-titanium wire (0.017 inch × 0.025 inch) | W1 | Wire: Nickel-titanium, Coating: Rhodium |
| | W2 | Wire: Nickel-titanium, Coating: Xylan |
| | W3 | Wire: Nickel-titanium, Coating: Epoxy |

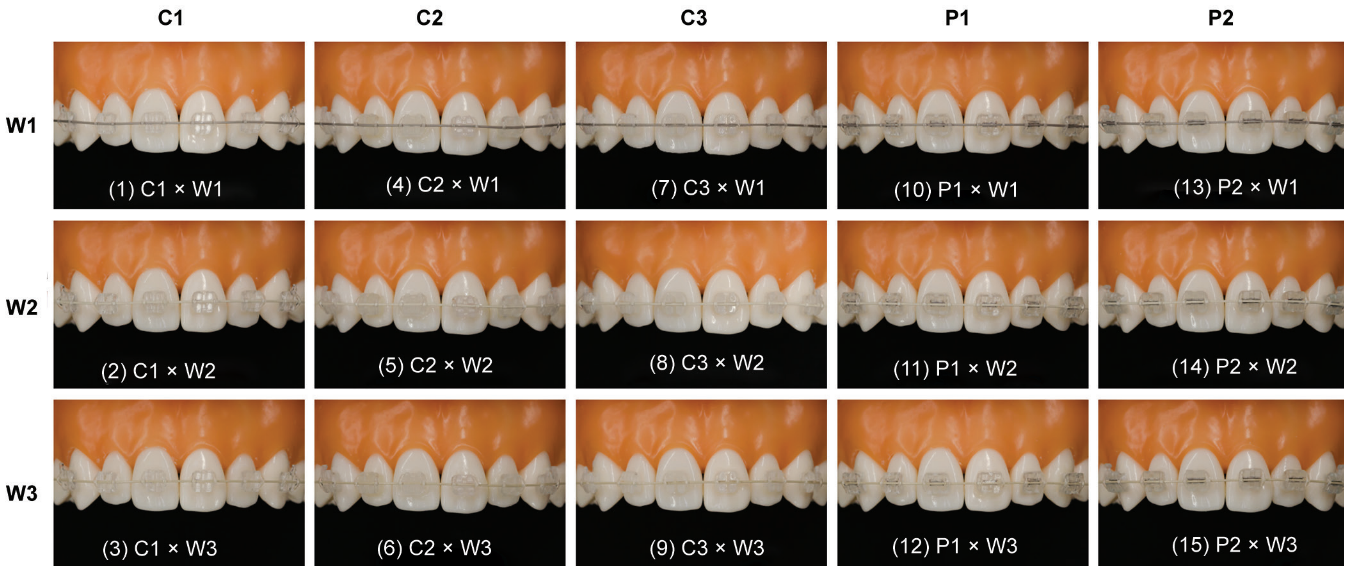



**Fig. 1:** Fifteen pictures for the bracket/wire combination were prepared. Identifiable information such as letters of pictures was excluded from the actual survey

**Table 2:** Mean reflectance at 450–750 nm (Ref., %) and Commission Internationale de L'éclairage (CIE) lightness ($L^*$) and color ($a^*$, $b^*$) values for each bracket samples

| | *C1* | | *C2* | | *C3* | | *P1* | | *P2* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Mean* | *S.D.* | *Mean* | *S.D.* | *Mean* | *S.D.* | *Mean* | *S.D.* | *Mean* | *S.D.* | *p value* |
| **Ref.** | 89.62[a] | 1.91 | 84.75[b] | 2.51 | 90.97[a] | 2.03 | 62.65[c] | 3.55 | 52.88 | 2.09 | 0.000* |
| $L^*$ | 95.37[a,b] | 0.88 | 93.25[b] | 1.15 | 96.16[a] | 0.79 | 83.10[c] | 1.88 | 77.49 | 1.23 | 0.000* |
| $a^*$ | −0.68[a] | 0.18 | 0.26[a] | 0.18 | −1.57 | 0.23 | −0.92[b,c] | 0.20 | −1.05[c] | 0.07 | 0.000* |
| $b^*$ | −0.13 | 0.26 | 1.78[c] | 0.38 | 2.81[b] | 0.44 | 2.03[b,c] | 0.57 | 3.86[a] | 0.55 | 0.000* |
| | *W1* | | | | *W2* | | | | *W3* | | |
| | *Mean* | *S.D.* | | | *Mean* | *S.D.* | | | *Mean* | *S.D.* | *p value* |
| **Ref.** | 38.62[c] | 1.25 | | | 62.69[a] | 0.94 | | | 51.87[b] | 0.93 | 0.000* |
| $L^*$ | 67.48[c] | 0.95 | | | 82.76[a] | 0.66 | | | 77.60[b] | 0.62 | 0.000* |
| $a^*$ | 1.25[a] | 0.06 | | | −0.79[c] | 0.14 | | | −0.02[b] | 0.03 | 0.000* |
| $b^*$ | 3.56[c] | 0.17 | | | 12.26[b] | 0.28 | | | 13.62[a] | 0.06 | 0.000* |

