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Optimising the methodology for assessing tear meniscus height using digital imaging

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ABSTRACT

Purpose: To determine the optimum method for assessing tear meniscus height using digital imaging.
Method: The tear meniscus of 38 participants (mean age 32.5 ± 10.6 years, 45 % male) was video recorded three times, each for a period of five seconds following two natural blinks using the Oculus Keratograph 5M, first with infrared and subsequently with visible (white) light. Still images at 0.5 s intervals from the last blink, up to 5 s, were extracted from the video recording and the lower eyelid tear meniscus height was measured using ImageJ at seven locations; immediately below pupil centre and at 1 mm, 3 mm and 6 mm, nasally and temporally. Dryness symptoms were assessed with the Ocular Surface Disease Index (OSDI) and tear film stability with non-invasive tear breakup time with the Oculus Keratograph 5M.
Results: A significant difference in the tear meniscus height was measured with infrared (0.29 ± 0.08 mm) compared to white light (0.27 ± 0.08 mm; $p < 0.001$). Tear meniscus height increased significantly with repeated measurement (first: 0.27 ± 0.08 mm; second 0.27 ± 0.08; 0.28 ± 0.09; $p = 0.005$). In each case, following a significant decrease immediately after a blink, the tear meniscus height was stable between 1.0 and 2.5 s and increased thereafter ($p < 0.001$). A consistent tear meniscus height measurement was achieved by measuring within 1 mm of the pupil midline, but increased more peripherally ($p < 0.001$). Differences in height, while statistically significant, were not clinically significant except in the peripheral measurements.
Conclusion: Tear meniscus height should be measured in a consistent manner, either with infrared or white light. A single measurement from the top of the meniscus to the eyelid margin within 1 mm of the pupil midline, from an image captured 1.0 to 2.5 s after two blinks, is sufficient.

1. Introduction

The tear film is critical for the hydration, nutrition and anti-microbial protection of the cornea, hence a reduction in its volume can result in ocular surface disease. While tear volume has traditionally been assessed with the Schirmer test or phenol red thread test, these are invasive and can trigger reflex tearing [1]. They are therefore not recommended as suitable tests to assess tear volume in clinical practice [1]. Phenol red thread test results are only weakly correlated with other established methods such as tear meniscus height and fluorophotometry [2,3] and the Schirmer test has poor repeatability, sensitivity and specificity [1]. As approximately 75–90 % of the tear film volume is held in the lower lid tear meniscus [4,5], assessment of the lower tear meniscus height is considered a non-invasive surrogate for tear volume estimation in the clinical setting [6]. This is easily performed with direct observation, ideally with a digital imaging camera, but can also be conducted non-invasively with optical coherence tomography [7,8]. The height of the meniscus is reduced in patients with aqueous deficient dry eye [9]. The Tear Film & Ocular Surface Society (TFOS) Dry Eye Workshop (DEWS) II Diagnostic Subcommittee proposed tear meniscus height assessment as the key subtype differentiator for aqueous-deficient dry eye disease, with a cut-off value of 0.20 mm or lower, which has subsequently been confirmed by a number of studies [1,10,11]. It has been suggested that tear meniscus height should be measured directly below the pupil midline to avoid artefact arising from more peripheral lid morphologies such as lid-parallel conjunctival folds [12–15]. The

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optimal timing of the assessment after a blink has not been established, but a time of 3–4 s has been proposed [16].

This study aimed to determine the optimum digital imaging method for assessing the tear meniscus height, by evaluating the impact of: 1. the illumination source (infrared or white light), 2. Consecutive measurements; 3. the time between a blink and meniscus height measurement, and 4. the location along the lower lid margin at which the measurement is taken.

2. Methods

All procedures were conducted at the Aston and Cologne Schools of Optometry Eye Clinics according to the Helsinki Declaration for Experimentation on Humans, and the study was approved by the Aston University Research Ethics Committee. Prior to commencement, all participants provided written informed consent, after being provided ample time to review and comprehend the Participant Information Sheet.

Eligibility required participants to be over 18 years of age and without active ocular surface disease other than dry eye or use of any medication that could affect the ocular surface or tear film. Experienced contact lens wearers were asked to remove their lenses at least two hours before starting the assessments and could wear lenses after the completion of the tests.

The study involved a single visit for each of 38 participants (mean age 33 ± 11 years, 45 % male, 83 % Caucasian and 17 % West Asian). The tear meniscus was video recorded using the Keratograph 5M (Oculus, Wetzlar, Germany) three times following two natural blinks, first under infrared conditions and subsequently with white light (due to the potential for reflex tearing with white light). Still images were extracted from the video recordings at 0.5 s intervals from the last blink, up to 5 s and the perpendicular distance from the lower eyelid margin to the tear meniscus apex was measured using the length tool in ImageJ (https://imagej.net/ij/; NIH, Bethesda, MD, USA) directly beneath the pupil centre and 1 mm, 3 mm and 6 mm nasally and temporally. The ImageJ tool was calibrated using a ruler imaged with the Keratograph 5M for pixel-to-millimetre conversion, and all measurements were performed by a single trained observer to ensure consistency. The repeatability of this observer's measurements was assessed 10 times on a single image, with the 95 % confidence interval found to be 0.007 mm. Dryness symptoms were assessed with the Ocular Surface Disease Index (OSDI) questionnaire and tear film stability with the average of three separate non-invasive tear breakup time measurements with the Oculus Keratograph 5M.

