

Effect of small head tilt on ocular fundus image: Consideration of proper head positioning for ocular fundus scanning

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Abstract

Head tilt and resultant ocular cyclotorsion can influence the results of ophthalmologic examinations. Thus, proper head positioning during fundus scanning has been emphasized. However, there is no perfect method to control the head tilt and little is known about the effect of small head tilts. In this study, we investigated the effect of minimal head tilt on the ocular cyclotorsion which we cannot easily detect.

Forty-seven participants without ophthalmologic or vestibular abnormalities were recruited as normal subjects. Their faces were positioned at the desired head tilt using a customized adjustable head tilter and facial and fundus photographs of both the left and right eyes were taken in the upright neutral position; as well as at rightward and leftward head tilts of 2°, 4°, and 6°. The actual head tilt was determined using the facial photographs by measuring the slope of a line that intersected the corneal reflexes of both eyes. Rotational changes in the fundus images were recorded and the correlation of these changes with the degree of head tilt was determined.

The degree of head tilt was significantly correlated with rotational changes in the fundus images from both the right and left eyes ($P < 0.001$; right eye: $R^2 = 0.897$, left eye: $R^2 = 0.899$). The mean relative compensations for head tilt, mediated by the ocular counterrolling reflex, were 0.376 ± 0.255 in the right eye (range: -0.02 to 1.0), and 0.350 ± 0.263 in the left eye (range: -0.03 to 1.0), and exhibited a significant negative correlation with head tilt ($P < 0.05$). The mean relative compensation of the right eye did not differ significantly from that of the left eye ($P = 0.380$), but the value did vary widely among individuals and within individuals.

Even very small head tilt was partially and variably compensated for, and caused significant rotation in the fundus image. We concluded that proper head positioning does not guarantee the minimal ocular cyclotorsion change of the eyes and image-adjusting technique would be a better solution for minimizing errors from ocular cyclotorsion changes.

Abbreviation: OCT = optical coherence tomography.

Keywords: effect of head tilt on ocular imaging device, effect of head tilt on the fundus image of eye, head tilts, ocular counterroll

1. Introduction

Many ophthalmological imaging devices are able to scan the ocular fundus and acquire information. Because the eyeball is a 3-dimensional structure, some factors, such as direction of the visual axis and cyclotorsion of the eyeball influence these processes. Several studies have reported the effects of changes in

head position in the context of retinal imaging as well as that these changes can lead to measurement discrepancies.^[1–3] Thus, proper head positioning to minimize the ocular cyclotorsion change and visual fixation to provide proper alignment of the ocular fundus have been emphasized in the sequential follow-up of diseases involving ocular fundus.

Head tilt toward the shoulder evokes the ocular counterrolling reflex, which occurs in a direction opposite to that of the head tilt.^[4] The reflex is mediated by the semicircular canals in response to head rotation and is maintained during the head tilt by otolith organs, which react to the direction of gravitational force.^[4] The ocular counterrolling reflex, which is triggered by lateral head tilt, in turn activates the superior oblique and superior rectus muscles of ipsilateral eye as well as the inferior oblique and inferior rectus muscles of the contralateral eye. This causes incyclotorsion of ipsilateral eye and excyclotorsion of contralateral eye (Fig. 1). Previous studies investigated head tilt and ocular counterrolling and found that the relative compensation for head tilt by ocular counterrolling ranged from 13% to 22%.^[5–9] However, most previous studies only investigated the effect of large head tilts more than 10°, and little is known about small head tilts. In addition, to our knowledge, there is no method to control the head tilt perfectly, and small degree of head tilt is hard to detect. Thus, we investigated the effect of minimal head tilt on the ocular cyclotorsion.

