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# Eye-tracking system-based evaluation of orthodontists' and patients' visual attention to facial features before and after orthognathic surgery treatment

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**Abstract**

This research aims to determine the differences between the patient and orthodontist in terms of their visual attention using an eye-tracking system-based evaluation system for assessing facial features before and post orthognathic surgery. The participants included patients who underwent orthognathic treatment (n=26; mean age, 26.04 ± 6.6 years) at the Showa University Dental Hospital and orthodontists with ≥5 years of experience at our department (n =10, mean age, 31.4 ± 2.2 years). Visual attention was assessed using an eyeglass-type device (eye tracker). Facial photographs of each patient, both frontal and side views, were shown on a monitor to the patients and orthodontists, and their respective visual attention was comparatively assessed. SPSS Statistics 25 was used for the study data statistical analysis. The results were contrasted between the patients and the orthodontists using a linear mixed model, with photographs labeled with the same number serving as repeat factors. Total fixation analysis demonstrated that patients focused more on the lower face postoperatively (P=0.044), while orthodontists focused more on the entire face both postoperative and preoperatively. The postoperative findings also demonstrated significant differences in many areas. There was a significant difference in how orthodontists and patients examined the face. This study found differences in visual attention between patients and orthodontists when they examined facial features before and after orthognathic surgery.

**Key words**: orthognathic surgery treatment, eye-tracking technology, visual attention

## Introduction

Orthognathic treatments seek to restore stomatognathic function, establish normal occlusion, improve maxillofacial structure form, and improve the facial aesthetic. Choosing the appropriate procedure for orthognathic surgery depends on the functional and aesthetic treatment goals following the characteristics and chief complaints of the individual patients. It can be anticipated that occlusion and function will improve and that facial appearance will change. However, it is challenging for an orthodontist to pinpoint which area of the face the patient is concerned about at the beginning of orthognathic treatment. In clinical practice, there have been reports wherein orthognathic treatment or reoperation is required to improve the chief complaint following camouflage treatment[1,2].

In recent years, with an increase in social recognition, the number of cases of orthodontic treatment has increased. Patients' aesthetic expectations have also risen. The advancement of various orthognathic treatment techniques has made it possible to perform surgery precisely following treatment plans, allowing patients with jaw deformity demands to be met. However, it is unknown whether this is reflected in patient satisfaction. To date, research on facial contours has primarily focused on examinations that use facial photographs, model analysis, and subjective evaluation (questionnaires) in conjunction with lateral head X-ray standard photograph analysis[2]. These are crucial in fields like orthodontic treatment, orthognathic surgery, and plastic surgery. Furthermore, in recent years, it has become

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feasible to superimpose pre- and postoperative data collected from non-contact three-dimensional optical scanners and cone-beam computed tomography on invariant regions of hard tissue using three-dimensional image analysis software and extract images of soft tissue using the same coordinate axes. Therefore, changes in soft tissue can be evaluated more precisely. Previous studies have examined facial morphology and postoperative changes using these methods. Morphological analysis using CT has broadly been used for preoperative and postoperative evaluations of patients with jaw deformities[3–6]. A limitation of traditional methods (e.g., questionnaires) is their subjectivity in evaluating patient satisfaction with preoperative and postoperative changes, including those of soft tissue.

In this study, we would like to investigate the deeper psychology of what patients are looking at when comparing preoperative and postoperative photographs against this limitation. We also hope to obtain objective data through eye-tracking.

Eye-tracking systems have been prevalently used in the field of psychology; however, they have recently been applied to several fields, including support for people with disabilities and analysis of eye gaze while driving automobiles. Furthermore, the use of eye-tracking systems for locating visual attention to facial features has been reported[6, 7]. An eye-tracking system that captures what people directly look at can objectively and quantitatively evaluate patients' visual attention distribution[8, 9]. The goal of this study was to reduce the subjectivity associated with the assessment of facial appearance by using an eye-tracking system when compared with traditional orthodontic treatment assessment methods (IOTN, questionnaires). The successful application of eye-tracking systems has contributed to the widespread use of this technology in facial perception research (e.g., facial expression, sex, race, and facial features)[10–12].

