AI Provides Deeper Understanding of Meibomian Gland Morphology and Function

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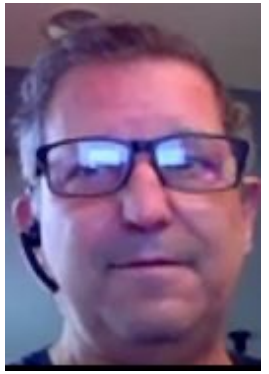

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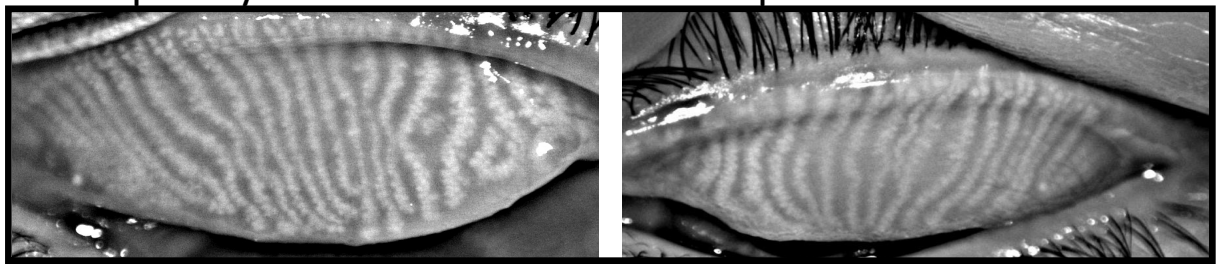
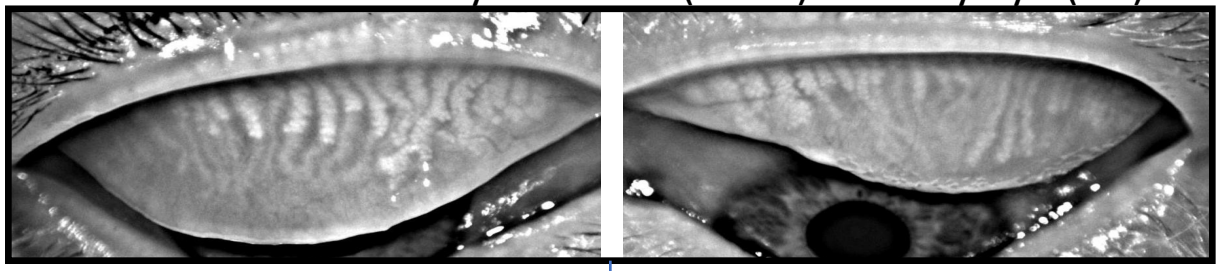
Background: What is Meibography and Why is It Important?

Infrared Imaging of Everted Eyelid and Exposed Meibomian Glands (MG)

- Healthy MG secrete lipid-rich meibum
- Lipid layer stabilizes tear film and protects ocular surface

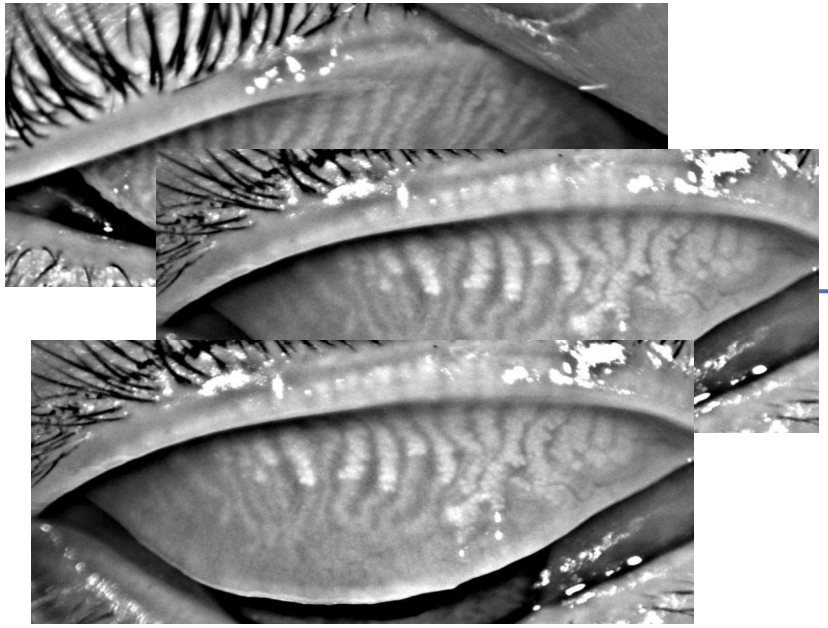


- Meibography can reveal MG pathology
- Can lead to MG Dysfunction (MGD) and Dry Eye (DE)