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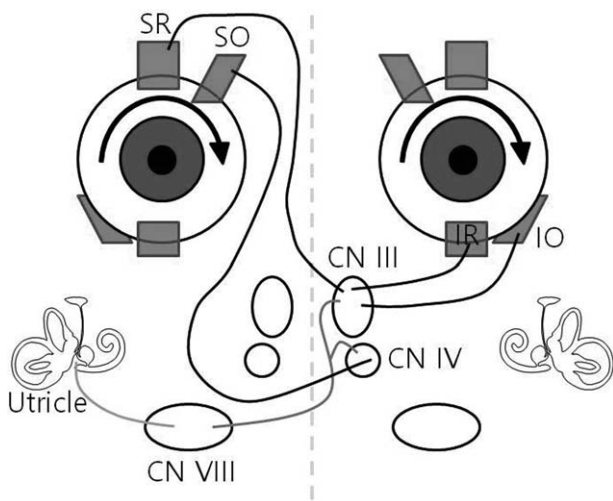


Figure 1. Connections of otolith organ, cranial nerve nuclei, and extraocular muscles mediating the ocular counterrolling reflex. Head tilt stimulates ipsilateral otolith organ and evokes the ocular counterrolling reflex. The otolith organ stimulates ipsilateral vestibular nucleus (CN VIII), which stimulates contralateral oculomotor nucleus (CN III) and trochlear nucleus (CN IV). The oculomotor nucleus (CN III) activates the superior rectus muscle (SR) of ipsilateral eye as well as the inferior oblique (IO) and inferior rectus (IR) muscles of the contralateral eye, and the trochlear nucleus (CN IV) activates the superior oblique muscle (SO) of ipsilateral eye and excyclotorsion of contralateral eye.

2. Materials and methods

Forty-seven subjects who met our eligibility criteria were recruited. All subjects provided written informed consent. The study was approved by the Institutional Review Board of Seoul St. Mary's Hospital, and adhered to the tenets of the Declaration of Helsinki.

We asked all volunteers about their medical history, and measured their visual acuity, refractive error (using an automatic refractometer [Canon R-F10; Canon Inc., Tokyo, Japan]), and ocular deviation. In addition, we examined their ocular motility, carried out the Worth 4-dot test, and performed a slit-lamp biomicroscopic examination. From among the volunteers, we recruited those with a best-corrected visual acuity equal to or better than 20/20; single binocular vision; no history of ophthalmic or vestibular disease, or use of medication that may influence visual or vestibular function; no ocular deviation, including phoria; and no suspicious extraocular muscle motility disorder or ocular pathology capable of visual disturbance, as normal subjects.

Fundus photographs were taken using a digital fundus camera (KOWA VX-10i, Kowa, Inc., Tokyo, Japan) after pharmacological pupil dilation. The Kowa VX-10 provides a round green light as a target for visual fixation. The original chin rest was removed from the table of the fundus camera, and a custom-made face positioner and frame, which had a rectangular window and rulers at all sides, were attached to the table (Fig. 2A). The rulers at both the left and right sides had the same scale and gradations at the same levels. The face positioner had a goniometer and a suspended weight, according to which the degree of head tilt could be adjusted (Fig. 2A and B). A digital camera was placed on a tripod behind the fundus camera at the level of subject's eyes. In order to allow measurement of actual head tilt, the subject's face was photographed using the digital camera immediately before the fundus photographs were taken. The procedure was as follows: after the face positioner was adjusted to the desired head tilt, the subject's face was placed into the positioner; the subject's face was photographed using the digital camera under illumination by a flashlight; and the fundi of the left and right eyes were photographed using the fundus camera. Both the facial photographs and fundus photographs of the left and right eyes were obtained at the upright neutral position, as well as at both rightward and leftward head tilts of 2°, 4°, and 6°.