Studies in the field of orthodontics using eye-tracking systems for evaluating changes in the visual attention on facial structures and orthodontic treatment have been reported[13, 14]. Previous research has supplemented subjective visual analog scale scores with data from facial photographs for orthodontic treatment analyses, including psychosocial aspects from an aesthetic perspective that deepen the understanding of the analysis[15]. In the current study, we targeted patients with jaw deformities while also increasing the round mark of the area of interests (AOI) to identify the fixation sites in greater detail. Thus, the primary goals of this study were to analyze frontal and lateral facial photographs before and after orthognathic surgery using an eye-tracking system and to contrast the differences in visual attention of patients and orthodontists.

## Material and methods

*Participants*

Visual attention was discovered using the Tobii Pro Grass2 (Eye Tribe Tracker sensor, Tobii Technology KK, Stockholm, Sweden). The visual materials used included facial photographs of patients who had orthognathic treatment at Showa University Dental Hospital between January 2014 and March 2020, before and $\geq 3$ months after surgery. Analyses were conducted using four images (preoperative and postoperative frontal and lateral views). Details of the patients (age, gender, treatment details, and surgical settings) were acquired from medical records. Eye-tracking was conducted on 36 participants, including 26 patients (18 men, 8 women; 2 were excluded because the eye-tracking system could not be adjusted for them) and 10 orthodontists (5 men, 5 women). All 36 participants also completed a questionnaire. The average age of the patients was $26.04 \pm 6.6$ years and that of orthodontists was 31.4 $\pm 2.2$ years. The orthognathic treatment conducted was 2Jaw for 19 patients and 1Jaw for 7 patients. Furthermore, the patients in the ongoing study required corrective surgical treatment and therefore deserved Grades 3–5 in the IOTN classification. The subdivision of skeletal sex classification was breakdown of skeletal sex classification was Cl.III (Mesio-Occlusion–the mandibular molar is mesial to the maxillary first molar) patients (n=24) and Cl.II (Disto-Occlusion–the mandibular molar is distal to the maxillary 1st molar) (n=2) patients.

The patients were presented with four photographs of themselves (preoperative and postoperative frontal and lateral views). The preoperative and postoperative lateral and frontal facial images of the 26 patients were presented to the orthodontists. The exclusion qualifications were the same for the jaw deformities and orthodontists patients: (1) eye disease (e.g., cataract, infection, trauma, and strabismus) at the time of evaluation or within the past 6 months; (2) substantial deterioration of visual acuity (e.g., myopia / strabismus) and corrected visual acuity of $\leq 0.7$ (visual acuity could be self-reported based on the results of a medical examination); (3) having previously undergone LASIK or implantation of implantable contact lenses; (4) using contact lenses for astigmatism or hard contact lenses ; (5) measurements that were considered difficult to undertake due to the use of eyeglasses (e.g., the pupil could not be detected well via calibration) ; (6) having eyelash extensions ; or (7) other reasons for which the researchers determined that participation would be challenging. The study was authorized by the Clinical Trial Review Committee of Showa University Dental Hospital (approval number : SUDH0046).

*Visual materials*

Preoperative assessment and assessed preoperative and 3-month postoperative facial photographs of patients who had orthognathic treatment at the Showa University Dental Hospital (Tokyo, Japan) between January 2014 and March 2020.

The analysis was performed using preoperative frontal and lateral view and postoperative frontal and lateral view images. The same neutral background was used in all the photographs. Facial photographs of patients with large scars, eccentric hairstyles, tattoos, earrings, or dark makeup were exempted from the analyses. All the photographs were sized equally.

*AOIs and landmarks*

AOI is used in eye-tracking research to refer to the region or area that is being watched or considered. The AOIs included five items : the lower face, cheeks, nose, eyes, and entire face. Each of the five items was predefined as an AOI based on anthropometric landmarks. Visual convergences to areas other than these five items were excluded from the analysis. The AOI on the face was defined as the region where the participant's gaze lingered (stared) for > 0.1 s when each image was displayed. Figure 1 depicts a map of the face.

