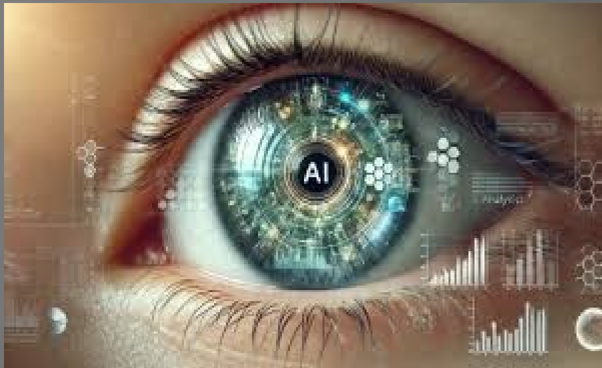

ARTIFICIAL INTELLIGENCE IN OCULAR SURFACE DISEASE

RIGHT INTERVENTION AT THE RIGHT TIME

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Disclosure

Ocular Surface Diseases: Scope and Impact

- Ocular surface diseases (pterygium, keratoconus, infectious keratitis, dry eye, etc.) affect the cornea/conjunctiva and are major causes of ocular morbidity .
- For example, keratitis is the fifth leading cause of blindness globally .
- These conditions often require multiple examination modalities (slit lamp, imaging, clinical tests) due to complex anatomy .
- Early and accurate diagnosis is critical to prevent vision loss and improve quality of life.
- AI promises to enhance detection and screening efficiency.

Artificial Intelligence in Ophthalmology

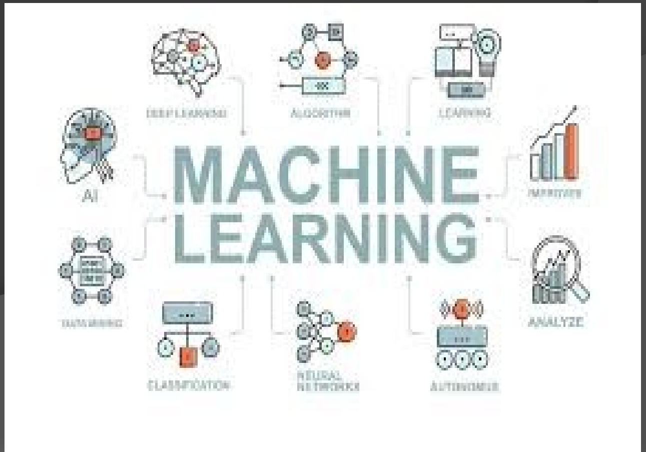
- AI use began in retinal diseases: the first FDA-approved AI device (2018) was for diabetic retinopathy .
- AI has since been applied to AMD, glaucoma, and cataracts.
- Recent efforts extend AI to ocular surface.
- These models learn subtle image features beyond human perception.
- **Machine Learning (ML):**

  Includes algorithms (support vector machines, random forests, etc.)
- **Deep Learning (DL):**

  Involves neural networks trained on large datasets .

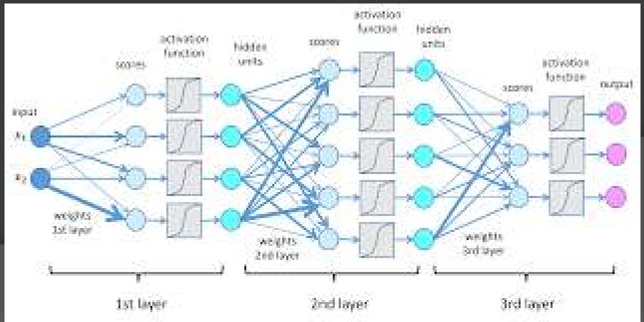
Machine Learning (ML)

- Machine learning involves algorithms that allow computers to learn from **structured data** and improve their performance on a task over time.
- The system learns patterns from input data to make decisions or predictions.
- **Example:** Spam filters in email learn to recognize spam messages based on patterns in past emails.
- **Types:** Supervised learning, unsupervised learning, reinforcement learning.