Identical letters indicate that mean values were not significantly different

archwire and bracket appliance used, all questions pertaining to the applicable archwire and bracket appliances were included in the test.

## Results

### Color Measurements (Objective Evaluation by Spectrophotometer)

The average reflectance, $L^*$, $a^*$, and $b^*$ values of the bracket and archwire samples are shown in Table 2. The reflectance of bracket samples C3 and C1 was significantly higher than that of the other bracket samples; $L^*$ showed significantly higher values for C3 than did all the other bracket samples; P1 and P2 showed significantly lower values than did the other bracket samples. For $a^*$, C2 showed significantly higher values than did all the other bracket samples, and C3 showed significantly lower values than did all the other bracket samples. $b^*$ showed significantly higher values for P2 than did all the other bracket samples, and C1 showed significantly lower values than did all the other bracket samples. For the archwire samples, significant differences were observed among all the samples in the reflectance parameters $L^*$, $a^*$, and $b^*$. For both reflectance and $L^*$, W2 showed the highest values, followed by W3 and W1. $a^*$ showed the highest values in the order of W1, W3, and W2, and $b^*$ showed the highest values in the order of W3, W2, and W1.

Table 3 displays the correlations (Pearson's product rate correlations) between each parameter in this study. There was a strong positive correlation between the reflectance and $L^*$ ($r = 0.994$). There were weak negative correlations between $a^*$ and reflectance ($r = -0.509$) and $L^*$ ($r = -0.564$), and between $b^*$ and reflectance ($r = -0.457$) and $L^*$ ($r = -0.402$), which were not significant at the 5% level. A positive correlation was observed between $a^*$ and $b^*$ but was not significant at the 5% level ($r = 0.070$).