*Eye-tracking system*

The basic idea is to use a light source to illuminate the eye, causing highly visible reflections, and a camera to capture an image of the eye showing these reflections. The image captured by the camera is then used to identify the light source's reflection on the cornea (glint) and in the pupil. We can then calculate the cornea and pupil reflections—the direction of this vector, along with other geometrical features of the reflections, is then used to calculate the gaze direction. When it comes to remote, non-intrusive eye-tracking the most commonly used technique is the pupil-center corneal reflection. We used a computer with Tobii prograss2 Studio software and Tobii prograss2 (Tobii Technology AB, Stockholm, Sweden). The participants viewed the images from a distance of 60.0 cm in front of a 23.0-inch monitor screen. Before viewing the images, they were informed that the objective of the study was to evaluate facial appearance in jaw deformity treatments. The monitor was placed in a private room to thwart objects other than the visual materials from attracting the participant's attention. Before each measurement, calibration was done by having study participants track points on a blank sheet, after which their eye images were collected and analyzed. Orthodontists viewed all faces, whereas participants viewed only their own faces.

Each participant could freely view the images, which were shown for 15.0 s each. Analysis was

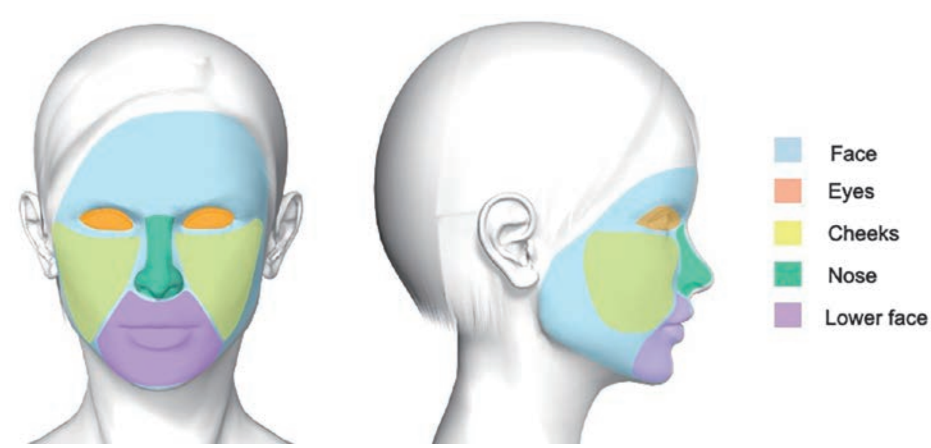


Fig. 1. A picture of the face with the areas of interest visible from the frontal and lateral viewsIn eye-tracking research, the region of interest is defined as the area that is considered to be gazed at. The region of interest is defined as in this study, the five regions of interest were (1) eyes, (2) cheeks, (3) nose, (4) lower face, and (5) the entire face including (1)-(4) .

conducted following calibration and verification.

*Statistical analysis*

SPSS Statistics 25 (IBM Corporation, Armonk, NY, USA) was employed for statistical analysis. Among the 26 photographs (numbers 1–26) assessed independently by both groups of participants, the results were contrasted between the patients and the orthodontists using a linear mixed model, in which photographs labeled with the same number were repeat factors.

A mixed model was employed to evaluate whether there were substantial variations in total fixation time, the number of fixations, and time to the first fixation on the AOI between patients and orthodontists.

A quantile-quantile (Q–Q) plot was created and used to visually confirm normalcy. Deviation from the straight line was observed in unusual cases, but linearity was affirmed in most cases, guaranteeing that there would be no concerns about using the linear mixed model as the analysis method.

The result graph depicts the average value and its 95% confidence interval. The significance level was set to $\alpha=0.05$ (both sides), and $P<0.05$ was considered statistically substantial.

## Results

*Total fixation time*

Figure 2 depicts the total fixation time results, which represent the total time that the participant fixed their gaze at each AOI during the duration that the image was displayed (15.0 s). The comparison of the total fixation time for the orthodontist and patient groups indicated a considerably longer total fixation time in the patient group for the lower face in the postoperative lateral view ($P=0.044$). However,

