Original Article

Strip meniscometry in dry eye disease: correlations with standard diagnostic tests

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ABSTRACT

Background: Dry eye disease (DED) is a multifactorial condition with a globally rising prevalence. Diagnosis relies on both symptoms and clinical tests, but these methods demonstrate variability. Strip meniscometry (SMTube) represents a rapid, non-invasive alternative method, but its diagnostic value remains uncertain. We evaluated the correlation of its findings with those of established DED evaluations.

Methods: In this cross-sectional study, we recruited 100 individuals with and without DED (n = 50 each) who visited a tertiary ophthalmology clinic. Diagnosis of DED was based on symptomatology and standard criteria, including a tear break-up time (TBUT) < 5 s or Schirmer test I result < 5 mm, along with an Ocular Surface Disease Index (OSDI) score > 12 and corneal fluorescein staining grade > 1. The exclusion criteria included ocular surgery, allergy, or contact lens use. All participants underwent comprehensive ophthalmic examination and standardized DED assessments (OSDI, tear meniscus height [TMH], SMTube, TBUT, corneal fluorescein staining, and Schirmer test I), conducted in a controlled setting by a single examiner during 9–11 AM to ensure consistency.

Results: The DED group was significantly older ($P < 0.05$). No significant sex difference was observed between groups ($P > 0.05$). The OSDI, TMH, SMTube, TBUT, corneal fluorescein staining, and Schirmer test I findings differed significantly (all $P < 0.001$), while SMTube application discomfort rates were similar between groups ($P > 0.05$). In the DED group, SMTube correlated moderately with TBUT ($r = +0.41$, $P < 0.05$) and OSDI ($r = +0.43$, $P < 0.05$), while the Schirmer test I correlated weakly with TBUT ($r = +0.34$, $P < 0.05$) and moderately with TMH ($r = +0.52$, $P < 0.05$). In the controls, no significant correlations were observed between tear metrics and SMTube or Schirmer test I findings (all $P > 0.05$), except for corneal fluorescein staining, which showed a weak negative correlation with SMTube ($r = -0.28$, $P < 0.05$) and a moderate positive correlation with Schirmer test I findings ($r = +0.51$, $P < 0.05$).

Conclusions: SMTube findings differed significantly between the DED and control groups and correlated moderately with those of established diagnostic assessments, particularly the TBUT and OSDI. Unlike Schirmer testing, SMTube results are closely associated with symptom severity, suggesting its utility in reflecting patient-reported discomfort. Given its simplicity, non-invasiveness, and correlation with key clinical indicators, SMTube may serve as a valuable adjunct in the multimodal assessment of DED. However, further studies are needed to establish its diagnostic accuracy and to confirm its clinical utility.

KEYWORDS

dry eye disease, strip meniscometry, schirmer test, ocular surface disease index, tear break-up time, tear meniscus height, data correlation

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INTRODUCTION

Dry eye disease (DED) is a multifactorial disorder of the ocular surface that is characterized by a loss of tear film homeostasis and is accompanied by symptoms such as eye discomfort, visual disturbance, and tear film instability, potentially involving damage to the ocular surface [1-3]. The prevalence of DED is rising globally, particularly among aging populations and those with increased screen time or environmental exposures [4]. Accurate diagnosis and severity assessments are critical, as DED negatively impacts individuals' quality of life and imposes substantial healthcare costs [5, 6].

DED evaluation relies on a combination of subjective symptom assessments and objective clinical tests. The Ocular Surface Disease Index (OSDI) questionnaire is widely used to quantify symptom severity and functional impact [7]. Common diagnostic parameters include the tear break-up time (TBUT), Schirmer test I, corneal fluorescein staining grade, and tear meniscus height (TMH), each of which captures distinct pathophysiological aspects of the disease [8, 9]. However, these tests may vary in sensitivity and reproducibility, and their relationships to one another are not yet fully established [10, 11].

Strip meniscometry (SMTube) has emerged as a rapid, non-invasive method for assessing tear volume by measuring capillary tear uptake from the lower tear meniscus [12]. Compared to traditional methods, such as Schirmer testing or TMH evaluation, the SMTube is less time-consuming and does not require anesthesia, potentially enhancing patient comfort and increasing clinical utility [10, 13-15]. An SMTube measurement below the 2.5-mm threshold has been suggested to serve as a practical clinical marker for the preliminary screening of DED [12]. Nevertheless, its diagnostic accuracy and its correlation with established DED assessments require further validation.