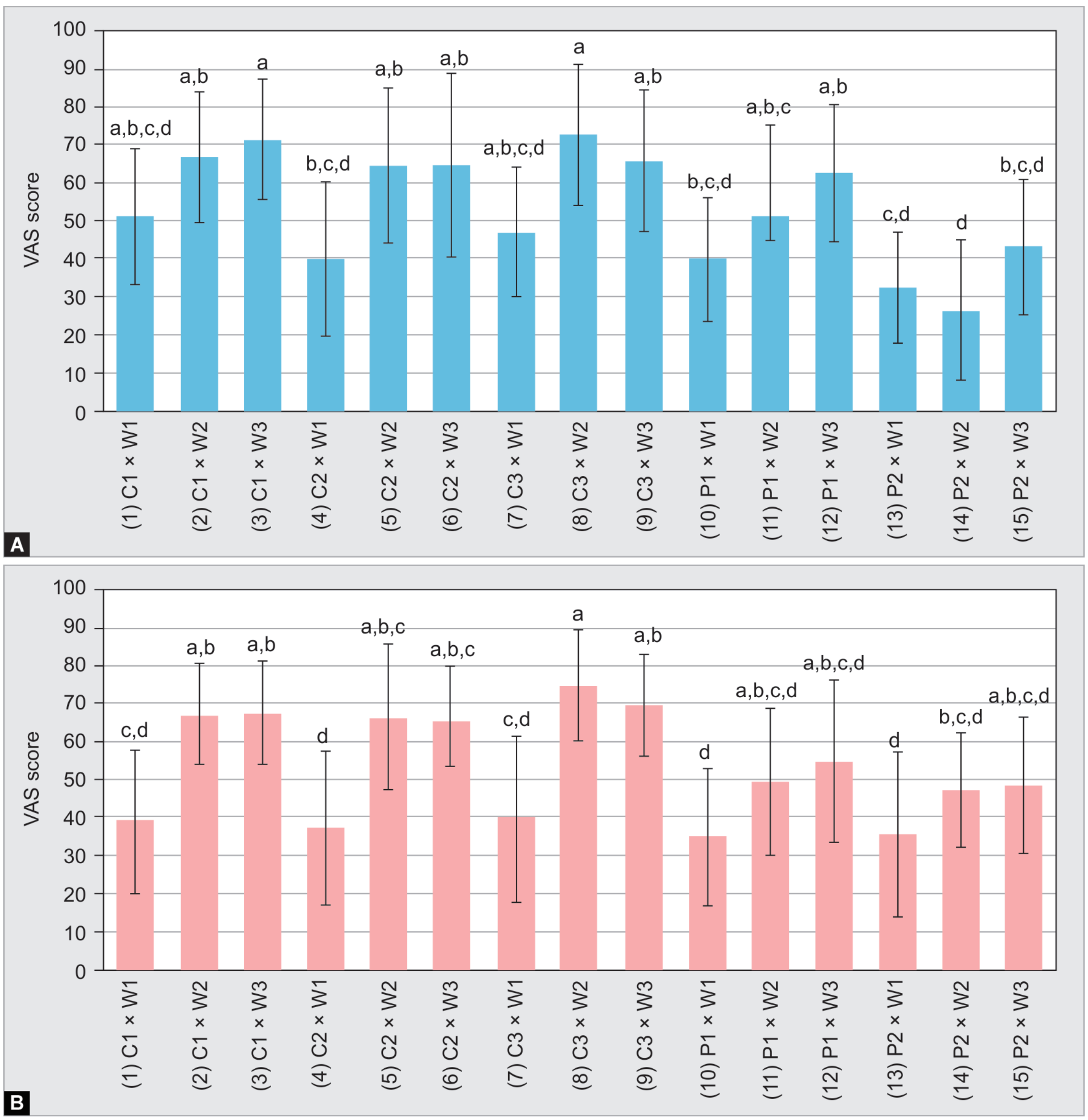
### Survey (Subjective Evaluation by the VAS Method)

Figure 2 show the VAS scores for esthetic evaluation by the layperson group and the orthodontist group. In the layperson group, the VAS scores for esthetic evaluation were higher for the combinations (8), (3), (2), (9), (6), (5), (12), (11), (1) and (7). Among the scores, the scores

**Table 3:** Pearson's product–moment correlation coefficient between each parameter of this study

| | *Reflectance* | $L^*$ | $a^*$ | $b^*$ | *VAS score of layperson group* | *VAS score of orthodontist group* |
|---|---|---|---|---|---|---|
| **Reflectance** | 1.000 | | | | | |
| $L^*$ | 0.994** | 1.000 | | | | |
| $a^*$ | −0.509 | −0.564 | 1.000 | | | |
| $b^*$ | −0.457 | −0.402 | 0.070 | 1.000 | | |
| **VAS score of layperson group** | 0.644* | 0.664* | −0.241 | 0.169 | 1.000 | |
| **VAS score of orthodontist group** | 0.640* | 0.680* | −0.436 | 0.382 | 0.853** | 1.000 |

*Indicates that the correlation coefficient is significant at the 5% level; **Indicates that the correlation coefficient is significant at the 1% level




**Figs 2A and B:** VAS score results by a survey of: (A) Layperson group; (B) Orthodontist group. Identical letters indicate that mean values are not significantly different ($p$ <0.05, Tukey's test) for combinations (3) and (8) were significantly higher than for (4), (10), and (13) to (15), including the P2 bracket. Meanwhile, in the orthodontist group, VAS scores for esthetic evaluation were high for the combinations (8), (9), (3), (2), (5), (6), (12), (11) and (15). Among the scores, the score of combination (8) was significantly higher than those of (1), (4), (7), (10), and (13), including the W1 archwire and significantly higher than that of (14). A comparison of the two groups showed that the combinations in which only the layperson group responded with high evaluations were (1) and (7), and the combination for which only the orthodontist group responded with a high evaluation was combination (15). Combination (8) was the most highly rated in both groups.

Figure 3 shows the comparison of esthetic evaluation VAS scores between the layperson and orthodontist groups for each combination of bracket and archwire appliance. In comparing the layperson and orthodontist groups, most of the combinations did not show any significant differences. However, for combination (14), the layperson group gave a significantly lower VAS score than did the orthodontist group.