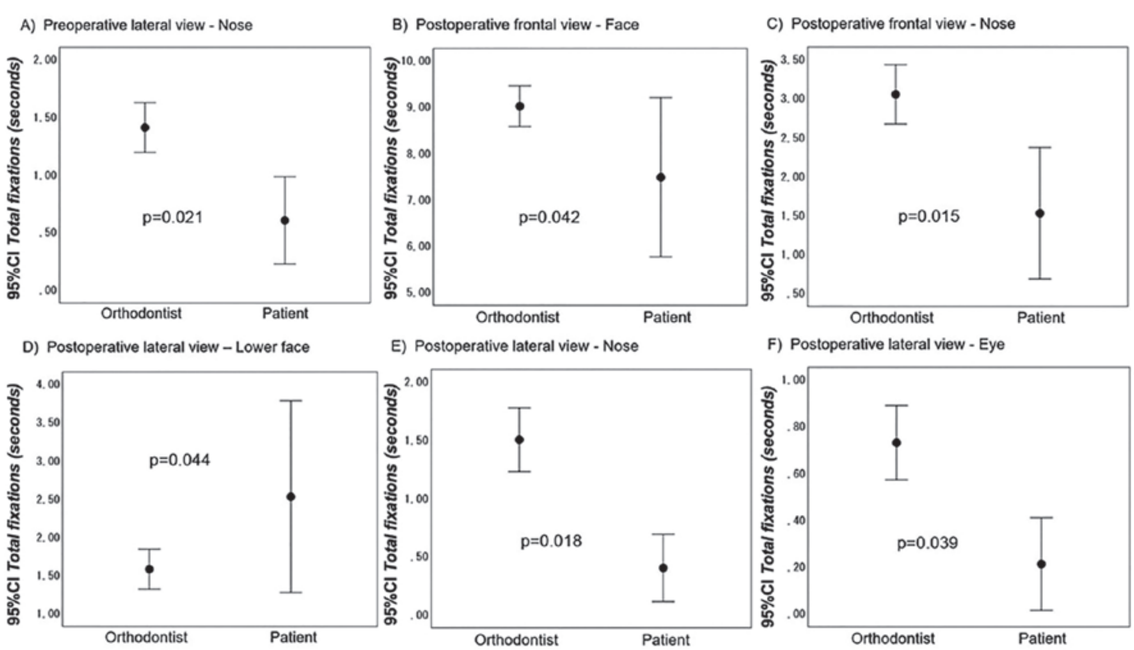


Fig. 2. To determine whether there was a significant difference between patients and dentists in total fixation time on the AOI, a mixed model was used.
The vertical axis shows a 95% CI total fixation time (sec) and the horizontal axis shows the subject (dentist and patient). In the figure, the standard deviation is represented by bars and is larger for patients than dentists.
The regions depicted here (A～F) are those where subjects at each AOI saw statistically significant differences in total fixation time within a 15-second image presentation time.Significant differences in gazing points in the eyes, nose, and face (A, B, C, E, and F) were found in the orthodontist group. In the patient group, significant differences were found in the lower face (D). $^*P<0.05$

(A) Preoperative lateral view: Nose $^*P=0.021$ Orthodontist>Patient
(B) Postoperative frontal view: Face $^*P=0.042$ Orthodontist>Patient
(C) Postoperative frontal view: Nose $^*P=0.015$ Orthodontist>Patient
(D) Postoperative lateral view: Lower face $^*P=0.044$ Patient>Orthodontist
(E) Postoperative lateral view: Nose $^*P=0.018$ Orthodontist>Patient
(F) Postoperative lateral view: Eye $^*P=0.039$ Orthodontist>Patient

no statistically significant differences were found between patients and orthodontists for any of the other items. In the orthodontist group, preoperative lateral view-nose (P=0.021), postoperative frontal view-face (P=0.042), postoperative frontal view-face (P=0.015), postoperative lateral view-nose (P=0.018), and postoperative lateral view-eye (P=0.039) were considerably long in the total fixation time. These findings showed that the patients focused on the lower face in the postoperative period, while orthodontists were broadly focused on the entire face in both the postoperative and preoperative periods.