In this study, we compared SMTube with traditional DED assessments in a clinical population comprising individuals with and without DED. Specifically, we examined the associations between SMTube or Schirmer test I values and other diagnostic parameters, including the TBUT, TMH, OSDI scores, and corneal fluorescein staining grades. By investigating the interrelationships among these tests, we sought to determine the diagnostic value of SMTube and its potential utility in the multimodal assessment of DED.

METHODS

In this cross-sectional study, we recruited consecutive individuals with and without DED who were referred to the ophthalmology clinic of a tertiary hospital between September 2019 and September 2020. The study protocol was approved by the relevant institutional review board and adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all participants prior to enrollment.

Participants with DED were identified based on the presence of dry eye symptoms and meeting the following diagnostic criteria: a Schirmer test I result < 5 mm [9, 16] or TBUT < 5 s [8, 17], along with an OSDI score > 12 [7, 18] and a corneal fluorescein staining grade > 1 [19]. Control participants without DED were selected from patients referred to the ophthalmology clinic for unrelated reasons, such as refractive errors, spectacle prescriptions, or cataract surgery. The exclusion criteria were a history of atopy or allergy; Stevens–Johnson syndrome; thermal, chemical, or radiation injuries; previous ocular surgery or corneal transplantation; use of topical ocular medications other than artificial tears; current contact lens wear; or unwillingness to participate.

All participants underwent a comprehensive ophthalmological evaluation performed by a cornea fellowship-trained ophthalmologist (S.H.D.). The assessments included manifest refraction, using an auto-kerato-refractometer (KR-800; Topcon Co., Tokyo, Japan); measurement of uncorrected and best-corrected distance visual acuity, using a Snellen chart (CP-770; NIDEK Co., Ltd., Gamagori, Japan), in decimal notation; and intraocular pressure measurement, via Goldmann applanation tonometry (Haag-Streit, Koeniz, Switzerland). Anterior and posterior segment examinations were conducted using slit-lamp biomicroscopy (BQ 900, Haag-Streit), followed by a dilated fundus examination with a 78-diopter lens (Volk Optical Inc., Mentor, OH, USA).

DED Evaluation Protocol: DED-specific assessments were performed between 09:00 and 11:00 under controlled conditions (room temperature: 21–24°C; humidity: 40–60%), by the same examiner (S.H.D). The sequence of evaluations included administration of the OSDI questionnaire, followed by determination of the TMH, SMTube, TBUT, corneal fluorescein staining, and Schirmer test I values.

The OSDI questionnaire [7] was administered by the examiner. This questionnaire includes 12 questions related to ocular symptoms, visual function, and environmental triggers [7]. Scores were calculated according to the standard formula and were recorded. The TMH was measured using slit-lamp biomicroscopy following a standardized technique [20]. The slit beam (0.05-mm width, 5-mm height) was positioned at a 90° angle to the central portion of the lower tear meniscus, with magnification set to 32×. A graticule scale, integrated into the ocular eyepiece, with 0.2-mm interval markings was used for direct measurements [20].

The inferior tear meniscus volume was assessed using the SMTube (SMTube; Echo Electricity, Shirakawa, Japan), a single-use diagnostic device featuring a central micro-channel with a 20-μm aperture and hydrophobic sidewalls that guide tear fluid exclusively along the central channel [12]. Upon insertion of the tube into the lower tear meniscus, tear fluid ascends the channel via capillary action and is stained blue by a dye at the top of the strip, to allow visual measurement. A millimeter scale printed on the strip allows for direct reading of the wetting length. The tip of the strip was gently placed on the lateral

Figure 1. Measurement of the tear meniscus volume using the strip meniscometry tube (SMTube; Echo Electricity, Shirakawa, Japan). The SMTube features a central channel with a 20-μm aperture and with hydrophobic sides to restrict tear infiltration into the periphery. Upon insertion into the tear meniscus of the lateral third of the lower eyelid, while avoiding contact with the cornea and conjunctiva, tear fluid ascends the central channel by capillary action and is stained blue allowing visual assessment. A millimeter scale printed on the side of the strip allows immediate measurement after 5 s of contact.

third of the lower eyelid margin, without touching the ocular surface. It was held in place for 5 s, and then removed immediately. The length of the blue-stained wetting on the strip was measured directly in millimeters (Figure 1) [21, 22]. Participants were also queried about any sensation of discomfort, itching, pain, or awareness during this test, with responses coded as 1 (positive) or 0 (negative).