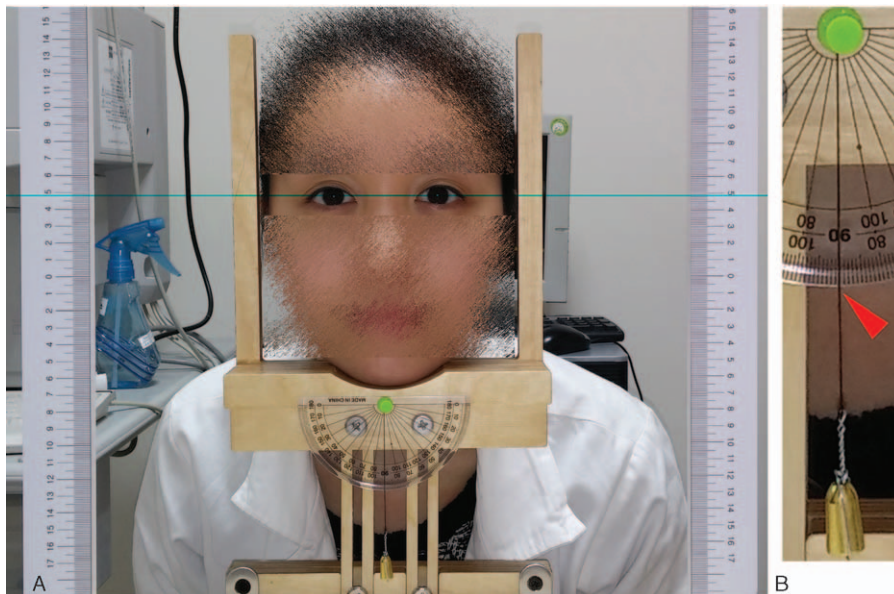


Figure 2. Head positioner and measurement of head tilt. (A) A tiltable head positioner and frame, which has rulers at both the right and left sides. After the face positioner was adjusted to the desired head tilt, the subject's face was placed onto the positioner. The subject's face, along with the frame, was photographed under illumination by a flashlight. On the facial image, a line was drawn intersecting the light reflex points of both eyes (light blue line). Then the actual degree of head tilt was measured by determining the slope of the line. (B) A goniometer with suspended weight. The black line indicates the degree of head tilt (red arrowhead).

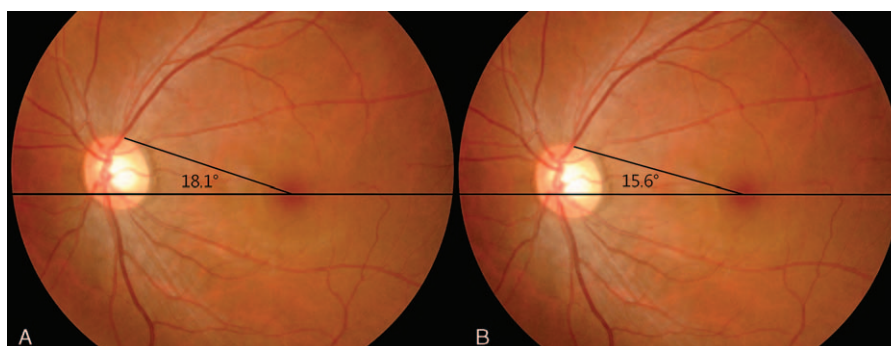


Figure 3. Measurement of rotational change in the ocular fundus image. A line was drawn connecting the foveola to the point where the optic nerve head margin meets the temporal border of the superior temporal retinal vein. Then the angle between that line and the horizontal plane was measured. (A) A representative example of a fundus photograph of the left eye at the upright head position. The measured angle is 18.1°. (B) A representative example of a fundus photograph at 3.8° rightward head tilt. The angle is 15.6°, and the change of the angle was therefore 2.5° for a 3.8° rightward head tilt in this example.

On the facial photograph, we drew a line intersecting the corneal reflexes of both eyes. The slope of the line, and thus the actual degree of head tilt, was measured (Fig. 2A). To measure the ocular cycloduction change according to head tilts, we drew a line intersecting the foveola and the point where the optic nerve head margin meets the temporal border of the superior temporal retinal vein on the fundus photograph. We then measured the angle between the line and horizontal plane (Fig. 3). The degree of head tilt, as well as the changes in the measured angle on the fundus images, was recorded in both the right and left eyes.

