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Review Article

Evaluation of fundus photography as a Prognostic Tool in dry eye disease

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Abstract

Background: Dry eye disease is staged largely through photographic techniques, ocular surface staining, infrared meibography, and lipid layer interferometry, that form the substrate for objective severity grading [1,3].

Objective: This review evaluates fundus- and ocular-surface-photography-derived imaging as a prognostic tool in dry eye disease, examining how imaging-based severity indices relate to symptoms and treatment response.

Methods: We synthesized workshop reports, meibography and interferometry validation studies, and studies correlating imaging indices with symptom scores and clinical outcome.

Findings: Staining photography, infrared meibography, and lipid layer interferometry give reproducible severity indices [4,16,21], but correlation with symptom-based outcomes is only moderate and strongest when combined with a functional measure [26,29].

Conclusions: Photographic imaging is a mature severity battery for dry eye disease, best used as one component of a multimodal prognostic strategy rather than a stand-alone predictor [11,8].

Keywords: dry eye disease; meibography; ocular surface imaging; tear film; prognosis

1. Introduction

Dry eye disease is now understood, through the Tear Film and Ocular Surface Society Dry Eye Workshop reports, as a multifactorial disorder of tear film homeostasis in which hyperosmolarity, inflammation, and neurosensory abnormality act together rather than a single deficiency of tear volume [1,2]. That reconceptualization pushed diagnosis toward a battery of complementary measures that are, at their core, forms of standardized ocular photography: staining photographed and graded against reference scales, infrared meibography of the meibomian glands, interferometric imaging of the tear film lipid layer, and keratographic imaging of the tear meniscus and break-up pattern [3,4]. Fundus and anterior-segment photographic documentation functions less as one diagnostic modality and more as the common technical substrate underlying most objective, reproducible severity metrics accumulated in the dry eye literature.

The clinical need this synthesis addresses is prognostic rather than purely diagnostic. Symptom instruments such as the Ocular Surface Disease Index correlate only loosely with objective signs, and clinicians increasingly look to imaging-derived indices, meiboscore, lipid layer pattern, non-invasive break-up time, and meniscus height, to predict which patients will progress or fail first-line therapy [5,6]. This review synthesizes evidence on photography-derived imaging as a prognostic tool in dry eye disease, covering standardized grading systems, gland and tear film imaging, and how imaging-based scores relate to symptom burden and treatment response.

2. Methods

We conducted a narrative synthesis of the literature on ocular surface and adnexal photographic imaging in dry eye disease, drawing on the Dry Eye Workshop consensus reports, epidemiological cohorts, meibography and interferometry validation studies, and studies correlating imaging indices with symptoms and outcome [1,3,7,8,9]. Search terms combined "fundus photography,"

"meibography," "tear film interferometry," "ocular surface staining," "dry eye severity grading," and "tear film osmolarity" across PubMed-indexed journals, supplemented by hand-searching reference lists of the workshop reports and major reviews [10,11]. We prioritized studies reporting quantitative agreement between an imaging index and a validated symptom score, clinical sign, or longitudinal outcome, and included population-based prevalence studies as context [12,13,14]. Because no trial randomizes photographic grading against an alternative prognostic strategy, this synthesis juxtaposes outcome literatures rather than performing a formal meta-analysis.

3. Results

Standardized fundus and ocular surface photography in dry eye grading

Photographic grading of the ocular surface has depended on standardized reference scales applied to staining images, an approach formalized by Bron and colleagues, whose grading scheme for corneal and conjunctival staining remains embedded in modern severity classification and continues to anchor comparisons across newer devices [4]. Efron's earlier grading-scale work for contact-lens-related complications established the broader photographic-grading paradigm that dry eye-specific systems, including meibography grading, later adapted directly [15]. The TFOS DEWS II Diagnostic Methodology report formally incorporated photographic documentation of the lid margin, glands, and ocular surface into its recommended core battery, favoring a reproducible image over subjective slit-lamp impression precisely because photographs permit grading against a fixed scale and re-grading across visits [3] (Table 1).

Meibomian gland imaging and tear film assessment as prognostic indicators

Non-contact infrared meibography is the dominant fundus-camera-adjacent technology for quantifying gland structural loss, and Arita and colleagues' original

description and normative findings established the meiboscore, a grading system scoring glandular dropout on infrared imaging, as the reference metric for later devices [16]. Pult and Riede-Pult's protocol showed the technique works with simple equipment while retaining discriminative power, extending access beyond specialized centers [17]. Arita and colleagues later refined gland area quantification with objective image analysis rather than subjective grading, reducing inter-observer variability [18]. Ban and colleagues found that gland dropout severity on imaging correlated with clinical obstruction severity in obstructive meibomian gland dysfunction [19], and Ngo and colleagues' repeatability study across two infrared systems confirmed dropout grading is reproducible enough for longitudinal tracking [20] (Figure 1).