To record the TBUT, a 2-μL aliquot of 1% fluorescein dye was instilled into the conjunctival sac via a micropipette. Individuals were instructed to blink three times to ensure even dye distribution across the ocular surface. Using slit-lamp biomicroscopy with a cobalt blue filter, the time from the last blink to the first appearance of a corneal dark spot, indicating tear film disruption, was measured by using a stopwatch. The mean of three measurements was calculated. A TBUT ≤ 5 s was considered indicative of DED [8]. Corneal fluorescein staining was evaluated using the National Eye Institute/Industry Workshop grading scale, with a score ranging from 0 to 3 assigned based on the density and distribution of punctate staining [19].

The Schirmer test I was performed without anesthesia to measure reflex tear production. A standardized filter paper strip (5 × 35 mm), folded 5-mm from one end, was placed at the junction of the middle and lateral third of the lower eyelid margin, while avoiding corneal contact [9]. Participants closed their eyes for 5 min, after which the length of the wetted portion was recorded in mm. A reading < 10 mm was considered abnormal [16].

IBM SPSS Statistics for Windows, version 20.0 (IBM Corp., Armonk, NY, USA) was used for data analysis. The normality of data distribution of continuous variables was assessed with the one-sample Kolmogorov–Smirnov test. Descriptive statistics are reported as numbers, percentages, means, and standard deviations (SD), as appropriate. Groups were compared using independent-samples *t*-tests for normally distributed variables or non-parametric equivalents for non-normally distributed variables. Correlations between quantitative variables were analyzed using Spearman's rank correlation coefficient test. A two-sided *P*-value < 0.05 was considered statistically significant.

RESULTS

In total, 100 participants, comprising 50 healthy controls and 50 patients with DED, were enrolled. Of these, 46% (n = 46) were men and 54% (n = 54) were women. The overall mean (SD) age was 49.9 (17.1) years; the mean (SD) ages for male and female participants were 55.2 (12.3) and 44.5 (19.6) years, respectively. Participants in the DED group were significantly older than those in the control group (55.2 [12.3] vs. 44.6 [19.6] years; $P < 0.05$). The sex distribution did not differ significantly between the groups (DED: 40% men [n = 20], 60% women [n = 30]; controls: 52% men [n = 26], 48% women [n = 24]) (Table 1).

All measured clinical parameters showed statistically significant differences between the DED and control groups (all $P < 0.001$) including the OSDI score, TMH, SMTube value, TBUT, corneal fluorescein staining grade, and Schirmer test I results. In contrast, the proportion of participants reporting any discomfort during SMTube application was similar in both groups ($P > 0.05$). Detailed values for these comparisons are provided in Table 1.

Table 1. Demographic and clinical variable data for the study groups

Variable	DED (n = 50)	Control (n = 50)	*P*-value
Age (y), Mean ± SD	55.2 ± 12.3	44.6 ± 19.6	**0.002**
Sex (Male / Female), n (%)	20 (40) / 30 (60)	26 (52) / 24 (48)	0.229
OSDI (score), Mean ± SD	17.3 ± 3.9	7.5 ± 3.3	**< 0.001**
TMH (mm), Mean ± SD	0.2 ± 0.2	0.9 ± 1.0	**< 0.001**
SMTube (mm), Mean ± SD	2.8 ± 0.8	6.0 ± 1.3	**< 0.001**
SMTube Sensation (Yes / No), n (%)	9 (18) / 41 (82)	10 (20) / 40 (80)	0.799
TBUT (s), Mean ± SD	4.2 ± 0.9	16.6 ± 2.4	**< 0.001**
Corneal fluorescein staining (0 to 3), n (%)	0 (0) / 8 (16) / 38 (46) / 4 (8)	44 (88) /6 (12) / 0 (0) / 0 (0)	**< 0.001**
Schirmer test I (mm), Mean ± SD	4.0 ± 1.9	19.3 ± 5.1	**< 0.001**

Abbreviations: DED, dry eye disease group; y, years; SD, standard deviation; n, number; %, percentage; OSDI, ocular surface disease index, TMH, tear meniscus height; mm, millimeters; SMTube, strip meniscometry; TBUT, tear break-up time; s, seconds. Note: *P*-values < 0.05 are shown in bold.