The relative compensation for each head tilt by the ocular counterrolling reflex was calculated as follows: $1 - (\text{rotational change of the fundus image/actual degree of head tilt})$.

Photoshop CS5 (Ver. 12.0.1; Adobe, Inc.) was used to perform measurements on the images.

Univariate simple linear regression analysis was performed to analyze the correlations between degree of head tilt and resultant rotational change of ocular fundus image and compensation ratio by ocular counterrolling reflex. Student *T* test was performed to compare the resultant ocular counterrolling of rightward and leftward head tilt. Paired *T* tests were performed for interocular comparison of parameters. Statistical software (Ver. 13.0; SPSS Corp., Chicago, IL) was used for statistical analysis.

3. Results

Of the 47 recruited subjects, 23 (48.94%) were male. The mean age of the subjects was 27.76 ± 2.69 years (range: 25–33 years). The mean spherical equivalent of refractive error in the right eye was -3.813 ± 3.125 diopter (range: -11.75 to 0.25), and in the left eye -3.473 ± 2.529 diopter (range: -11.0 to -0.25).

The degree of rightward head tilt was significantly correlated with rotational change in fundus images from both the right and left eyes; 1° of rightward head tilt caused 0.816° counterclockwise rotational change of fundus image in the right eye ($R^2=0.637$, $P<0.001$, Fig. 4A) and 0.747° counterclockwise rotational change in the left eye ($R^2=0.619$, $P<0.001$; Fig. 4B). The compensation ratios of the ocular counterrolling reflex to rightward head tilt showed negative correlation (Fig. 4C and D). The compensation by ocular counterrolling reflex to rightward head tilt decreased 5.8% per 1° of head tilt in the right eye (regression coefficient = -0.058° , $R^2=0.116$, $P<0.001$) and 3.4% per 1° in the left eye (regression coefficient = -0.034° , $R^2=0.045$, $P=0.012$). The mean compensation ratios

of the ocular counterrolling reflex in the case of rightward head tilt were 0.387 ± 0.264 (range: -0.02 to 1.0) in the right eye and 0.362 ± 0.254 (range: -0.03 to 1.0) in the left eye. These values were not significantly different from each other ($P=0.267$). The degree of leftward head tilt was also significantly correlated with rotational changes in fundus images from both the right and left eyes ($P<0.001$; Fig. 5 A and B); 1° of leftward head tilt caused 0.725° clockwise rotational change in the right eye ($R^2=0.640$, $P<0.001$, Fig. 5A) and 0.733° clockwise rotational change in the left eye ($R^2=0.612$, $P<0.001$; Fig. 5B). The compensation ratios in both the right and left eyes at given leftward head tilts are shown in Fig. 5C and D. These ratios also showed weak but significant negative correlation to the degree of rightward head tilt (right eye: $P=0.026$, left eye: $P=0.029$). The compensation by ocular counterrolling reflex to leftward head tilt decreased 2.9% per 1° of head tilt in the right eye (regression coefficient = -0.029° , $R^2=0.037$) and 3.0% per 1° in the left eye (regression coefficient = -0.030° , $R^2=0.034$). The mean compensation ratios for leftward head tilt were 0.364 ± 0.245 (range: -0.02 to 1.0) in the right eye and 0.339 ± 0.273 (range: -0.02 to 1.0) in the left eye. These ratios were not significantly different from each other ($P=0.210$). The compensation ratio for rightward head tilt was not significantly different from that for leftward head tilt (right eye: $P=0.470$, left eye: $P=0.455$).