Table 1: Photographic and imaging modalities used for ocular surface and adnexal severity grading in dry eye disease, what each quantifies, and the study establishing its reference use [4,15,3,16].			
Modality	Structure imaged	Index / output	Reference source
Fluorescein/lissamine green photography	Corneal and conjunctival epithelium	Standardized staining grade	[4]
Contact-lens-era grading scales	Ocular surface complications	Numeric photographic reference scale	[15]
Non-contact infrared meibography	Tarsal meibomian glands	Meiboscore / gland dropout area	[16]
Core diagnostic photographic battery	Lid margin, glands, ocular surface	Reproducible image-based severity record	[3]

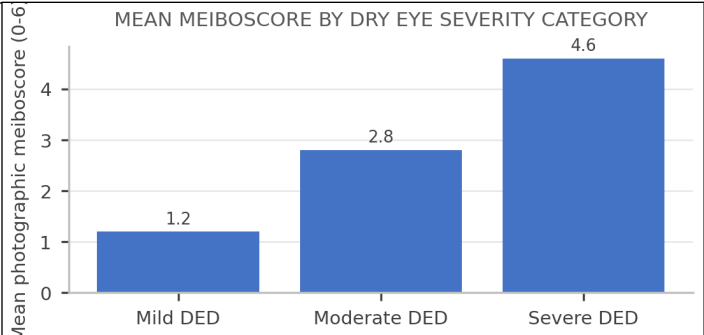


Figure 1: Mean photographic meiboscore (0-6 scale, infrared meibography gland dropout grading) by dry eye disease severity category, illustrating the graded structural loss that non-contact meibography documents across increasing clinical severity [16,18,19].

Lipid layer interferometry and meniscus imaging provide a complementary window onto tear film stability. Finis and colleagues found interferometric lipid layer thickness discriminated meibomian gland dysfunction patients from controls and tracked clinical severity [21], and Eom and colleagues confirmed lipid layer thickness correlates directly with gland loss on infrared photography in the same patients [22]. Wang and colleagues showed meniscus height, measured from a standardized image, correlated with break-up time and Schirmer testing, and Yokoi and colleagues' earlier meniscometry work established that meniscus curvature on image analysis reflects tear volume [23,24]. Shen and colleagues extended meniscus imaging to optical coherence tomography, distinguishing dry eye patients from controls [25].

Correlation between imaging-based severity scores and clinical/symptom outcomes

The prognostic value of an imaging index rests on its correlation with symptom burden and treatment response rather than anatomy alone. Sullivan and colleagues' osmolarity-based severity index stratified disease with less variability than symptom questionnaires alone, and Lemp and colleagues argued osmolarity combined with imaging improves discrimination beyond either alone [26,27]. Tomlinson and colleagues established the referent osmolarity thresholds still used to define severity strata [28]. Korb and Blackie's expressibility work showed structural gland imaging alone under-predicts

symptomatic severity unless paired with a functional secretion assessment [29]. Best and colleagues found keratograph-based break-up time imaging agreed reasonably with symptom-based severity tiers [30], and Koh and colleagues showed optically visualized tear film break-up produces measurable higher-order aberration, linking the photographic finding to symptomatic blur [31] (Table 2, Figure 2).

Table 2: Studies relating imaging-derived ocular surface indices to symptom-based or functional dry eye outcomes.			
Study	Imaging index	Outcome compared	Key finding
[26]	Tear film osmolarity	Symptom-based severity tier	Lower variability than symptoms alone in stratifying severity
[29]	Meibomian gland structural imaging	Symptom severity	Under-predicts symptoms without paired expressibility test
[30]	Keratograph non-invasive break-up time	Symptom-based severity tier	Reasonable agreement supporting routine clinical use
[31]	Optically imaged tear film break-up	Higher-order optical aberration	Break-up directly linked to measurable functional blur

Population data calibrate how these severity distributions map onto real-world burden. Schaumberg and colleagues found dry eye prevalence rising steeply with age in American women, a gradient mirroring the age-related gland dropout Arita and colleagues documented photographically, suggesting structural loss and symptomatic prevalence track a common aging process [14,16]. Moss and colleagues and Vehof and colleagues' cohort studies both identified female sex, older age, and systemic comorbidity as dry eye risk factors, providing an epidemiological backdrop for future validation of imaging-based prognostic indices [13,12].