Table 2. Correlation between SMTube or Schirmer test I values with TBUT, TMH, OSDI score, or corneal fluorescein staining

Variables	TBUT		TMH		Corneal fluorescein staining		OSDI score	
	DED	Control	DED	Control	DED	Control	DED	Control
SMTube	r = + 0.41, ***P* = 0.004**	r = + 0.20, *P* = 0.173	r = + 0.21, *P* = 0.142	r = + 0.04, *P* = 0.761	r = - 0.02, *P* = 0.897	r = - 0.28, ***P* =0.048**	r = + 0.43, ***P* = 0.002**	r = - 0.18, *P* = 0.207
Schirmer test I	r = + 0.34, ***P* = 0.015**	r = - 0.05, *P* = 0.717	r = + 0.52, ***P* < 0.001**	r = + 0.03, *P* = 0.843	r= + 0.06, *P* = 0.694	r = + 0.51, ***P* < 0.001**	r = - 0.12, *P* = 0.167	r = - 0.18, *P* = 0.205

Abbreviations: SMTube, strip meniscometry; TBUT, tear break-up time, TMH, tear meniscus height, OSDI, ocular surface disease index; DED, dry eye disease group. Note: *P*-values < 0.05 are shown in bold.

The correlations between the SMTube and Schirmer test I values and other clinical parameters (TBUT, TMH, OSDI score, and corneal fluorescein staining grade) are summarized in Table 2. In the DED group, SMTube correlated moderately with TBUT (r = +0.41, $P < 0.05$) and OSDI (r = +0.43, $P < 0.05$), while the Schirmer test I correlated weakly with TBUT (r = +0.34, $P < 0.05$) and moderately with TMH (r = +0.52, $P < 0.05$). In the control group, no significant correlations were observed between the TBUT, TMH, or OSDI score and either the SMTube or the Schirmer test I values (all $P > 0.05$; Table 2). However, the corneal fluorescein staining grade in the controls exhibited a significant weak negative correlation with the SMTube value (r = -0.28, $P < 0.05$) and a moderate positive correlation with the Schirmer test I result (r = +0.51, $P < 0.05$). In contrast, no significant correlations were found between the corneal fluorescein staining grade and either the SMTube or Schirmer test I values in the DED group (Table 2).

DISCUSSION

In this study, we demonstrated that SMTube values were significantly lower in patients with DED than in healthy controls and correlated moderately with the TBUT and OSDI scores. Unlike the Schirmer test I, the SMTube values showed stronger associations with symptom severity, emphasizing its potential as a non-invasive, symptom-relevant diagnostic tool for DED.

Our findings agreed with those of earlier reports. A large-scale study by Miyasaka et al. [12] found that the SMTube values correlated significantly with both the TBUT and Schirmer test I result, with a 2.5-mm cut-off proposed for DED screening [12]. Negishi et al. [21] (Table 3) also showed that the SMTube value was significantly associated with dry eye symptoms, such as irritation and photophobia, while the Schirmer test I results lacked such associations [21], supporting the clinical utility of the SMTube. Alshammeri et al. [22] demonstrated that SMTube values were significantly reduced in aqueous-deficient DED and were closely aligned with fluorophotometric tear turnover rates, with a cut-off value 3.75 mm showing 67% sensitivity and 88% specificity [22].

Singh et al. [23], reported excellent diagnostic accuracy for the SMTube, with an area under the curve of 0.994, in DED (Table 3). Ibrahim et al. [14] further showed that combining the SMTube with fluorescein-based TBUT enhanced diagnostic sensitivity and specificity [14]. Ayaki et al. [24] noted diurnal variability in SMTube values, with significant decreases observed throughout the day, a factor that may explain the variability in symptoms and measurements [24]. Our study demonstrated that the SMTube values correlated moderately with TBUT and OSDI scores.

Supportive evidence for the clinical utility of SMTube was also derived from animal studies (Table 3) [15, 25-28]. In canine models of keratoconjunctivitis sicca, the SMTube values strongly correlated with Schirmer test I results (r = 0.848) and the TBUT (r = 0.773), with excellent sensitivity and specificity, depending on disease severity [15]. Shinzawa et al. [26] demonstrated that the SMTube values accurately tracked tear volume reduction in a murine dry eye model, correlating with ocular surface staining grade and the TBUT [26]. These studies [15, 25-28] affirmed the physiological relevance and adaptability of the SMTube across species and experimental models.