MGD → Poor Lipid Quality/Quantity → Unstable Tear Film → Tear Evaporation/Breakup → Hyperosmolarity → Activation of Corneal Nerves → DE Symptoms

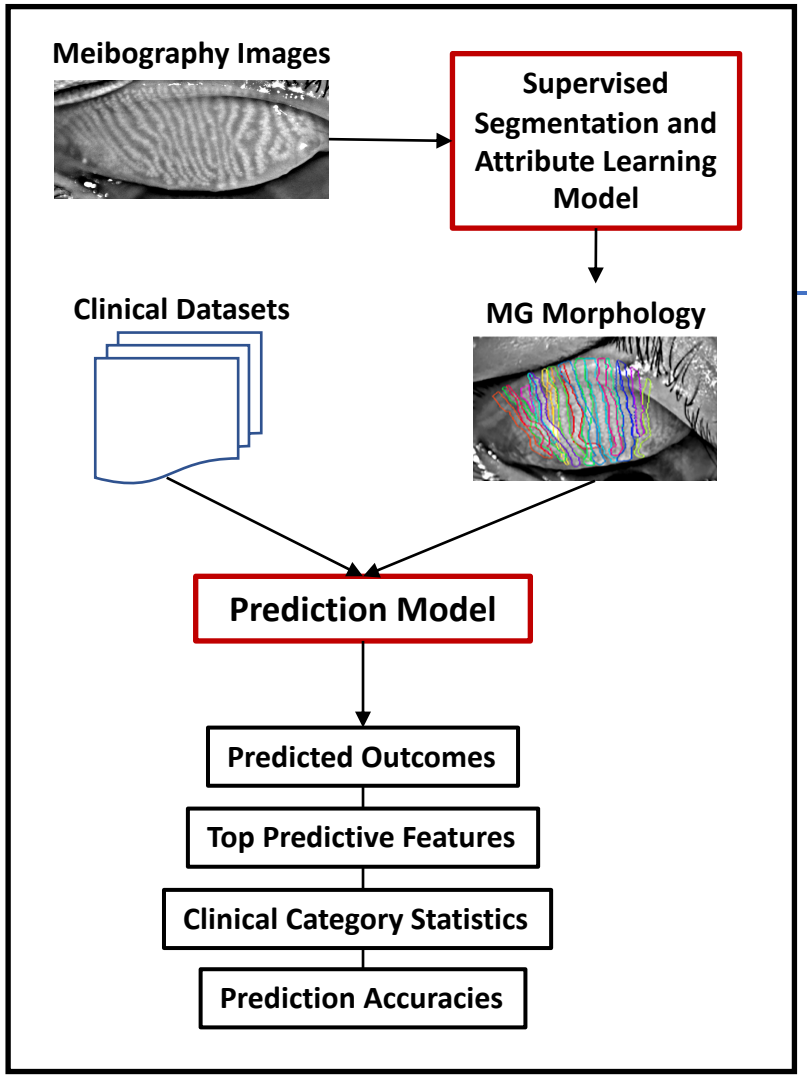
Machine Learning (ML): What Can We Learn from Meibography Using AI?