2.1. Statistical analysis

The data were analysed using IBM SPSS Statistics (v29, Chicago, IL, USA). Normality of the data distribution was confirmed with the Kolmogorov–Smirnov test ($p > 0.05$), and data between repeated measurements, with varying illumination spectra, with time from a blink, and across lateral eyelid position visits, were compared with repeated measures analysis of variance. A p value of <0.05 was considered statistically significant. Based on 11 measurements over time and a minimum of two comparisons with a repeated measures analysis of variance, the required sample size was 20 participants (G*Power v3.1.9.6 Universität Kiel, Germany).

3. Results

Participants had an average OSDI score of 22.9 ± 18.8 (range 0.0 to 59.1) and non-invasive breakup time 11.5 ± 6.0 s (range 2.8 to 22.7 s). Based on these two assessments, 13 (34 %) met the Tear Film and Ocular Surface Society Dry Eye Workshop II diagnosis of dry eye disease. Tear meniscus height was <0.1 mm in 0.7 % of measurements, between 0.1 and 0.2 mm in 16.9 %, between 0.21 and 0.3 mm in 50.1 %, between 0.31 and 0.4 mm in 24.2 % and >0.4 mm in 8.0 % of eyes.

Tear meniscus height measured significantly higher with infrared (0.29 ± 0.08 mm) than with white light (0.27 ± 0.08 mm; $p < 0.001$). Tear meniscus height increased significantly with repeated measurement (mean infrared and white light values for first: 0.27 ± 0.08 mm; second 0.27 ± 0.08; and third 0.28 ± 0.09 assessment; $p = 0.005$; Fig. 1).

After a significant decrease in height immediately following a blink with either infrared or white light ($p < 0.001$), the tear meniscus height remained stable between 1.0 s and 2.5 s ($p > 0.15$) and then increased ($p < 0.001$; Fig. 2).

A consistent tear meniscus height measurement was achieved by measuring within ± 1 mm of the pupil midline ($p > 0.15$), but heights increased at more peripheral locations ($p < 0.001$) (Fig. 3). Mean central tear meniscus height (0.26 ± 0.07 mm) did not differ from the mean of the three measurements within ±1mm of centre (0.26 ± 0.05 mm; $p = 0.534$).

4. Discussion

This study aimed to determine the optimum digital imaging methodology for assessing the tear meniscus height. In examining the illumination spectrum (infrared or visible white), the order was purposely not randomised as the homeostasis of the tear film is easily disrupted; it was felt that refraining from blinking for at least 5 s while illuminated with white light could stimulate reflex tearing. However, the measured tear meniscus height was systematically lower with white light than under infrared light despite a 5.4 times higher overall irradiance and higher energy wavelengths (Fig. 4). This might suggest possible optical artefact in the way in which tear meniscus height is visualised under white light compared to infrared. This highlights the importance of using the same device and conditions for measurements each time whether within a practice setting, following up patients and monitoring treatment effects, or in the research setting.

Taking multiple consecutive measurements from images at 0.5 s intervals resulted in a small, but statistically significant progressive increase in tear meniscus height. A progressive increase in tear meniscus height was expected with multiple measures over time as the tears settle back to the meniscus. The repeatability of three measurements within ±1 mm of the pupil's vertical midline from a single image was high (<0.005 mm 95% confidence interval), hence a single measurement on the lower eyelid margin at the vertical midline of the pupil from a single image capture is sufficient as a clinical index of whether or not there is aqueous deficiency. While the statistically significant differences noted over time after a blink were less significant clinically, maximum consistency was observed between 1.0 and 2.5 s following two non-forced blinks suggesting this is the optimal time within which to capture the measurement. The slight increase with time had been noted previously, but in a study that used 2% fluorescein to enhance the visibility of the

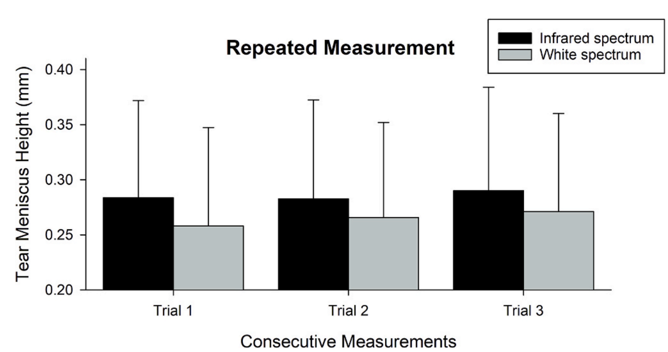

Fig. 1. Tear meniscus heights measured following two natural blinks, under infrared and white light conditions, for three successive trials. N = 38. Error bars = ±1 standard deviation.