The degrees of both directional head tilt and fundus image rotational change in the right and left eyes were significantly correlated (regression coefficient = 0.673 , $R^2=0.897$ and $P<0.001$ and regression coefficient = 0.681 , $R^2=0.899$, respectively; Fig. 6). The means of the compensation ratios for both rightward and leftward head tilts were 0.376 ± 0.255 (range: -0.02 to 1.0) in the right eye and 0.350 ± 0.263 (range: -0.03 to 1.0) in the left eye. These values were not significantly different from each other ($P=0.380$). Figure 7 shows box plot graphs of the compensation ratio distribution in all study subjects.

4. Discussion

Head tilt and accompanying ocular counterrolling reflex have been the interest of strabismus specialists, and most of previous studies have focused on the diagnosis of ocular motility disorders. However, head tilts and resultant cyclotorsional changes of the eyeball can influence results of various ophthalmology practice including astigmatism axis and retinal images. Currently, many retinal imaging devices are being used in various fields of

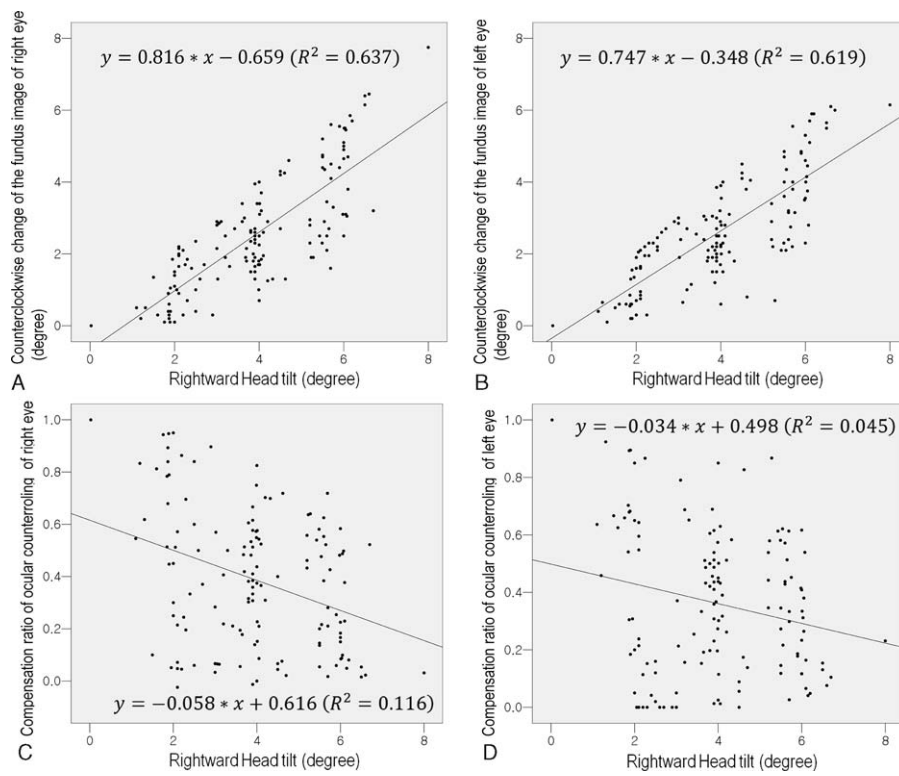


Figure 4. (A and B) Graphs showing the correlation between rightward head tilt and counter-clockwise rotational change in the fundus photographs of the right eye (A) and left eye (B). (C and D) Scatter plots showing the relative compensation by ocular counterrolling in the right eye (C) and left eye (D) for rightward head tilt. Relative compensation, the compensation ratio, was calculated as follows: $1 - (\text{rotational change in the fundus image}/\text{actual degree of head tilt})$.