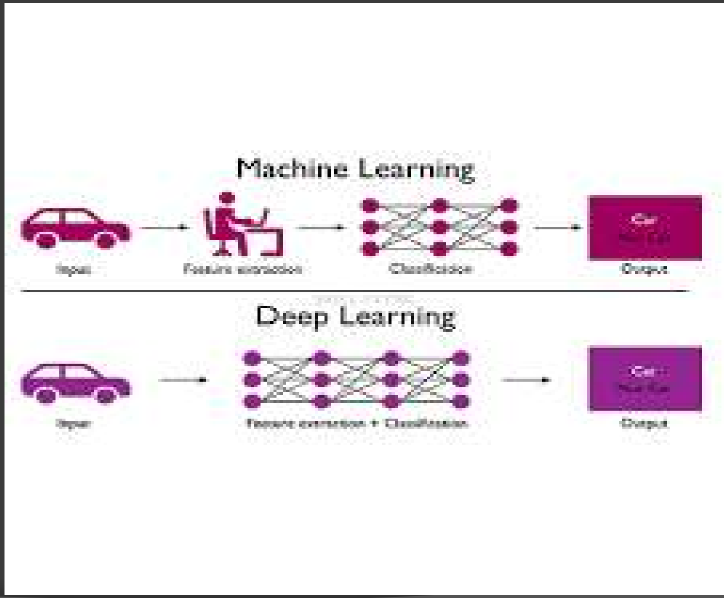
Deep Learning **(DL)**

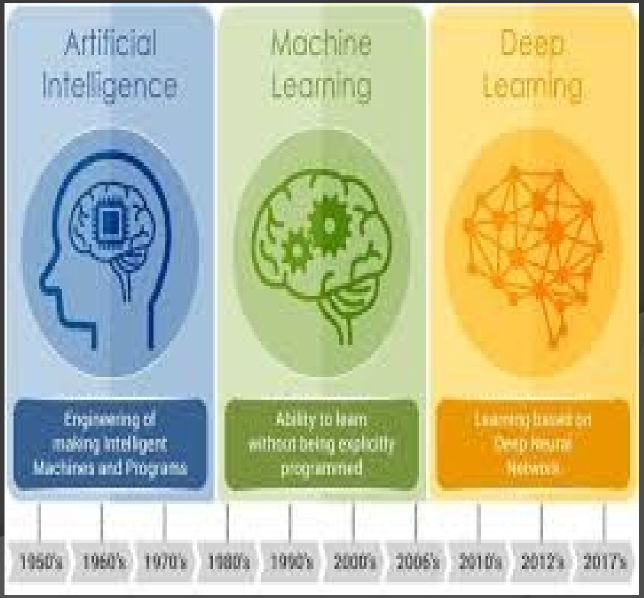
- Deep learning is a subset of ML that uses **artificial neural networks** with many layers (hence "deep") to model complex patterns in large volumes of data.
- It is especially powerful in tasks like **image recognition**, **natural language processing**, and **speech recognition**.
- **Example**: Self-driving cars use deep learning to detect pedestrians, signs, and obstacles.
- **Key technology**: Deep neural networks (DNNs), convolutional neural networks (CNNs), recurrent neural networks (RNNs).

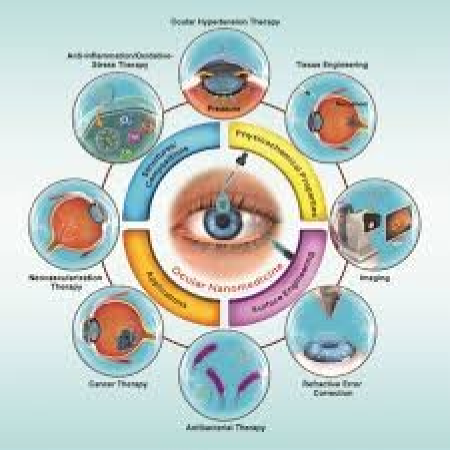


So,

- **ML** is the broader field focused on learning from data.
- **DL** is a specialized, more powerful approach using layered neural networks, especially for unstructured data like images and text.