*Initial fixation time*

The time taken before the participant fixed his or her gaze on each AOI in the image was defined as the initial gaze time. Figure 3 summarizes the participants' initial fixation time. Compared with the orthodontists, the patients took a considerably longer time before fixating their gaze both the preoperative (P=0.009) and postoperative views (P=0.039). The patient was the first to identify the face in the frontal view. The orthodontist group had a considerably longer initial fixation time for the cheek (P=0.010) and eye (P=0.021) in the preoperative lateral view. This indicates that the orthodontist group was more fixated on the contour of the preoperative lateral view. Furthermore, in many of the photographs, the patients fixed their gazes first at the cheeks (P=0.354), although the difference was not statistically substantial. Both the postoperative and preoperative results suggested that there was no substantial variation between the patient and orthodontist groups with respect to where they first gaze.

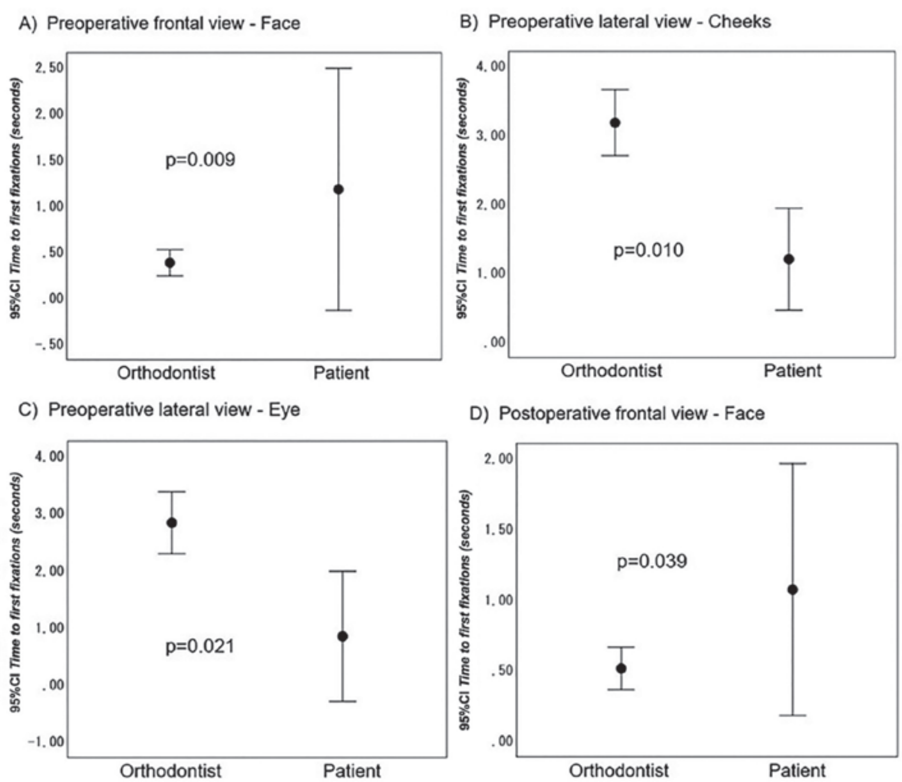


Fig. 3. The time to first fixation on the AOI was compared between patients and dentists using a mixed model to determine whether there was a discernible difference.The areas where significant differences were obtained in the subjects' total fixation time at each AOI within a 15-second image viewing time are shown here (A∼D). Orthodontists demonstrated significantly different gazing points in the preoperative lateral cheeks and eyes (B, C), while patients demonstrated similarly different gazing points in the preoperative and postoperative frontal faces. Initial gazing time, which measures the amount of time taken to look, is a measure of how long a person looks.

(A) Preoperative frontal view : Face*P=0.009 Patient>Orthodontist
(B) Preoperative lateral view : Cheeks*P=0.010 Orthodontist>Patient
(C) Preoperative lateral view : Eyes*P=0.021 Orthodontist>Patient
(D) Postoperative frontal view :: Face*P=0.039. Patient>Orthodontist

*Number of times AOIs were viewed*

There were no significant variations in the number of times the AOIs were viewed between the patient and orthodontist groups. Figure 4 summarizes the number of times AOIs were viewed. The orthodontist group viewed AOIs substantially more times than the patient group: preoperative frontal views of the face ($P=0.002$) and nose ($P<0.001$); preoperative lateral views of the face ($P=0.027$), nose ($P=0.009$), and eyes ($P=0.039$); postoperative frontal views of the face ($P<0.001$), nose ($P<0.001$), and eyes ($P=0.026$); and postoperative lateral views of the face ($P=0.001$), nose ($P=0.001$), and eyes ($P=0.031$). These findings suggest that the orthodontist group had more fixation point movement because they attempted to view the entire facial structure and their gazes covered a much larger area than the patient group.