A correlation analysis revealed a significantly high positive correlation at the 1% level between the VAS scores of the layperson and orthodontist groups ($r = 0.853$). There was a significant positive correlation in the layperson group at the 5% level between the VAS score and reflectance ($r = 0.644$) and between the VAS score and $L^*$ ($r = 0.664$). Significant positive correlations were observed in the orthodontist group at the 5% level between the VAS score and reflectance ($r = 0.640$) and between the VAS score and $L^*$ ($r = 0.680$).

## Discussion

Before discussing the color measurement results, we discuss the validity of the results of color measurement using a spectrophotometer. Because color measurement is strongly affected by the surrounding environment at the time of measurement, it is necessary to devise a method to obtain reproducible data. In particular, most esthetic brackets are transmissive and may be strongly affected by ambient light and the color and material of the back of the bracket. In a previous study using a spectrophotometer similar to the device used in this study, the $L^*$, $a^*$, and $b^*$ values of ceramic brackets were reported to be 75.8 – 98.3, −0.5 to 0.3, and 2.6 – 4.8, respectively, whereas the $L^*$, $a^*$, and $b^*$ values of plastic brackets were reported to be 77.6 – 82.0, –1.4 to −0.2, and 4.6 – 8.0, respectively.[14] The $L^*$ of ceramic brackets examined in this study ranged from 93.25 to 96.16, the $a^*$ ranged from −1.57 to 0.26, and the $b^*$ ranged from −0.13 to 2.81, whereas the $L^*$ of plastic brackets ranged from 77.49 to 83.10, the $a^*$ ranged from −0.92 to −1.05, and the $b^*$ ranged from 2.03 to 3.86, indicating a similar trend to that reported above. Although the type and number of bracketed samples used, measurement instruments, and background preparation methods were different, the results of the spectrophotometric measurements were considered valid.

For the bracket samples, C3 and C1 showed significantly higher reflectance values than did the other bracket samples. For the $L^*$ value, C3 showed significantly higher values than did all other bracket samples, whereas P1 and P2 showed significantly lower values than did the other bracket samples. The ceramic brackets could be said to have shown high values for both reflectance and $L^*$, whereas the plastic bracket showed low values. W2 showed the highest values for both reflectance and $L^*$ for the archwire samples, followed by W3 and W1. A correlation analysis also showed a strong positive correlation between reflectance and $L^*$ ($r = 0.994$), suggesting that the $L^*$ value increased along with the reflectance. Samples with smooth surfaces, such as ceramic brackets (C1, C2, and C3), showed significantly higher reflectance values and higher $L^*$ values, presumably because the surfaces acted as mirrors. In terms of color, there was no significant correlation between reflectance and $L^*$, or between $a^*$ and $b^*$, although significant differences in $a^*$ and $b^*$ were observed between samples.

Meanwhile, in the subjective evaluation by VAS score, the combination of “bracket: C3, archwire: W2” was rated the highest in both the layperson and orthodontist groups and was