Challenges in Ocular Surface

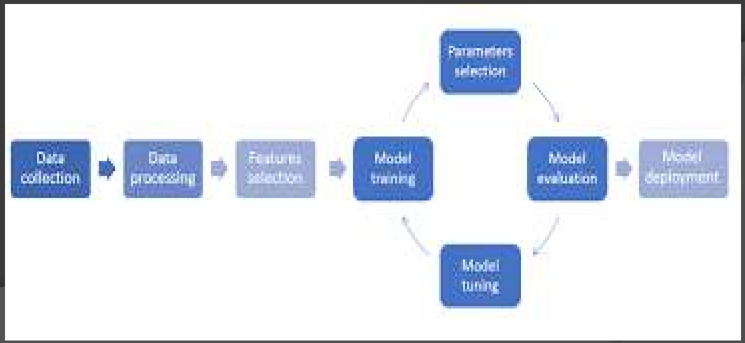
- Unlike retinal imaging (standard fundus photos), ocular surface assessment uses **diverse data**: anterior segment photos, topography maps (Pentacam), slit-lamp microscopy, and tear-film metrics .

- **Variability** in image quality (illumination, eyelid position), and **subjective grading** (e.g. pterygium severity) **complicate diagnosis**.

- AI can standardize interpretation by learning consistent image features, potentially improving inter-observer agreement.

AI Model Development Pipeline

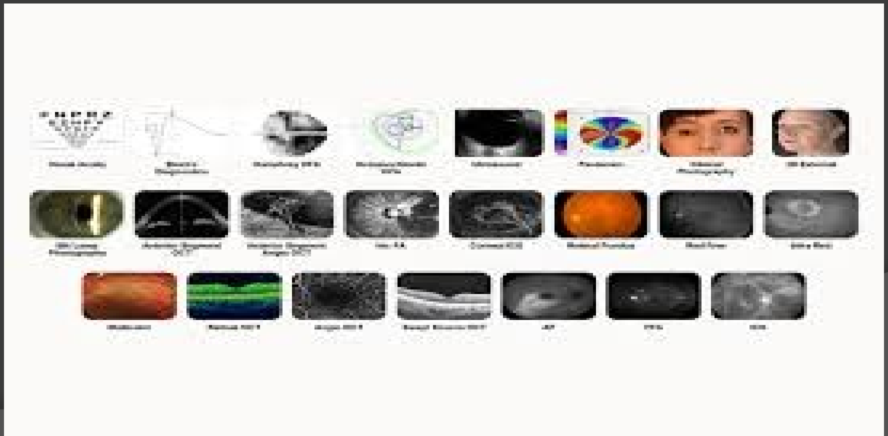
- A typical AI workflow involves: collecting and curating a large dataset of ocular surface images, excluding low-quality data, then splitting into **training**, **validation**, and **test** sets .
- Deep neural networks (e.g. CNNs) are trained on the labeled images to learn features. Models are iteratively refined on the validation set, then evaluated on held-out test images to measure accuracy .
- Model performance is **quantified** (accuracy, sensitivity, specificity) before considering clinical deployment.



Ocular Surface Imaging Modalities

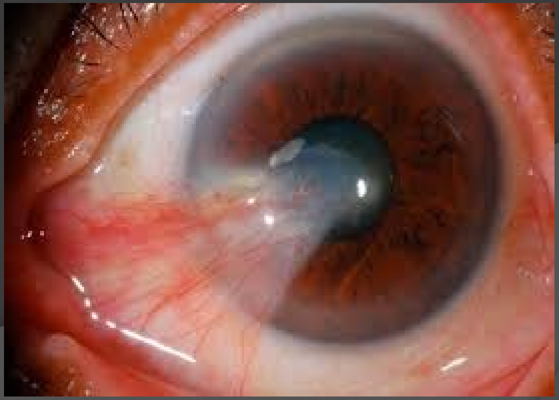
- Various imaging devices are used in OSD diagnosis : anterior segment photography (pterygium), corneal topography/tomography (keratoconus), slit-lamp microscopy/confocal (keratitis), and meibography/interferometry (dry eye).