Table 3. Summary of human [12-14, 21-24, 29-36] and animal [15, 25-28] studies on tear strip meniscometry

Author (Year)	Type of study	Key Findings
Human Studies		
Ayaki et al. (2023) [29]	Cross-sectional retrospective cohort	SMTube values showed significant seasonal variation (lowest in winter and highest in summer/fall), and correlated with the TBUT, Schirmer test value, staining scores, and dryness symptoms. Environmental conditions should be considered when interpreting SMTube results.
Miyasaka et al. (2022) [12]	Cross-sectional	SMTube values correlated significantly with traditional dry eye tests, particularly the TBUT, and aligned with key symptoms, such as dryness, irritation, and pain. A cut-off value of 2.5 mm was identified as optimal for screening, with an AUC of 0.618. These findings support the SMTube as a rapid, non-invasive tool for initial dry eye assessment, demonstrating both clinical and symptomatic relevance.
Schulze et al. (2021) [13]	Cross-sectional	SMTube values reliably indicated reduced tear volume in patients with keratoconjunctivitis sicca, with a sensitivity of 0.79–0.89 but a specificity of 0.42–0.50. It correlated well with established tests. The test can be performed rapidly, although it is best used alongside other diagnostics for accurate dry eye assessment.
Negishi et al. (2020) [21]	Cross-sectional	SMTube values were significantly associated with dry eye symptoms—particularly irritation and photophobia—and correlated with the TBUT, while the Schirmer test results showed no such associations. Despite a moderate correlation between the two tests, SMTube demonstrated greater relevance to both subjective symptoms and tear film stability, supporting its use as a rapid, non-invasive alternative for routine dry eye assessment.
Alshammeri et al. (2019) [22]	Cross-sectional	SMTube values were significantly reduced in aqueous-deficient DED and correlated strongly with tear turnover rate. With a 67% sensitivity and 88% specificity, the SMTube offers a fast, low-cost, and non-invasive method for diagnosing aqueous DED.
Rashid et al. (2020) [30]	Cross-sectional	SMTube values significantly correlated with Schirmer test results, the TBUT, and OSDI scores. Lower SMTube values indicated worse dry eye symptoms and MGD. The SMTube offers a rapid, non-invasive assessment of tear volume and stability, and is suitable for large-scale screening.
Osawa et al. (2020) [35]	*In vitro* and a clinical study	SMTube values were significantly elevated in lacrimal passage obstruction and decreased after treatment, correlating with anterior segment optical coherence tomography tear meniscus parameters and epiphora severity. These results indicate that the SMTube is a practical tool for evaluating tear retention and therapeutic effects in lacrimal passage obstruction.
Ayaki et al. (2019) [24]	Cross-sectional	SMTube values showed significant diurnal decline from morning to night; 52.8% of cases had low SMTube values upon waking vs. 83.3% of cases who had low values at night. SMTube self-examination revealed decreasing tear meniscus volumes throughout the day.
Ishikawa et al. (2019) [36]	Cross-sectional	The SMTube showed high accuracy (AUC: 0.88, sensitivity: 82%, specificity: 84%) in diagnosing lacrimal obstructive diseases, outperforming the Schirmer test I, TMH, and TMA. SMTube values decreased significantly after surgery, indicating its usefulness in both diagnosis and treatment monitoring.
Singh et al. (2019) [23]	Cross-sectional	The SMTube value, lower TMH, and lower tear meniscus depth showed excellent diagnostic performance for identifying DED cases with > 95% sensitivity and specificity. An SMTube value < 5 mm was highly accurate (AUC: 0.994), making this test a reliable, non-invasive alternative method to the TBUT for clinical diagnosis.
Ishikawa et al. (2018) [31]	Cross-sectional	The SMTube value and DED-related quality-of-life score questionnaire showed 71% and 79% sensitivity, and 85% and 91% specificity for dry eye, respectively. Their combined use improved specificity to 97%. Both tools are fast and well-suited for screening for dry eye during routine health checkups.
Shinzawa et al. (2018) [32]	Cross-sectional	SMTube values correlated strongly with anterior segment optical coherence tomography-determined TMH and TMA; an SMTube cut-off of 3.8 mm distinguished DED from normal eyes with high accuracy, confirming the diagnostic value of the SMTube in DED.
Lee et al. (2017) [33]	Cross-sectional	The SMTube and Keratograph5M differentiated non-Sjogren syndrome aqueous-deficient DED from normal eyes, with the SMTube showing higher diagnostic accuracy (AUC: 0.947). Both methods correlated with dry eye parameters, supporting their use in assessing aqueous deficiency, particularly when interpreted alongside MGD status.
Ibrahim et al. (2011) [14]	Cross-sectional	The SMTube showed significantly lower scores in DED cases and did not trigger reflex tearing. Combined with the TBUT, the SMTube value improved diagnostic sensitivity and specificity, supporting its use as a non-invasive dry eye screening method.
Dogru et al. (2006) [34]	*In vitro* and clinical study	The SMTube findings correlated with standard dry eye parameter results and improved after punctal plug therapy, demonstrating its value as a fast, non-invasive tool for diagnosing and monitoring dry eye syndromes.
Animal Studies		
Nascimento et al. (2023) [15]	Experimental	SMTube values showed a significantly high correlation with Schirmer test I results and a moderate correlation with the TBUT in dogs with keratoconjunctivitis sicca. A threshold of 7.0 mm/5 s on the SMTube demonstrated robust diagnostic accuracy for identifying tear deficiency, with a sensitivity and specificity of 76% and 97% for severe cases, 91% and 96% for moderate cases, and 100% and 87% for subclinical cases, respectively.
Kovalcuka et al. (2021) [25]	Experimental	In healthy cats, the mean SMTube value was 4.68 mm/5 s and the Schirmer test result was 12.46 mm/min, with no significant eye-to-eye differences. Both tests are reliable for tear assessment, but the SMTube results may vary with skull conformation and age, warranting individualized interpretation in the clinical context.
Shinzawa et al. (2019) [26]	Experimental	In a murine dry eye model, SMTube values decreased significantly after dry exposure and showed strong correlations with standard tear function parameters, validating the SMTube as a reliable, rapid method for assessing tear volume in experimental settings.
Miyasaka et al. (2019) [27]	Experimental	SMTube values demonstrated a strong correlation with Schirmer test results, outperforming the phenol red thread test in identifying canine tear deficiency. A 10-mm/5-s cut-off yielded high sensitivity, making the SMTube a rapid and effective screening tool for ruling out normal tear function.
Rajaei t al. (2018) [28]	Experimental	Normal SMTube values were established in dogs (9.66 mm), cats (10.5 mm), and rabbits (4.72 mm). The SMTube values correlated weakly with Schirmer test I results only in dogs, with no influence of age or sex across species.