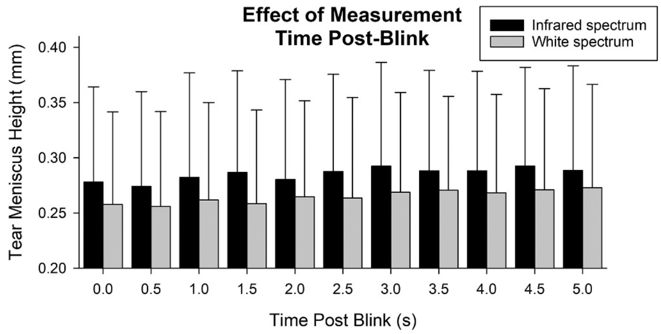

Fig. 2. Mean tear meniscus heights, as assessed under infrared and white light conditions, according to time of measurement, following two natural blinks (n = 38). Error bars = ±1 standard deviation.

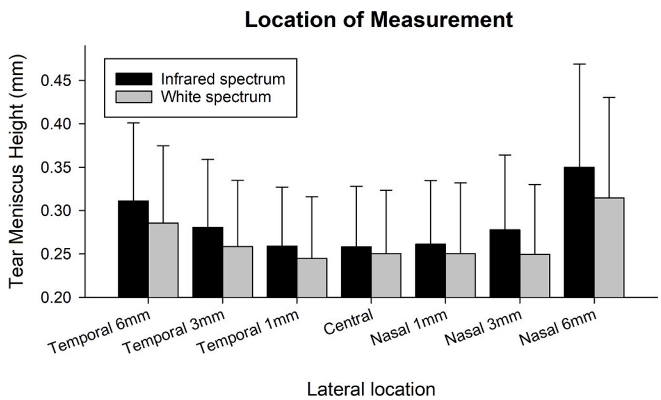

Fig. 3. Mean tear meniscus heights as measured directly below pupil centre, and at varying distances from centre, nasally and temporally, under infrared and white light conditions for n = 38. Error bars = ±1 standard deviation.

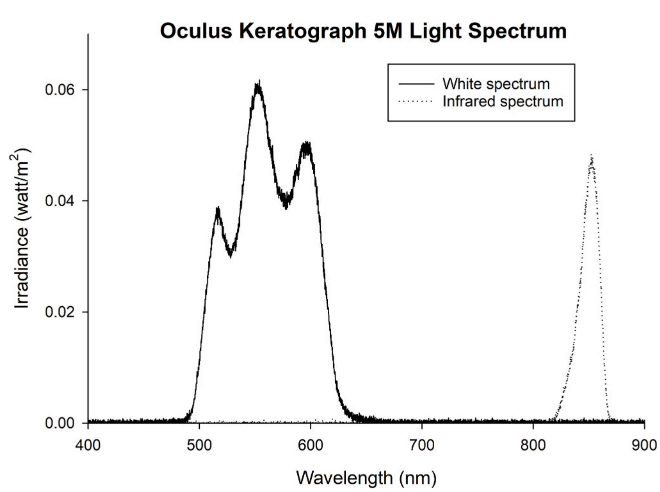

Fig. 4. White and infrared spectrum emitted by the Oculus Keratograph 5M illumination measured with Maya2000 Pro spectrometer (Ocean Optics, Orlando, Florida, USA).

tear meniscus [16], which might explain the longer time of between 3 and 4 s recommended to visualize tear meniscus height.

The current study was limited by the use of only one digital imaging device to capture the tear meniscus height, but the findings are likely translatable to the majority of instruments for assessing the anterior eye such as slit-lamp biomicroscopes and dedicated dry eye/corneal topography systems. Measurement after two gentle (non-forced) blinks was selected as this patient instruction is commonly used by automated devices for triggering commencement of the timer for non-invasive breakup time measurements, but this instruction itself was not investigated to determine whether it is optimal. The participants included those with a wide range of dryness symptoms and tear film stabilities, so the results are expected to be widely generalisable in dry eye detection and monitoring. The average changes identified were small except for the peripheral measurements, so while statistically significant, most are unlikely to be clinically significant. The inter-observer and inter-session reproducibility has been found to be high when using the Keratograph 5M with the coefficient of variation being around just 0.2% [17].The impact of environmental conditions such as humidity and temperature on tear meniscus height has not been assessed, although previous research suggests the tear meniscus height is robust to changes in humidity and exposure to airflow [18].

In conclusion, this study provides evidence to suggest that a single measurement of tear meniscus height at the lower eyelid margin, performed consistently in a clinic with either infrared or moderate intensity visible white light, is clinically sufficient to determine whether the meniscus height is above or below the recommended 0.2 mm threshold that indicates aqueous deficiency in an individual. The measurement should be made within ± 1 mm of the vertical midline of the pupil from an image captured between 1.0 and 2.5 s after requesting the patient blinks twice.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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