Introduction

Smartphones have become a huge part of life, many people spending a large amount of time making phone calls, checking email or, for example, watching movies. Indeed, smartphone dependence is expected to increase proportionally with the projected increases in user numbers.

While viewing smartphones, sustained effort for the purpose of accommodation and ocular-surface changes such as dry eye have been known to occur. Ocular changes related to near vision are believed to result in temporary but significant intraocular pressure (IOP) fluctuations as well. A previous study on IOP changes during smartphone work noted significant increases in healthy young subjects’ IOP. Also, IOP fluctuation was found to be much greater under low-light conditions than in daylight.

Underlying ocular-structural changes occurring while reading or writing on a smartphone, however, have not yet been studied. Thus prompted, we undertook an ante-
rior-segment optical coherence tomography (AS-OCT) investigation of anterior chamber (AC) angle change during reading or writing on a smartphone.

Materials and Methods

This study was approved by the Seoul National University Hospital Institutional Review Board and faithfully adhered to the tenets of the Declaration of Helsinki. All of the participants provided their written informed consent.

Study Participants

This study was conducted on healthy volunteers who had visited Seoul National University Hospital’s Glaucoma Clinic between March and July 2017 for routine ophthalmologic examinations. The eligible participants were under the age of 40, had normal near vision in both eyes, and showed no abnormal findings in any ophthalmic examinations. Patients were excluded for any of the following reasons: history of any ocular pathology; intraocular surgery or significant trauma; any associated systemic disease. When both eyes of a subject proved eligible, right eyes were selected for the study.

Prior to experimentation, all of the subjects underwent a complete ophthalmic examination: visual acuity assessment, refraction, slit-lamp biomicroscopy, gonioscopy, Goldmann applanation tonometry (Haag-Streit, Koniz, Switzerland), and funduscopic examination. Additionally, they underwent central corneal thickness measurement (CCT: Orbscan 73 II, Bausch & Lomb Surgical, Rochester, NY, USA) and Visante AS-OCT (Carl Zeiss Meditec, Inc. Dublin, CA, USA).

Protocols of Smartphone Work

A single smartphone (Samsung Galaxy S6, Samsung Electronics Co., Ltd., Seoul, Korea; 5.1-inch screen, 577 ppi pixel resolution) with a customized brightness setting (432 cd/m²) was used. The participants were instructed to perform standardized work (i.e., to read a sample text on a smartphone and, subsequently, to type it on the same device) in their habitual posture. At the outset of the experimentation, the viewing distance (from smartphone to subject’s right eye) and head posture (angle difference between upright head position and viewing head posture) were evaluated. During smartphone usage, participants were directed to maintain the same distance and head posture. All of the experiments were conducted under a low-light (luminance level: 100 lux) condition.

On each smartphone screen, an English-language article was presented. The text font was 1.5 mm in size (i.e., the vertical height of a lowercase letter without ascenders or descendeds, as measured through a +20 diopter [D] lens with a ruler and of black color on a white background. The lines were double-spaced. For the purpose of sustaining the participants’ concentration on the screen, they were asked to type the sentences continuously as they appeared.

AS-OCT Imaging

AS-OCT imaging was performed under the low-light condition by a single operator who was blind to the participants’ clinical information. Baseline AS-OCT imaging was undertaken after 5 minutes of darkness adaptation by the subject. Scans were centered on the pupil, and were obtained along the horizontal (nasal-temporal angles at 0-180°) and vertical (superior-inferior angles at 90-270°) axes according to the standard anterior-segment single-scan protocol. As the eyelids can interfere with acquisition of AS-OCT images in the 90-270° positions, the operator moved the upper and lower lids gently out of the way in order to image the inferior/superior angle, taking special care to avoid inadvertent pressure imparted to the globe. To obtain the best-quality image, the examiner, for each scan, performed saturation and noise adjustment as well as polarization optimization. The best images chosen were those showing the least eyelid motion and the fewest image artifacts. The same lighting condition and scan protocol were applied for the AS-OCT examination of the baseline and post-smartphone work. A single glaucoma specialist (Y.K.K.) masked to the subjects’ clinical data analyzed the AS-OCT parameters, which included the trabecular–iris space area (TISA750), angle-opening distance (AOD750), iris thickness (IT750), and iris curvature at the horizontal...
and vertical axes, as described in previous studies.\textsuperscript{5,6}