## Discussion

The primary goal of this study was to analyze the profile and frontal photographs of patients before and after orthognathic surgery using an eye-tracking system and compare visual attention differences between patients and orthodontists. The findings showed that orthodontists' visual attention was distributed across a wide region, including the nose and midface, and was not limited to a single site. Fixation was evaluated using three parameters: A) total fixation time, B) initial fixation time, and C) the number of AOIs views.

Ethical constraints existed due to the use of photographs of actual patients from the present study design. We would like to affirm as a limitation that no comparison of the control group was made in this study. In future studies, we hope to improve the study design by comparing the control group to synthetic schematic drawings rather than personal information.

*Total fixation time*

The results of the comparison between the orthodontists and patients indicated a substantial difference only in the total fixation time on a specific part. These findings show that orthodontists and patients clearly have different fixation sites and methods when evaluating facial appearance. These findings suggest that orthodontists consider the overall balance of the face, rather than just specific areas such as the jawbone, before proceeding with treatment after formulating a treatment plan. In other words, when the orthodontists thoroughly evaluated the entire face, including the profile, the mouth was only considered a part of the face. Furthermore, the patients focused their view on the lower face, which was the site of the primary complaint, for a longer time. This suggests that the patients evaluated facial appearances by focusing on specific features rather than considering the overall facial appearance from a wider perspective. Exemplary, in the case of patients with mandibular prognathism, it is feasible that the patients did not fully understand the position and size of the maxilla and mandible, and their understanding of reversed occlusion is based solely on the position of the mandible. This reemphasizes the importance of explaining whether the reversed occlusion was caused by the maxilla or the mandible, as well as the surgical procedure and treatment method in detail to patients. Furthermore, in the case of patients with significant jaw deformities, it is possible that after correction of the part that the patient was most concerned about, a deformation that was not previously noticeable emerged postoperatively as a new area of concern. Specifically, there were cases where the distortion of the maxilla became noticeable as a result of correcting the mandible deformation, which consequently made the patient more concerned about the height of their eyes as a result of correcting the jawbone deviation[16]. Consequently, if there is deformation in an area other than the area of the chief complaint before surgery, it is essential to explain such situations clearly and provide all relevant information to the patient in an adequate manner. That is, assuming the patient has long attributed the mandibular anterior protrusion and deformity to only the mandible, the patient is highly likely to be surprised when informed that the procedure will involve an osteotomy of both the mandible and the maxilla. Hence, it is critical to accurately convey treatment details and ensure that the patient fully comprehends them. It is important to note that the need for maxillary osteotomy is determined based on numerous factors, including abnormal jawbone size and morphology, maxillary deformation, the extent to which the mandible and maxilla can move, and nose morphology.

Previous studies using eye-tracking found that the total fixation time on the eyes is the longest[8]. It has also been reported that the eyes are initially observed multiple times before the line of sight subsequently moves to the mouth with a similar visual pattern[17, 18]. Studies on eye-tracking have revealed that regarding the face, the area around the