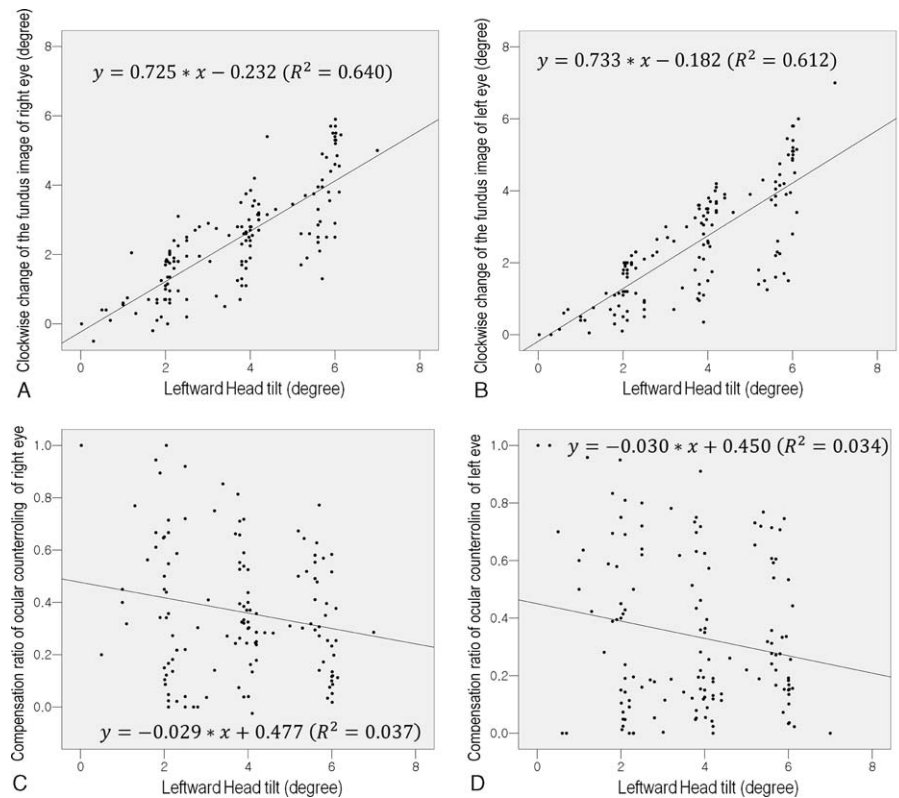


Figure 5. (A and B) Graphs showing the correlation between leftward head tilt and clockwise rotational change in the fundus photographs from the right eye (A) and left eye (B). (C and D) Scatter plots showing the relative compensation by ocular counterrolling in the right eye (C) and left eye (D) for leftward head tilt. Relative compensation, the compensation ratio, was calculated as follows: $1 - (\text{rotational change in the fundus image}/\text{actual degree of head tilt})$.

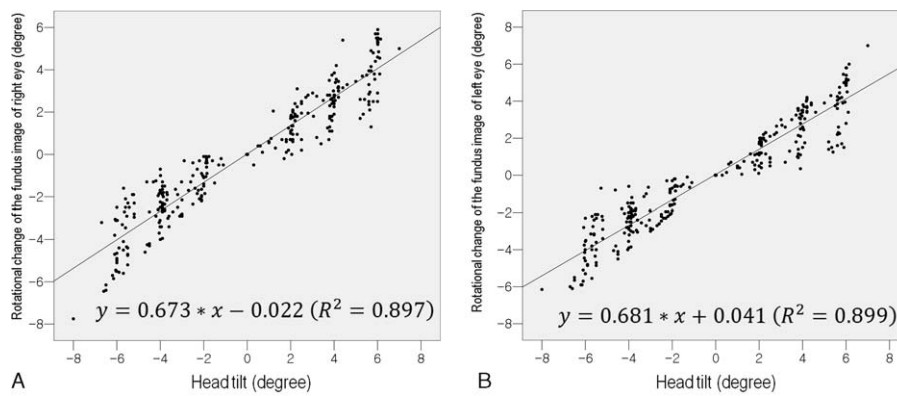


Figure 6. Graphs showing the correlation between head tilt and rotational change in the fundus photographs from the right eye (A) and left eye (B). Rightward head tilt: -, leftward head tilt: +, counter clockwise rotation: -, clockwise rotation: +.