**Measurements of IOP**

An experienced glaucoma specialist (AH) measured IOP using a hand-held, anesthetic-free rebound tonometer (iCare PRO; Tiolat, Helsinki, Finland). To avoid bias, the investigator was blind to the resultant values, which were recorded by an independent observer (S.U.B). All of the participants were instructed to maintain, in an upright sitting posture, a contra-lateral-eye view of the smartphone screen during the IOP measurement. The IOP reading was obtained by contact of the probe tip with the central cornea, with minimal eyelid manipulation. Each IOP value was measured in the series mode: the final value was calculated by taking 6 automatic measurements, discarding both the highest and the lowest readings, and averaging the remaining 4.\textsuperscript{7}

The subjects underwent 3 sets of IOP measurements: 1) pre-work (baseline) (2 measurements), 2) during smartphone work (5, 15 and 25 minutes), and 3) post-work (5 and 15 minutes). The pre-work IOP was measured after 5 minutes’ low-light adaptation, and the value averaged from the two measurement series was taken as the final pre-work IOP.

**Statistical Analysis**

Longitudinal IOP changes were compared between pre-work and each interval value by Wilcoxon signed rank test. The extents of IOP change at the various time points were compared by Friedman test. The statistical analysis was performed with the SPSS statistical package (IBM SPSS ver. 22.0; IBM Corp., Armonk, NY, USA). A \( p \)-value less than 0.05 was considered to be statistically significant, unless the Bonferroni correction method for multiple comparisons was used, in which case a value less than 0.017 was the standard.

**Results**

A total of 21 participants (21 eyes) took part in the current study. Their mean age was 28.6 ± 4.1 (range: 22-38) years; 11 were men (52.4%) and 10 women (47.6%). The participants’ demographic and clinical data are both summarized in the Table 1.

The post-smartphone-work ocular anatomic features (i.e., TISA750, AOD750, IT750, and iris curvature) under the low-light condition were as follows. After 15 minutes of smartphone work, the average TISA750 and AOD750 had decreased, from 0.22 to 0.19 mm\(^2\) (\( p < 0.001 \)) and from 0.57 to 0.41 mm (\( p < 0.001 \)), respectively; meanwhile, the average IT750 and iris curvature values had increased, from 0.50 to 0.54 mm (\( p < 0.001 \)) and from 0.20 to 0.22 mm (\( p = 0.001 \)), respectively (Fig. 1).

The pre-work mean IOP under the low-light condition was 13.9 ± 1.9 (range: 10.3-16.8). The mean IOP significantly increased immediately after 5 minutes of smartphone work (15.5 ± 1.7 mmHg; \( p = 0.03 \)), which change represented a 12.0\% increment from the pre-work value. This IOP elevation continued throughout the work: at 15 and 25 minutes, the mean IOP readings were 17.6 ± 2.1 (+27.0\%) and 17.1 ± 1.7 mmHg (+23.7\%) mmHg, respectively. The degrees of IOP increment were found to be statistically significant (\( p < 0.001 \) at both check-out points). Interestingly, 5 minutes after ceasing work, the mean IOP had dropped below the pre-work level (12.8 ± 1.9 mmHg; \( p < 0.001 \)), which difference represented an 8.3\% IOP reduction. The IOP returned to the pre-work level 15 minutes after cessation of work (13.9 ± 1.8 mmHg; -0.3\%; \( p = 1.00 \); Figs. 2, 3).