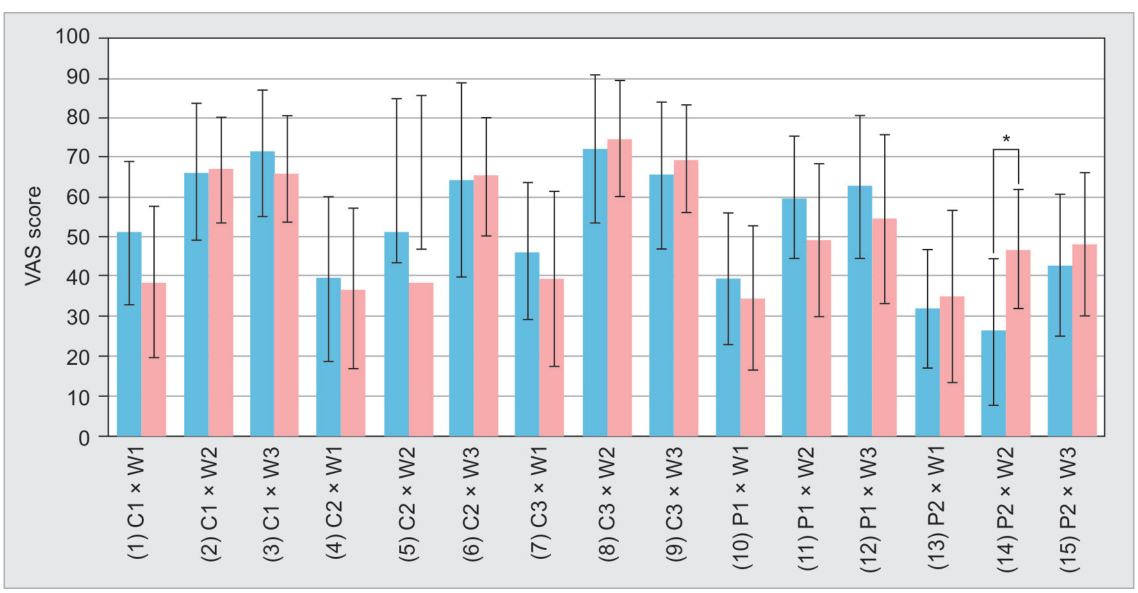



**Fig. 3:** Comparison of VAS scores between the layperson and orthodontist groups. No significant differences were observed in the VAS scores between the layperson and orthodontist groups except (14) (P2 × W2). *Indicates significant difference at $p < 0.05$ ($t$-test)

the orthodontic appliance combination with the highest $L^*$ and reflectance values. A correlation analysis showed significantly high positive correlations at the 5% level between VAS score and reflectance ($r = 0.644$) and between VAS score and $L^*$ ($r = 0.664$) in the layperson group. Significantly higher positive correlations were observed at the 5% level between the VAS score and reflectance ($r = 0.640$) and between the VAS score and $L^*$ ($r = 0.680$) in the orthodontist group. As such, the higher the $L^*$ and reflectance of the orthodontic appliance, the higher the subjective evaluation of esthetics in the photograph evaluation.

The VAS scores varied depending on the combination of appliances. However, as a result of comparing the ratings between the layperson and orthodontist groups, there was no significant difference with respect to the majority of combinations. In addition, there was a significant positive correlation at the 1% level between the VAS scores of the layperson and orthodontist groups ($r = 0.853$), suggesting that the trends in esthetic rating were similar between the two groups. Only combination (14) showed a predominantly lower VAS score for the layperson group evaluation than for the orthodontist group evaluation. This may be attributed to the specialized knowledge possessed only by orthodontists regarding the metal slot built into the esthetic bracket. The P2 bracket incorporates a stainless steel slot reinforcement to reduce friction in the archwire and ensure that the archwire's torque is fully transmitted to the teeth, even as the polymer degrades due to water absorption. The orthodontists understood why this stainless steel component was incorporated into the appliance and were familiar with it in daily clinical use, so they may not have appreciated its potential perception as esthetically unpleasing.

Additionally, the W2 archwire had the highest $L^*$ and reflectance. The archwire with the highest lightness combined with the stainless steel slots with the lowest lightness may have resulted in the greatest contrast in lightness and, therefore, a lower rating by the layperson group. The orthodontists were familiar with the structure and configuration of the brackets, and as such, even if the contrast in lightness was high, the orthodontists would not have rated such appliances as less esthetic.

In discussing the results of this study, it is necessary to address the limitations of the study's design. In this study, brackets and archwires were placed on the maxilla on an oral model for clinical use, and sample photographs were prepared by applying standardized photography methods. This study design aimed to provide more uniform and standardized photographs using multiple bracket and archwire sample combinations. However, other factors that affect esthetics (e.g., lips, saliva, mandibular teeth, tooth coloration, and mucosal coloration) must be compared using the actual oral cavity for accurate reproduction. Replacing the bracket samples in the actual oral cavity imposes a great burden on the patient and causes concerns regarding damage to the teeth and perioral tissues. Although preparing as many subjects as the number of sample combinations would reduce the burden on the patient, differences in the morphology, coloration, and occlusion of the teeth and surrounding tissues are also thought to directly affect the esthetic evaluation.

Furthermore, comparisons regarding esthetic evaluations between studies are very difficult to perform due to variations in the natural color of tooth enamel according to race, age, and gender, and the color parameters vary depending on the colorimetric protocol used.[15] In addition, because the orthodontic appliances are implanted in the oral cavity for long periods due to their characteristics, differences in materials and structures should result in different changes over the implantation period. Akyalcin et al. stated that when comparing plastic and ceramic brackets, plastic brackets were the most affected by color changes.[16] Therefore, it can be readily inferred that the difference in esthetic evaluation results between ceramic and plastic brackets increases over time.