Machine Learning Prediction Model

- Clinician Diagnoses
- Clinical Signs
- Symptoms
- Subject Characteristics

ML: Meibography Prediction Model Architecture – How We Learn



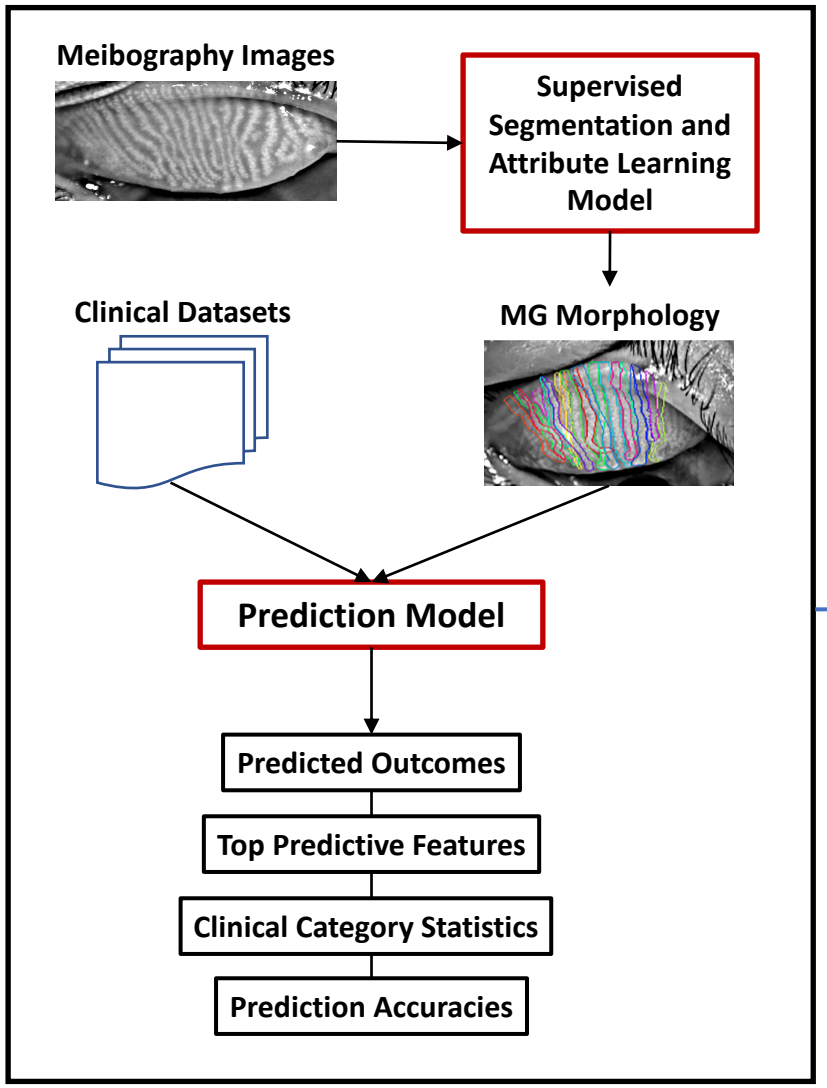
Implementation

- Segmentation and Attribute Learning Model:
  - Segments individual MGs from meibography images
  - Calculates eyelid-level and gland-level morphology metrics
- Combine with clinical / subject data for input to Prediction Model

Meibomian Gland Morphology	
Attribute	**Units**
Gland Length	mm
Gland Width	mm
Tortuosity	%
Local Contrast	%
Visible Glands	#
Gland Density	%
Gland Atrophy	% Area
Ghost Gland	[Yes/No]

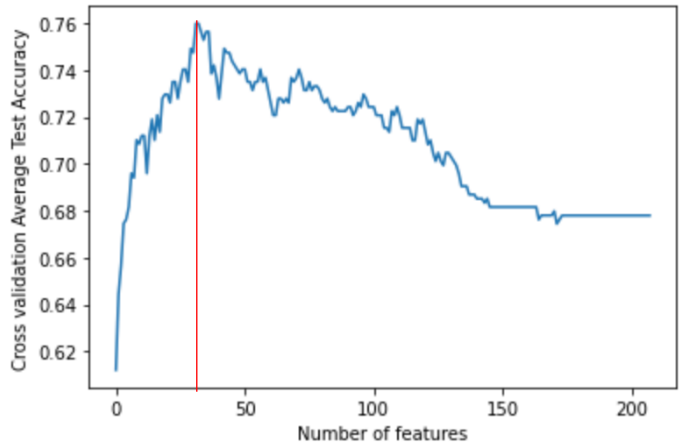
Clinical Datasets	
Summary Diagnoses	**Subjective Symptoms**
Meibomian Gland Dysfunction	Berkeley DEFC
Aqueous Deficiency	OSDI
Blepharitis	SPEED
Clinical Signs	DEQ-5
MG Morphology / Function	CLDEQ-8
Corneal / Conjunctival Staining	VAS Ratings Discomfort Severity
Lipid Layer Thickness / Variability	VAS Ratings Discomfort Frequency
NITBUT / FTBUT	VAS Ratings Dryness Severity
TMH / Schirmer	VAS Ratings Dryness Frequency