ophthalmology and constant image acquisition of the ocular fundus has been emphasized for serial follow-up of certain diseases like glaucoma or macular disease. Thus, minimizing the ocular cyclotorsion change becomes the interest of ophthalmologists in various fields. However, there is no perfect method to control the head tilt and we cannot easily detect very small head tilt. Further, to our knowledge, the effect of small head tilt has not been investigated yet. Thus, we investigated the effects of very small head tilt that we might be unaware of, and found that even the small head tilt are variably compensated by ocular counterrolling.

The head tilt in our study was a static head tilt, as opposed to a dynamic head tilt that occurs during sinusoidal lateral tilt. The static head tilt is known to induce less compensatory counterroll

than the dynamic head tilt.^[10,11] Previous studies about the static head tilt over 10 degree reported that relative compensation by ocular counterrolling was between 13% and 22%,^[5-9] and mean compensation at 5° of head tilt was between 26% and 45%.^[12] In the present study, the mean compensation for head tilts <8° by ocular counterrolling was about 36%. In addition, compensation by ocular counterrolling showed weak but significant negative correlations with degree of head tilt. These findings support the results of previous studies, wherein the relative amount of compensatory counterrolling was higher at relatively smaller head tilts.^[5,11] However, considering that a fixation target with a visual cue on the horizon (an earth fixed target) enhances ocular counterrolling^[13,14] and the digital fundus camera in our study only provides a round light as the target, using other device

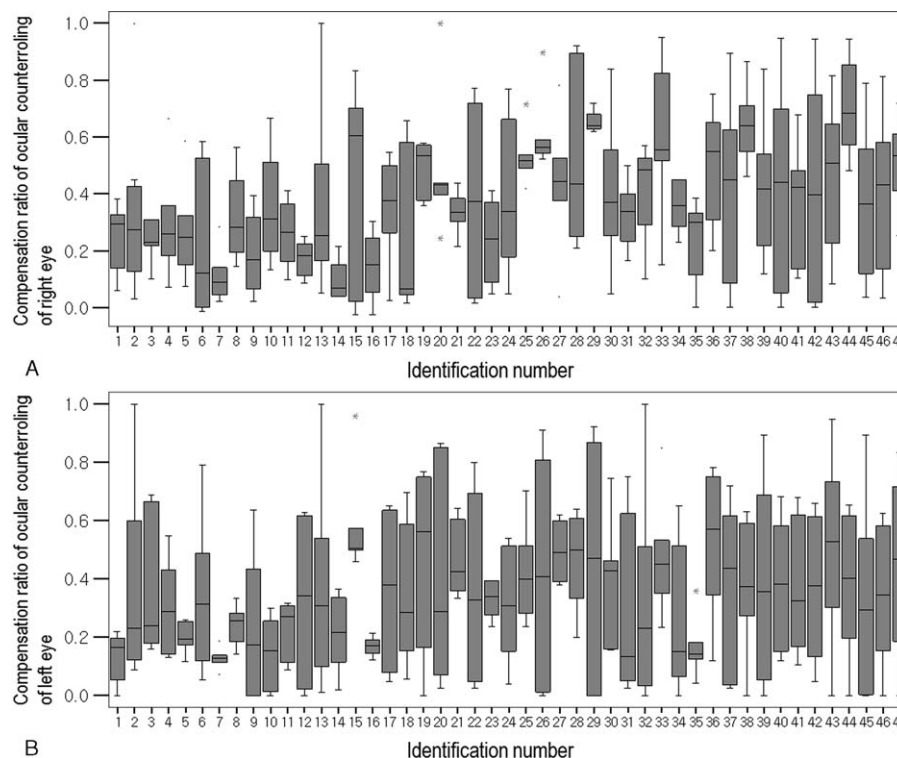


Figure 7. Box plots for each individual showing the distribution of relative compensation by ocular counterrolling for head tilt. Relative compensation, the compensation ratio, was calculated as follows: 1 - (rotational change in the fundus image/actual degree of head tilt).

providing an earth-fixed target might increase the compensation by ocular counterrolling.