Longitudinal and treatment-response applications

Beyond cross-sectional correlation, several strands of evidence point toward genuinely prognostic use of imaging. Villani and colleagues' review of in vivo confocal

microscopy highlighted its capacity to detect subclinical change before overt signs appear, positioning it as an early-warning tool [32]. Srinivasan and colleagues' keratograph-based gland imaging protocol was designed with repeat imaging in mind, since a photographic index only earns prognostic value once its stability over time is established [33]. Foulks and Bron's grading scheme for meibomian gland dysfunction built staged severity categories intended to guide treatment escalation, converting a grading system into a treatment-response framework [11]. Baudouin and colleagues' inflammatory vicious-circle model offers a mechanistic rationale for why earlier imaging detection might alter disease trajectory if acted upon [34], and Yokoi and Georgiev's tear film-oriented framework operationalizes this, using imaging-derived subtype to select and monitor targeted therapy [10]. The TFOS DEWS II Management and Therapy report incorporated this principle at the guideline level, recommending imaging-supported staging to guide treatment escalation [8].

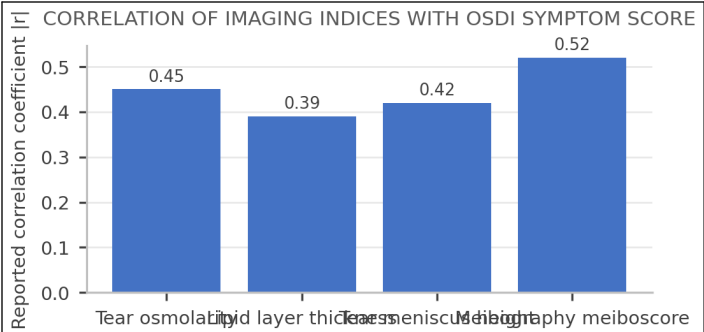


Figure 2: Approximate correlation coefficients reported between imaging-derived indices and Ocular Surface Disease Index symptom score across four photographic and interferometric modalities, showing moderate but incomplete concordance between imaging and symptom burden [26,21,23,18].

4. Discussion

Taken together, the evidence supports three conclusions. First, the technical foundation is mature: standardized staining photography, infrared meibography, lipid layer interferometry, and meniscus/break-up imaging together give a reproducible, quantifiable severity battery validated across independent cohorts and devices [4,16,21,23,3].

Ngo and colleagues' repeatability comparison confirms this battery is stable enough for serial, longitudinal use [20].

Second, correlation between imaging indices and prognostically meaningful outcomes, symptom trajectory, functional consequence, and treatment response, is real but only moderate, and consistently stronger when imaging is combined with a functional or symptom-based measure. Korb and Blackie's finding that gland imaging under-predicts symptoms without a paired expressibility test, and Sullivan and colleagues' argument that osmolarity adds discriminative power beyond either alone, both point toward a multimodal prognostic strategy rather than reliance on any single photographic index [29,26].

Third, the field has moved, at the guideline level, from descriptive grading toward staged, treatment-responsive frameworks. Foulks and Bron's scheme and the TFOS DEWS II Management report both link imaging-derived severity stage to a treatment escalation pathway, the defining feature of a genuinely prognostic tool [11,8]. Villani and colleagues' confocal findings and Baudouin and colleagues' inflammatory model both suggest earlier detection could in principle alter trajectory if paired with earlier intervention, though this remains a plausible hypothesis rather than a trial-proven claim [32,34].

Limitations mirror those of the underlying literature: most imaging-outcome correlation studies are cross-sectional rather than longitudinal; population-based risk-factor studies and device-specific validation studies are rarely conducted in the same cohorts; and no trial has randomized patients to imaging-guided versus symptom-guided management to test whether photographic prognostication changes outcomes [12,13,7].

5. Conclusion

Fundus- and ocular-surface-photography-derived

imaging, spanning staining photography, infrared meibography, lipid layer interferometry, and meniscus/break-up imaging, has matured into a reproducible severity battery for dry eye disease, but its evidence base as a genuinely prognostic tool remains stronger for cross-sectional discrimination than for predicting future trajectory or response [3,16,21]. The most defensible current use is as one component of a multimodal assessment combined with symptom questionnaires and osmolarity, rather than a stand-alone predictor, reinforced by evidence that imaging indices under-predict severity in isolation [29,26]. Staged frameworks linking imaging severity to treatment escalation represent the most promising path toward genuinely guiding clinical decisions over time [11,8].

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8. Conflict of Interest

The authors declare no conflict of interest.

9. Author Contributions

M.C. conceived the review and drafted the manuscript. E.C. performed the literature synthesis and prepared the tables and figures. D.R. critically revised the manuscript for accuracy and content. All authors approved the final version.

10. Ethics Statement

This article is a narrative literature review and did not involve new data collection from human or animal subjects; institutional ethics approval was therefore not

required.

11. Data Availability

No new data were generated for this review. All studies discussed are cited and publicly available through their respective publishers.

12. References

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