ML: Meibography Prediction Model Architecture – How We Learn



Prediction Model: Training and Evaluation

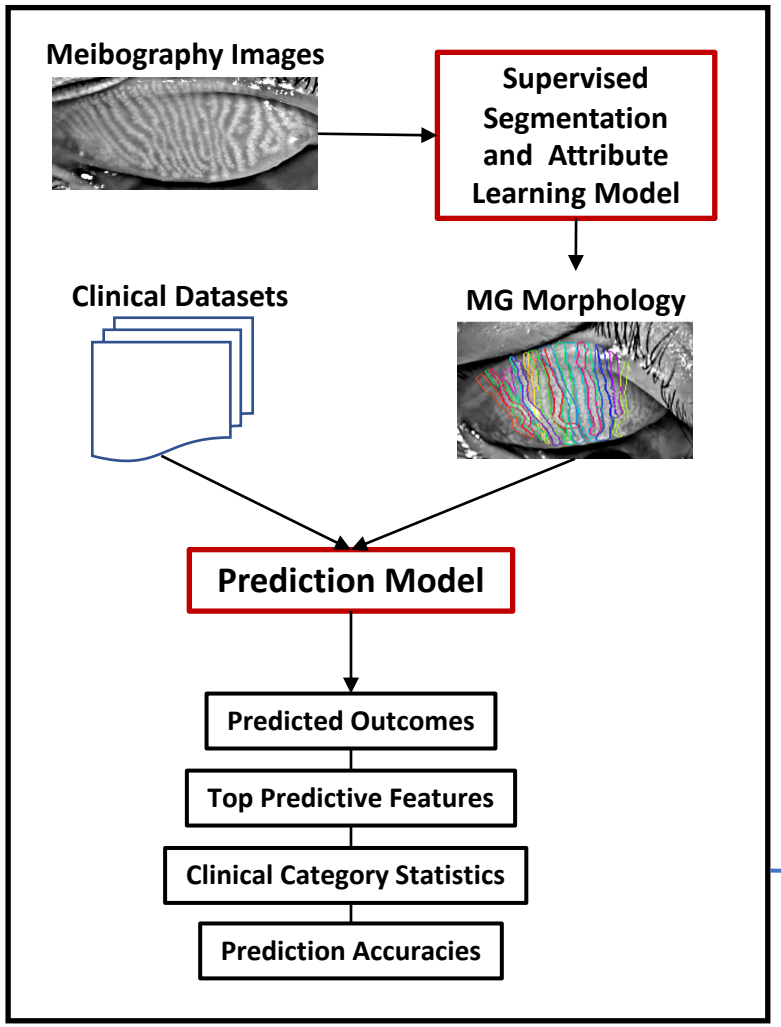
- n=458 meibography images with corresponding subject symptoms and clinical measurements



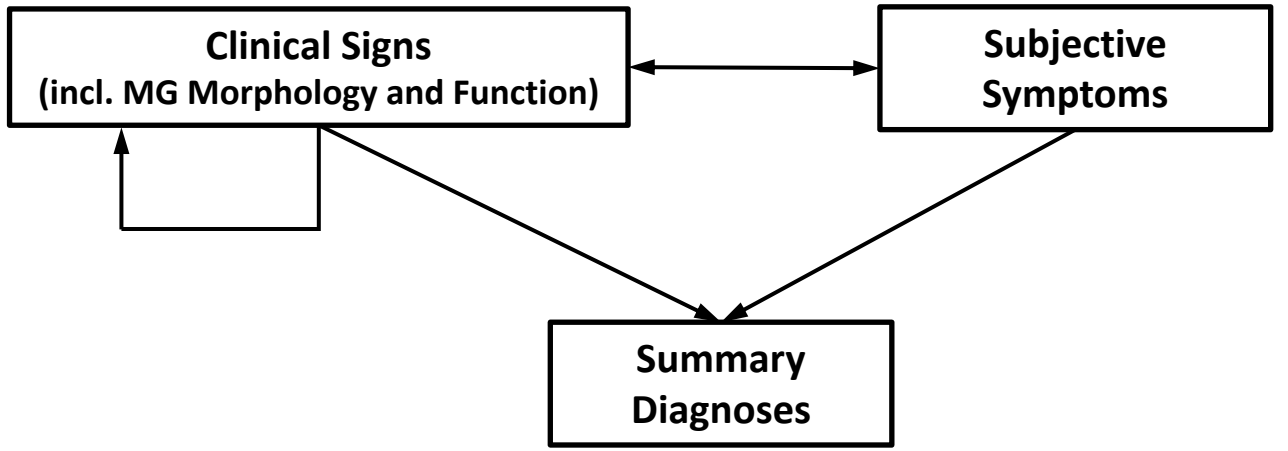
For each predicted outcome:

- Data and images randomly allocated into 5 model training and validation sets
- Train 5 models, each with different validation set
- Aggregate and rank highest weighted features from the 5 models
- Return mean accuracy and the median # of features used for prediction

ML: Meibography Prediction Model Architecture – How We Learn



Model Output: Predicted Outcomes and Statistics



Predicted Outcome [Predicted Classes]	Predictive Features	Class-wise Statistics	Total # Features	Prediction Accuracy (%)
Eyelid Margin Vascularization [Absent, Present]	Ghost MG (%)	[6, 15]	82	85.9
	MG Density (%)	[37, 34]		
	Visible MG: UL (#)	[18.4, 16.0]		
	Erythema: UL (0-3)	[0.14, 0.95]		

Meibography and Machine Learning: What Have We Learned So Far?

Meibomian Gland Morphological Features Are Among Highest Weighted Outcome Predictors

Greater MG Width	Greater Contrast	Lower MG Density	Greater % Atrophy	Greater % Ghost MG
Greater Meibum Quantity (98.0%)	Better Meibum Quality (94.0%)	Eyelid Notching (95.9%), Eyelid Skin Vascular. (85.9%)	Greater CS Extent (91.2%) More Erythema (99.1%) Greater Meibum Qty (98.0%)	Eyelid Skin Vascular. (85.9%), Lower Tear Meniscus Ht (72.6%), Lower VAS Comfort Rating (65.4%)

Fewer Visible Glands in Meibography Image

Diagnoses	MGD Diagnosis (74.4%), Aqueous Deficiency Diag. (85.2%), Blepharitis Diagnosis (73.7%)
Signs	Eyelid Skin Vascular. (85.9%), Schirmer < 5mm (92.5%), FTBUT < 9s (Non-Asian; 87.4%)
Symptoms	Higher OSDI Score (68.1%), Higher VAS Dryness Rating (66.1%), DEFC Debilitating Symptoms (CLW; 63.9%)

Meibography and Machine Learning: What Have We Learned So Far?

Meibography Features are Predictive of Some Summary Diagnoses with 74-85% Accuracy

MGD Diagnosis can be predicted with 74.4% accuracy

PREDICTOR	MGD	No MGD
# Visible MG	14.8	15.6
Lipid Layer Thickness (nm)	57.8	68.2
NITBUT (sec)	10.0	13.8

Aqueous Deficiency Diagnosis can be predicted with 85.2% accuracy

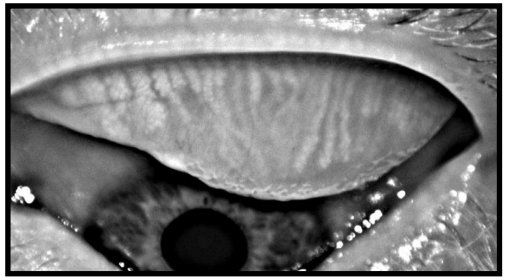
PREDICTOR	AQDEF	No AQDEF
# Visible MG	14.0	15.5
Conjunctival Staining (0-3)	2.2	1.4

Blepharitis Diagnosis can be predicted with 73.7% accuracy

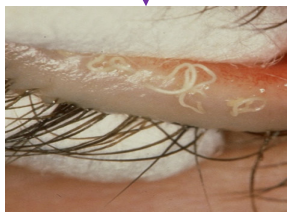
PREDICTOR	BLEPH	No BLEPH
# Visible MG	17.8	20.0
Age (yrs)	30.4	25.0
Lid Margin Erythema (0-3)	0.44	0.18
LOM Displacement (mm)	1.00	0.72

Meibography and Machine Learning: What Have We Learned So Far?