Static ocular counterroll in humans has been investigated using various methods. Kingma et al^[9] used infrared video oculo-graphy with whole body rotator and reported maximum compensation of 22% at 20° of body roll. Schworm et al and Pansell et al used infrared video oculo-graphy with adjustable head tilter and reported compensation ratio between 13% and 27%.^[5–7] Fesharaki et al used tiltometer and auto refractometer and reported compensation ratio between 22% and 45%.^[10] Averbuch-Heller et al^[8] and Collewijn et al^[10] used magnetic search coil technique and reported maximum compensation of 24% and 9.6%, respectively. In the present study, to measure the degree of head tilt, we calculated the angle between horizontal meridian and a line intersecting corneal reflex points of both eyes. Based on 3 reasons, we think that our head tilt measurement method is more precise than the methods used in previous studies. First, the methods of previous studies could not measure head tilt degree to the below decimal point. Second, head tilt set to desired angle using head tilter or tiltometer may not be precise. In the present study, the actual degree of head tilt exhibited difference with the angle that the head positioner was set to. Third, as has been pointed out in a previous literature,^[15] the magnetic search technique has a possible limitation of undetected coil slippage, which leads to underestimation of ocular cyclotorsion change.

To measure the change of ocular cyclotorsion precisely, we measured the angle between horizontal meridian and a line connecting the foveola and the point where the optic disc margin and the temporal border of the superior temporal retinal vein meet. Most previous studies measured ocular cyclotorsion angle by measuring the angle between a horizontal meridian and the line connecting the foveola and the disc center. The disc center was usually defined as the geographic center of the optic disc calculated by image editing software. We did not use the geographic center of the optic disc, because the eyeball is a 3-dimensional structure that the appearance of the optic disc may change according to ocular cyclotorsion and the resultant geographic center of the optic disc may change. We used the point where the optic nerve head margin and the superior temporal retinal vein meet, because the point does not change according to ocular cyclotorsion.

In the present study, the compensation ratios in the right eye did not differ from those in the left eye. This suggests that even small head tilt produces an equal amount of ocular counterrolling reflex in both eyes. However, the relative compensation for head tilt exhibited large variations, ranging from no compensation to full compensation (compensation ratio range: –0.03 to 1.0). Moreover, the relative amount of compensation varied widely within individuals (Fig. 7). These findings suggest that small head tilt does not always constitute a sufficient stimulus for the ocular counterrolling reflex, and that small head tilt can be variably compensated for.

This study has some limitations. First, subject number is relatively small. The larger subject study may reveal more reliable results. However, to our knowledge, this study recruited largest subjects among the studies dealt with head tilt and ocular counterrolling. Second, the subjects were all young adults of similar age. Thus, the results of our study may not be applicable

to subjects of other age groups. However, we think that young age of our study subjects produced results closest to physiology and free from pathologic changes related to aging.

When interpreting results obtained from ocular imaging devices, we must consider confounding factors such as ocular cyclotorsion by the head tilt. Thus, proper head positioning has been emphasized. When we designed this study, we expected that we could get the range of head tilt degree fully compensated by ocular counterrolling reflex. However, even the small head tilt under 8° was partially and variably compensated for. Thus, we concluded that ensuring proper head positioning and providing an earth-fixed target reduces cyclotorsional change of the eyeball, but does not guarantee minimal cyclotorsional changes. We thought that image adjusting technique like “Fo-Di” (Fovea to Disc) alignment technology of Spectralis OCT (Heidelberg Engineering, German) would be a better solution for minimizing errors from ocular cyclotorsional changes.

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