Up to now, no research has been done to quantitatively evaluate the esthetic properties of brackets and archwires in combination in the laboratory. As mentioned previously, a suitable study design for the comparative evaluation of the esthetic quality of orthodontic appliances is a subject for future research. In this study, the morphology and color tone of the teeth and surrounding tissues were standardized, and only the combination of archwire and brackets was changed in the photographs. This allowed for comparisons to be made under standardized conditions. These findings will provide useful information for the development of future orthodontic appliance study designs.

## Conclusion

The results of the esthetic evaluation of orthodontic appliances using photographs revealed that the higher the lightness and reflectance of the brackets and archwire, the higher the subjective evaluation.

## Orcid

*Naohiko Kawamura* https://orcid.org/0000-0003-3176-5260

## References

1. Iijima M, Zinelis S, Papageorgiou S, et al. Orthodontic brackets. In: Eliades T, Brantley W, editors. Orthodontic applications of biomaterials. Sawston, Cambridge: Woodhead Publishing; 2017; p. 75–96.
2. Khan RS, Horrocks EN. A study of adult orthodontic patients and their treatment. Br J Orthod 1991;18(3):183–194. DOI: 10.1179/bjo.18.3.183.
3. Birnie D. Ceramic brackets. Br J Orthod 1990;17(1):71–75. DOI: 10.1179/bjo.17.1.71.
4. Iijima M, Muguruma T, Brantley W, et al. Effect of coating on properties of esthetic orthodontic nickel-titanium wires. Angle Orthod 2012;82(2):319–325. DOI: 10.2319/021511-112.1.
5. Filho H, Maia LEG, Araújo MVA, et al. Influence of optical properties of esthetic brackets (color, translucence, and fluorescence) on visual perception. Am J Orthod Dentofacial Orthop 2012;141(4):460–467. DOI: 10.1016/j.ajodo.2011.10.026.
6. Kaphoor AA, Sundareswaran S. Esthetic nickel titanium wires–how much do they deliver? Eur J Orthod 2012;34(5):603–609. DOI: 10.1093/ejo/cjr089.
7. Ramadan AA. Removing hepatitis C virus from polytetrafluoroethylene-coated orthodontic archwires and other dental instruments. East Mediterr Health J 2003;9(3):274–278. PMID: 15751919.
8. Kusy RP. Orthodontic biomaterials: from the past to the present. Angle Orthod 2002;72(6):501–512. DOI: 10.1043/0003-3219(2002)072<0501:OBFTPT>2.0.CO;2.
9. Chu SJ, Trushkowsky RD, Paravina RD. Dental color matching instruments and systems. Review of clinical and research aspects. J Dent 2010;38(Suppl. 2):e2–e16. DOI: 10.1016/j.jdent.2010.07.001.
10. Joiner A. Tooth colour: a review of the literature. J Dent 2004;32(Suppl. 1):3–12. DOI: 10.1016/j.jdent.2003.10.013.
11. Stober T, Gilde H, Lenz P. Color stability of highly filled composite resin materials for facings. Dent Mater 2001;17(1):87–94. DOI: 10.1016/s0109-5641(00)00065-8.
12. Eliades T, Gioka C, Heim M, et al. Color stability of orthodontic adhesive resins. Angle Orthod 2004;74(3):391–393. DOI: 10.1043/0003-3219(2004)074<0391:CSOOAR>2.0.CO;2.

13. International Conference on Illumination. Colorimetry Technical Report CIE 15. 3rd ed. Washington, DC, USA: CIE; 2004.
14. Lee YK, Bin Y. Translucency and color match with a shade guide of esthetic brackets with the aid of a spectroradiometer. Dental Press J Orthod 2016;21(2):81–87. DOI: 10.1590/2177-6709.21.2.081-087.oar.
15. Bolt RA, Bosch JJ, Coops JC. Influence of window size in small-window colour measurement, particularly of teeth. Phys Med Biol 1994;39(7):1133–1142. DOI: 10.1088/0031-9155/39/7/006.
16. Akyalcin S, Rykiss J, Rody WJ, et al. Digital analysis of staining properties of clear esthetic brackets. J Orthod 2012;39(3):170–175. DOI: 10.1179/1465312512Z.00000000024.