Meibography Features are Predictive of Some Clinical Signs with >90% Accuracy



Lower Local Contrast



Poor Meibum Quality (94%)

Less Gland Width

Less Meibum Quantity (91%)

Lower Gland Density

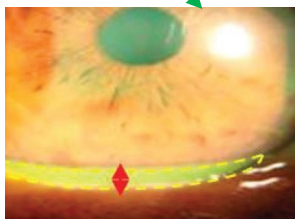
More Ghost Glands

Fewer Visible Glands

More Gland Atrophy

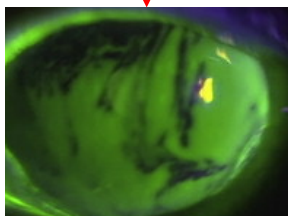
Eyelid Notching (95%)

Vascularization (86%)



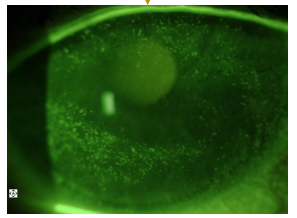
Lower TMH (86%)

Schirmer <5mm (93%)



FTBUT < 9s (87%)

Erythema (99%)



Corneal Staining (91%)

Meibography and Machine Learning: What Have We Learned So Far?

Meibography Features are Predictive of Some DE symptoms, but only with 64-68% Accuracy

Fewer Visible MG

↓

Higher OSDI Score (68.1%)
Higher VAS Dryness Severity Rating (66.1%)
Debilitating Symptoms DE in CLW (63.9%)

Greater % Ghost Glands

↓

Higher VAS Dryness Discomfort Rating (65.4%)

Meibography and Machine Learning: What Have We Learned So Far?

Meibography images alone can predict MG Function

MG Function Predictions Using Only MG Morphological Features									
Predicted Outcome	**Accuracy (%)**	**Highest Weighted Features**							
		Length	**Width**	**Tortuosity**	**Density**	**Contrast**	**%Ghost**	**%Atrophy**	**#MG**
Meibum Quality									
Upper Lid, Central	94.0	✓	✓	✓	✓		✓		
Lower Lid, Central	96.3		✓	✓	✓	✓			✓
Upper Lid, Entire	86.7		✓	✓		✓	✓		✓
Lower Lid, Entire	87.4	✓			✓	✓		✓	✓
Meibum Quantity									
Upper Lid, Central	97.2	✓	✓	✓				✓	✓
Lower Lid, Central	99.1	✓	✓				✓	✓	✓
Upper Lid, Entire	92.5		✓			✓	✓	✓	✓
Lower Lid, Entire	94.0	✓	✓		✓			✓	✓

Meibography and Machine Learning: What Have We Learned So Far?

Meibography images alone can predict some clinical signs

Other Clinical SIgns Predictions Using Only MG Morphological Features									
Predicted Outcome	**Accuracy (%)**	**Highest Weighted Features**							
		Length	**Width**	**Tortuosity**	**Density**	**Contrast**	**%Ghost**	**%Atrophy**	**#MG**
Eyelid Notching	95.4	✓	✓		✓		✓		✓
Blepharitis, Upper Lid	79.8	✓	✓	✓		✓	✓		
Blepharitis, Lower Lid	91.7	✓	✓		✓		✓		✓
Erythema, Upper Lid	96.8	✓	✓	✓		✓	✓		
Erythema, Lower Lid	97.0	✓			✓	✓	✓		✓
Lid Margin Redness	83.5	✓	✓		✓	✓	✓		
LoM Displacement, Upper Lid	84.6	✓	✓		✓	✓			✓
Lid Wiper Epitheliopathy, Width	82.0	✓		✓		✓		✓	✓
Corneal Staining Extent	90.6		✓		✓	✓	✓	✓	
Corneal Staining Depth	83.2	✓	✓		✓		✓		✓
Schirmer < 5mm	91.1	✓	✓	✓			✓		✓
FTBUT < 9s, Non-Asians	81.7			✓		✓	✓	✓	✓

- The highest accuracy **Symptoms** prediction: Debilitating Symptoms DE (DEFC), NonCLW – Accuracy = 79.6%

  Highest Weighted MG Features: Tortuosity, Contrast, Width, Length, # MG

- The highest accuracy **Diagnosis** prediction: Aqueous Deficiency – Accuracy = 79.5%

  Highest Weighted MG Features: Length, Tortuosity, Width, # MG, % Ghost

Meibography and Machine Learning: What Have We Learned So Far?