Abbreviations: SMTube, strip meniscometry; AUC, area under curve; DED, dry eye disease; TMH, tear meniscus height; TMA, tear meniscus area; TBUT, tear break-up time; OSDI, ocular surface disease index; MGD, meibomian gland dysfunction; mm, millimeters; s, second; min; minutes.

Our study contributes to the growing body of literature—comprising both human studies [12-14, 21-24, 29-36] and experimental animal studies [15, 25-28] (summarized in Table 3)—by providing real-world clinical comparisons among the SMTube, Schirmer test I, TBUT, TMH, corneal staining grade, and OSDI values. The moderate correlations observed between the SMTube value and both the TBUT and OSDI suggest that the SMTube value may better reflect tear film instability and symptom severity than does the Schirmer test I result, which demonstrated weaker or no such correlations.

Besides DED, the SMTube has been effectively applied in other tear-related conditions [35, 36]. Osawa et al. [35] reported elevated SMTube values in cases of lacrimal passage obstruction, which normalized after silicone tube insertion, and correlated well with anterior segment optical coherence tomography-based tear parameter findings and epiphora severity [35]. Similarly, Ishikawa et al. [36] found that the SMTube was superior to Schirmer test I and the TMH in diagnosing lacrimal obstructive diseases [36] (Table 3).

The strengths of this study include use of a standardized examination protocol, single-examiner assessments to reduce variability, and simultaneous evaluation of subjective and objective parameters. However, its limitations include a modest sample size, lack of longitudinal follow-up, and absence of advanced imaging (e.g., anterior segment optical coherence tomography) validation of the tear meniscus. Diurnal and seasonal variations were not also taken into account. Future studies should focus on multi-center cohorts, evaluate the diagnostic cut-off values of the SMTube in various populations, and explore its integration into multimodal DED diagnostic frameworks, ideally alongside imaging and symptom-based metrics.

CONCLUSIONS

SMTube values could effectively differentiate patients with DED from controls and correlated moderately with the TBUT and symptom scores, showing greater relevance than the Schirmer I test. The simplicity, non-invasiveness, and alignment with patient-reported symptoms of SMTube values support the practical utility of this method in DED evaluation. The SMTube may enhance current diagnostic strategies when used alongside conventional tests. Future large-scale, multi-center studies are warranted to validate its diagnostic accuracy, responsiveness to treatment, and integration into comprehensive dry eye assessment protocols.

ETHICAL DECLARATIONS

Ethical approval: The study protocol was approved by the relevant institutional review board and adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from all participants prior to enrollment.

Conflict of interests: None.

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