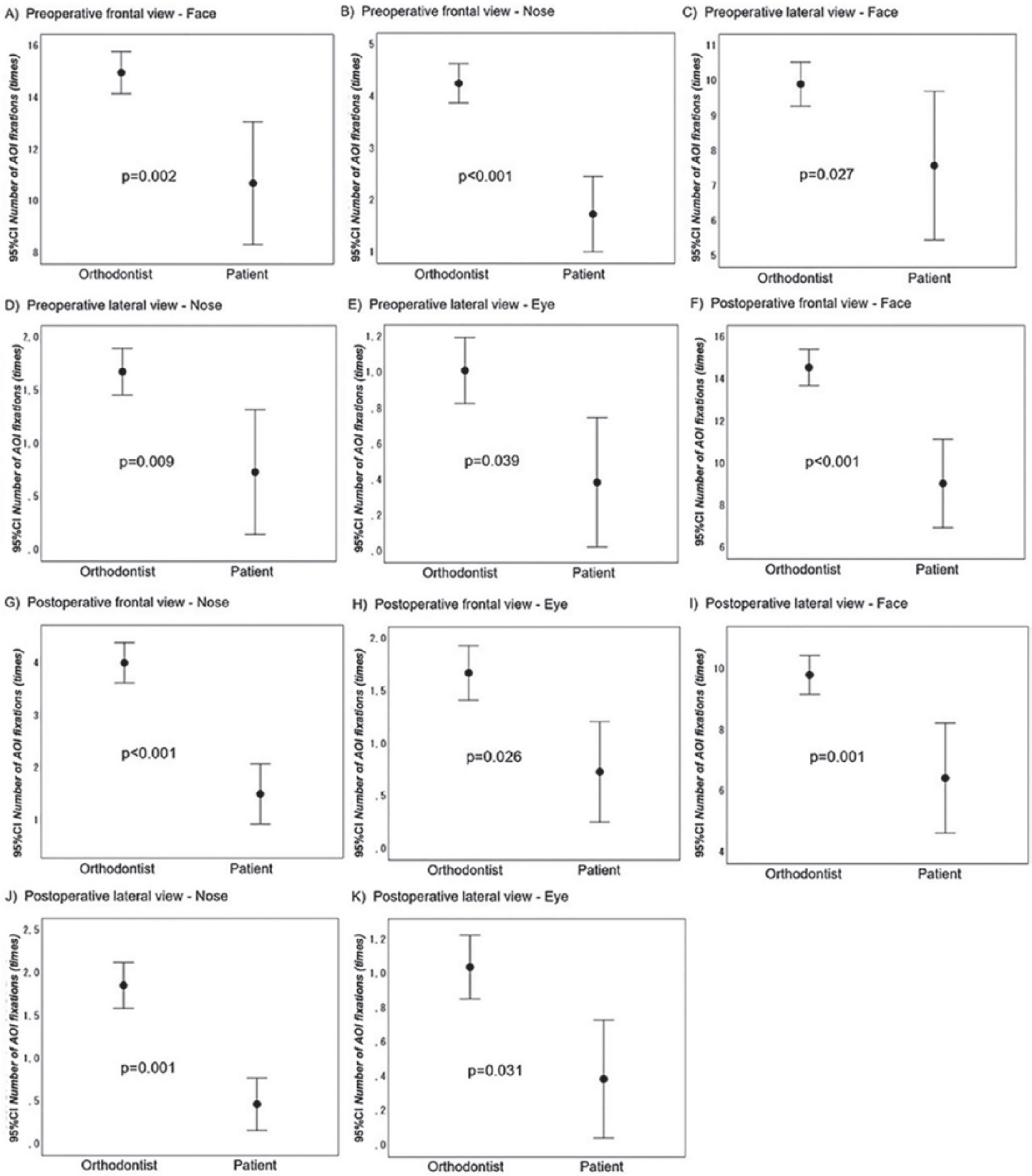


Fig. 4. A mixed model was used to evaluate whether there was a significant difference between patients and dentists in the number of fixations on AOI.
The areas where significant differences were obtained in the number of fixations for subjects at each AOI within a 15-second image display time are shown here（A～K）. In all results where statistically significant differences were obtained, mainly in the face, nose, and eye items, dentists gazed more frequently than patients（A～K）.
Preoperative frontal : face and nose / Preoperative lateral : face, nose, eyes / Postoperative frontal : face, nose, eyes / Postoperative lateral : face, nose, eyes
（A）Preoperative frontal view : Face*P＝0.009 Patient＞Orthodontist
（B）Preoperative lateral view : Cheeks*P＝0.010 Orthodontist＞Patient
（C）Preoperative lateral view : Eyes*P＝0.021 Orthodontist＞Patient
（D）Postoperative frontal view : Face*P＝0.039. Patient＞Orthodontist
（E）Preoperative lateral view : Eye*P＝0.039 Orthodontist＞Patient
（F）Postoperative frontal view : Face*P ＜ 0.001 Orthodontist＞Patient
（G）Postoperative frontal view : Eye*P ＜ 0.001 Orthodontist＞Patient
（H）Postoperative frontal view : Eye*P＝0.026 Orthodontist＞Patient
（I）Postoperative lateral view : Face*P＝0.001 Orthodontist＞Patient
（J）Postoperative lateral view : Nose*P＝0.001 Orthodontist＞Patient
（K）Postoperative lateral view : Eye*P＝0.031 Orthodontist＞Patient