Meibography images alone can predict some identifying patient characteristics

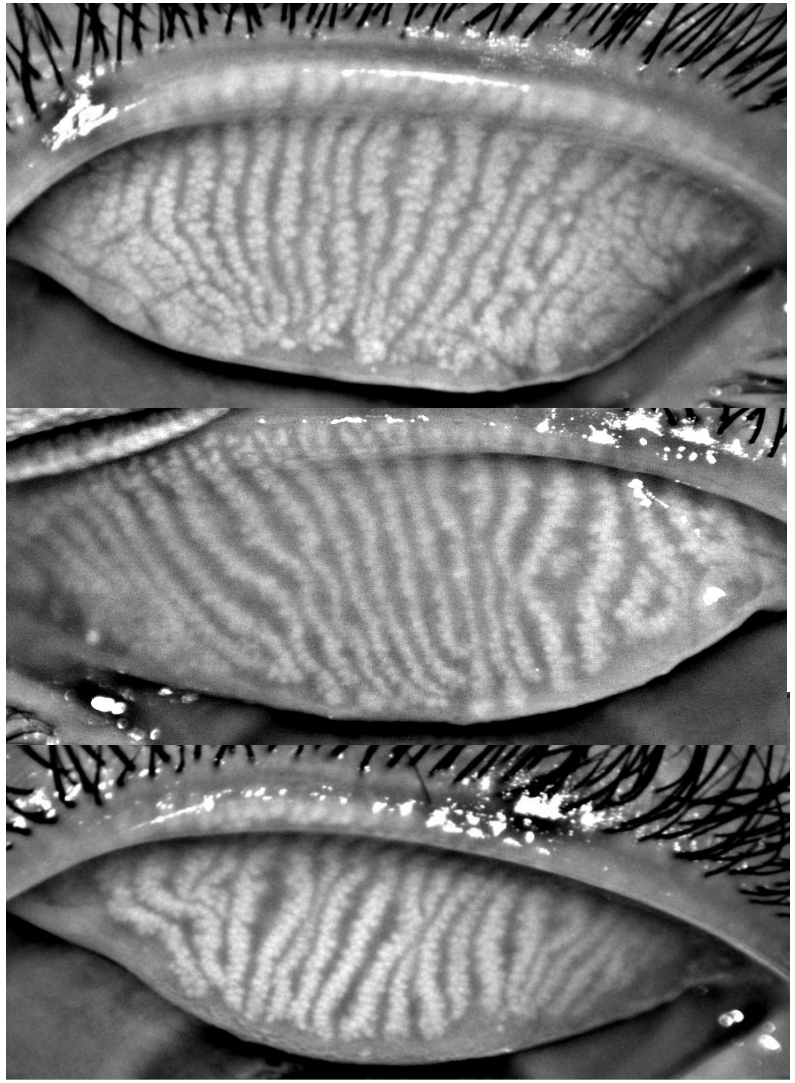
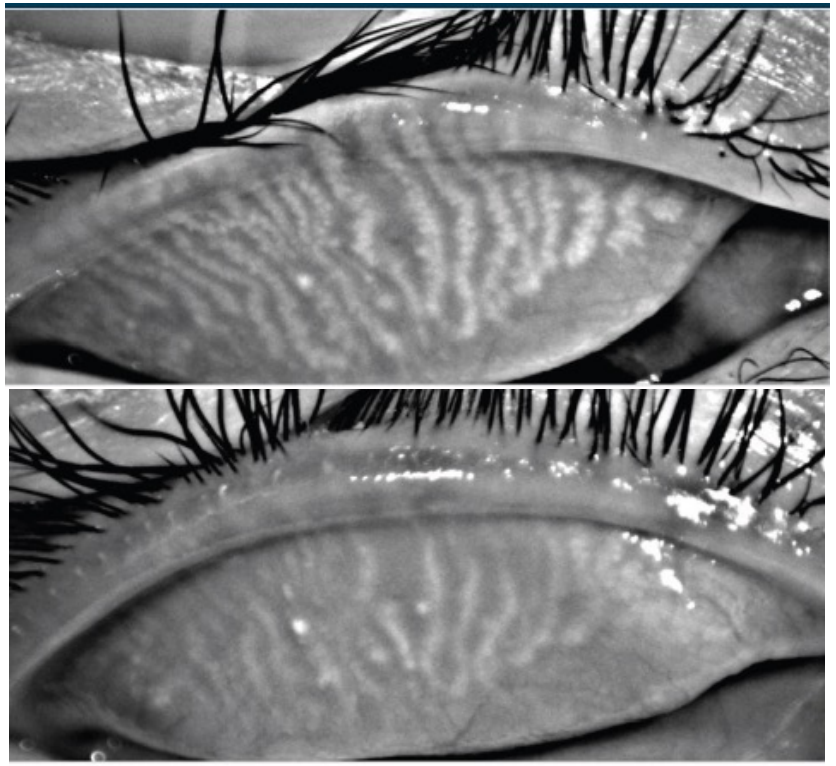
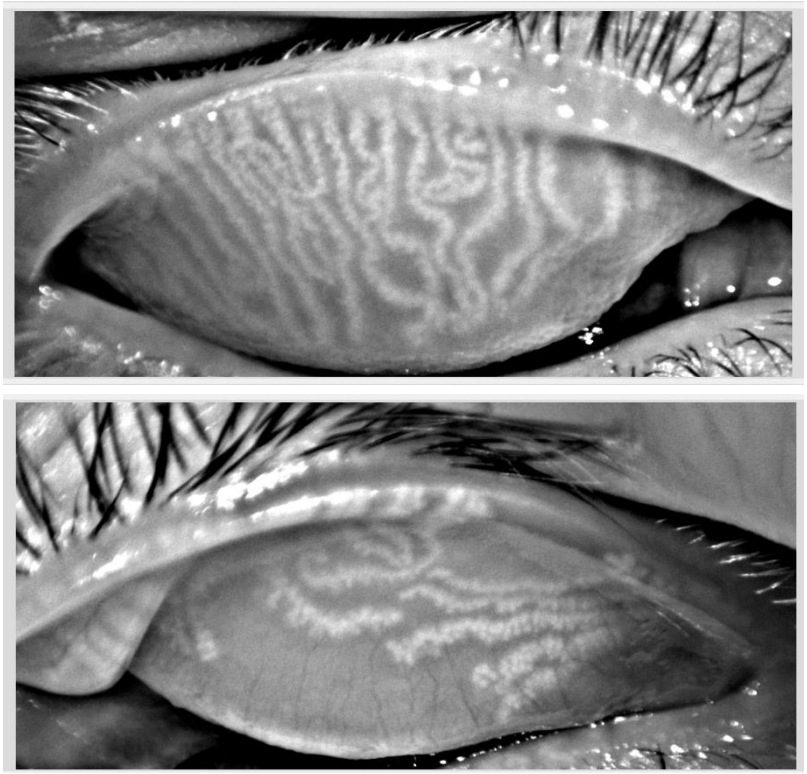
AGE can be predicted from meibography images alone (75.8% accuracy)

	Age ≤ 39	39 < Age < 50	Age ≥ 50
% MG Atrophy	18.1	25.2	33.6
% Ghost Glands	5.6	14.2	28.7

ETHNICITY can be predicted from meibography images alone (85.8% accuracy)

	Asian	Caucasian
% MG Density	42.0	39.2
% Ghost Glands	7.9	10.5

Conclusions

- Using machine learning, we can quickly and accurately quantify MG morphological features
- MG morphological features are predictive of MG function, clinical signs, subjective symptoms, and summary clinician diagnoses, with varying degrees of accuracy
  - Clinical signs predicted with higher accuracy than symptoms
- Meibography images can reveal characteristics of the patients who provided them
  - Predicted age and ethnic group from meibography images (75-86% accuracy)
- De-identified medical imaging is not currently considered Protected Health Information (PHI)
  - Meibography could soon be a biometric identifier of individuals (“fingerprint”)
  - Patient privacy laws and regulations need constant monitoring and updating as technology evolves

Summary