**Discussion**

A previous study on IOP change during smartphone work...
noted significant fluctuation in healthy young subjects. The present study demonstrated, moreover, that smartphone work in dark environment can induce both further pupillary dilatation and iris-structural alterations relative to the baseline results. Such AC-structural changes can be considered to be among the underlying mechanisms of IOP fluctuation incurred while engaging in reading or writing on a smartphone.

Ocular anatomic feature changes such as pupil diameter increase and iris thickening in darkness have been documented. However, it was clear from our AS-OCT parameters recorded before and after smartphone work that further

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**Figure 1.** Representative optical coherence tomography (AS-OCT) images for horizontal and vertical cross-sections of anterior segment in 30-year-old healthy female subject. The first row contains pre-work AS-OCT images under the low-light condition; the second row shows anterior-segment images after 15 minutes of smartphone work under the low-light condition. Min = minutes.

**Figure 2.** Graph depicting changes of IOP among 21 eyes during and after smartphone work under low-light condition (A). Graph showing IOP fluctuation during and after smartphone work, with pre-work IOP values in all participants converted to zero (B). Note that the X-axis is not to scale but simply depicts the times at which the IOPs were measured during and after the smartphone work. IOP = intraocular pressure.
Pupillary dilatation and iris-structural changes occur. The most remarkable differences after working on smartphone in a dark environment are increased pupil size, iris thickening and, thus, a more crowded angle structure. In diseases associated with abnormal AC angle width, angle width is correlated directly with extent of IOP fluctuation: narrower angles mean greater IOP fluctuation. It is known that, even in eyes with a normal open AC angle, various external factors including illuminance and changes in body or head position can effect IOP change. For example, normal subjects seated for an hour in a completely dark room showed apparent IOP rise. It is suspected, therefore, that if the AC angle structure becomes narrower while one is engaged in smartphone work under a low-light condition, transient IOP increase can occur, even in normal eyes.

Accommodation occurs when an eye tries to focus at near. Focusing on near objects induces 2-4 mmHg increase in IOP with a subsequent, small decrease of pressure level. Along with changes in IOP, reports of AC depth decrease, lens thickness increase as well as anterior movement of the anterior pole of the lens during accommodation are well documented. Such structural alterations also can contribute to AC angle crowding. Smartphones’ small screen size requires small font sizes, leading to closer viewing distances, which in turn increases the demands on accommodation. Thus, accommodation increase during smartphone work might affect IOP fluctuation as well as AC angle change.

In most cases, smartphone work is performed below eye level with the neck in the flexion posture. It has been found that in the course of smartphone work, an average neck flexion 33-45° from the vertical was maintained. The body and head positions influence IOP, and in the neck-flexion posture, IOP significantly increases relative to the neck-extension or neutral posture. Orienting the head with the face downward can allow movement of the lens/iris diaphragm anteriorly and narrowing of the AC angle structure. The prone position increases episcleral venous pressure, which further contributes to elevated IOP. Thus, viewing head posture also can be a factor affecting IOP rise and AC change during smartphone work.

The present study’s findings should be interpreted with...
due consideration for its limitations. First, factors including the type of smartphone, the screen size, screen resolution and brightness can affect AC angle structure. Thus, further studies on larger patient cohorts and under diverse experimental conditions would be expected to obtain more comprehensive information on the relationship between AC angle structure and smartphone usage. Second, elderly people with presbyopia and narrow-angle subjects might show, during smartphone usage, distinct patterns of IOP change as well as AC-structural change. Additional research on different subject groups, therefore, is prerequisite to any firm conclusions being drawn. Third, iris parameters under dark-light changes reflect ethnic differences.

In the current study, all of the subjects were Korean. Our results, accordingly, might not be directly applicable to other ethnicities. To conclude, during smartphone work under a low-light condition, IOP fluctuation can occur in healthy young subjects, which change might be associated with alterations of the AC angle structure.

References