eyes receives the highest degree of fixation[18–20], and this fixation shifts depending on jaw deformation and malocclusion[8, 21]. Furthermore, it was revealed that in the case of a well-proportioned facial image with left-right symmetry, fixation was seldom directed to a particular part and occurred only on the mouth as part of the entire face[6]. Therefore, currently there is no agreement regarding the measurement of fixation. Furthermore, because many studies used composite images, the results may differ from real-life eye movements. Because the current study used actual facial photographs, it was possible to investigate the participants' fixation patterns in a more clinically accurate manner.

*Initial fixation time*

Comparison of the initial fixation time, which denotes the time taken before the participants begin to fixate their gaze on each AOI, between orthodontists and patients, revealed substantial variations in the patient group for the preoperative and postoperative frontal facial images and the orthodontist group for the preoperative lateral view of the cheek and eyes. Because initial fixation time is complicated by multiple factors like photograph uniformity (sex / facial expressions), size, and individual idiosyncrasies such as the participants' visual patterns[22, 23], assessment using actual facial photographs, as in the current study, is difficult. Some studies excluded initial fixation time from the results because no statistically substantial variations were observed[7, 13]. Other studies reported that the eyes are where the participants cast their gaze initially[6, 22]. It may be seamless for this type of fixation pattern to emerge because what the participants were looking at was standardized as a result of the use of composite photographs[24]. The current study's findings did not reveal statistically significant results in terms of initial fixation time. However, when confirmatory studies were conducted using the analysis software, it was discovered that both orthodontists and patients tended to gaze at the cheeks first. One possible explanation is that the cheek area is in the center of the photograph, which is where fixation is most easily directed. However, because orthodontists frequently examine the nasolabial angle and the degree of midface depression, it can be assumed that this contributed to the outcome.

*Number of times AOIs*

The results of the comparison between orthodontists and patients regarding the number of times the AOI was viewed revealed no substantial variation. However, the number of times of fixation on the AOI among the orthodontist was significantly more often than among patients. As a result, it can be inferred that the orthodontists aimed to have a sense of the overall balance of the face, and consequently, there was more movement in the fixation point in the orthodontist group than in the patient group. Furthermore, more than 50% of the patients looked at only specific areas of the face while the remaining 50% looked at parts other than the face (e.g., clothes and background), limiting the detection of fixation point movement (the number of times a particular AOI was looked at). The first reason patients may have gazed at areas other than the face appeared to be related to the psychological issues common in patients with jaw deformity. Several studies have been published on the psychology of patients with jaw deformity before and after surgery[25, 26]. According to Ito *et al.*, patients with asymmetrical jaw deformity have low self-esteem and high depression scores. It is possible that low self-esteem scores may lead to diverting fixation from one's own face. Furthermore, the psychological situation varies when looking at one's face and the face of another person[27, 28]. It is possible that these psychological factors contributed to the disparity in fixation between patients and orthodontists.

## Conclusions

・Total fixation time

Patients clearly looked at the lower face in postoperative, while orthodontists looked at the entire face in postoperative and preoperative.

・Initial fixation time

No substantial variations were found between the patients and orthodontists.

・Number of times viewing AOIs

The orthodontists examined the entire face, whereas the patients tended to focus on specific AOIs.

The findings of this study indicate that the differences observed in the fixation point may be due to differences in treatment goals between patients and orthodontists, implying that it may be necessary to ensure that both parties are on the same page before beginning treatment. Furthermore, the use of an eye-tracking system for diagnosis appears to aid orthodontists in understanding the primary complaint that patients cannot express verbally. It was shown that explaining the expected change and treatment limitations before treatment initiation and ensuring that both parties share common treatment goals, can lead to better orthognathic treatment.

We aim to collect more data and investigate the relationship between fixation data and facial morphological features in greater depth by including temporal movement analysis of the fixation point.

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## Conflicts of interest

The authors declare no potential conflicts of interest concerning the research, authorship, and / or publication of this article.

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