- AI algorithms have been **adapted for each image type** to automatically detect disease patterns .



Pterygium: Background

- **Pterygium:** is a fibrovascular growth of conjunctiva onto the cornea, commonly linked to UV exposure (seen in outdoor workers) .
- It causes redness, irritation, induced astigmatism and, in advanced cases, vision encroachment .
- Grading **(size/vascularity)** is usually done **subjectively**.
- Early detection allows timely management before vision is threatened.



AI in Pterygium Diagnosis

- Early AI approaches used image processing (color segmentation, Hough transforms) with ~85–89% accuracy .
- Deep learning (CNN) systems now achieve higher performance. For example, “Pterygium-Net” detected pterygium with 95% sensitivity and 98.3% specificity.
- An EfficientNet-B6 based model classified images into **normal**, **pterygium requiring observation**, and **pterygium requiring surgery** with ~94.7% accuracy .
- These AI tools closely match expert diagnoses, offering objective screening especially useful in primary care or underserved areas .

AI in Pterygium Surgery Planning

- Predictive AI aids surgical decision-making.
- A DL model analyzing pre-op images predicted recurrence risk (80% specificity) .
- Patients flagged as high-risk could receive adjuncts (e.g., mitomycin C, graft) or closer monitoring.
- AI may also assist intra-operative planning: automated measurements of pterygium size could standardize excision margins and graft sizing.
- Overall, AI-driven risk stratification can improve surgical outcomes and resource allocation.
- AI can quantify immuno-histochemistry on excised pterygium tissue, improving reproducibility of pathological evaluation .

Keratoconus: Background

- **Keratoconus (KC):** is a progressive non-inflammatory thinning of the cornea leading to a cone-shaped protrusion and irregular astigmatism.

- Advanced KC causes significant vision distortion, but early (forme fruste) cases may be hard to detect clinically .
- Diagnosis relies on corneal tomography (Pentacam) to detect subtle curvature and thickness changes. Early identification is key (for timely collagen cross-linking).
- AI algorithms can analyze corneal maps to detect minute irregularities that precede clinical signs.

AI in Keratoconus Diagnosis

- Multiple AI models have been trained on corneal topography/tomography data. They achieve very high accuracy for established KC: reported models have ~99% accuracy .
- Since the signs of intermediate and advanced KC are quite common, clinical diagnosis is straightforward.
- **Atypical KC includes:** KC suspect (KCS), forme fruste KC (FFKC), and sub-clinical KC (SKC).
- AI approach increases its sensitivity up to 97.2% in abnormal eyes, eyes with KC, those with SKC, and normal eyes respectively.
- The diagnostic accuracy of the AI approach was further improved by including the posterior corneal surface and corneal thickness data

AI in Keratoconus Management

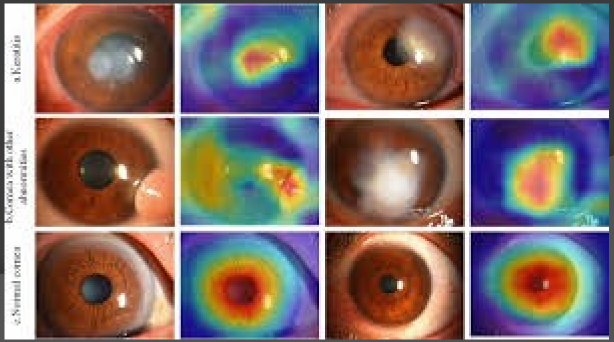
- Predictive AI tools may forecast disease progression. For example, deep learning on sequential corneal maps can predict which eyes will worsen, informing the timing of interventions (e.g. cross-linking).
- AI could assist in surgical planning: modeling corneal behavior to optimize cross-linking protocols .
- For contact lens and IOL planning, AI could simulate corneal refractive changes to optimize lens design for keratoconic eyes.
- Post-keratoplasty, AI may aid refractive management by simulating astigmatism outcomes.

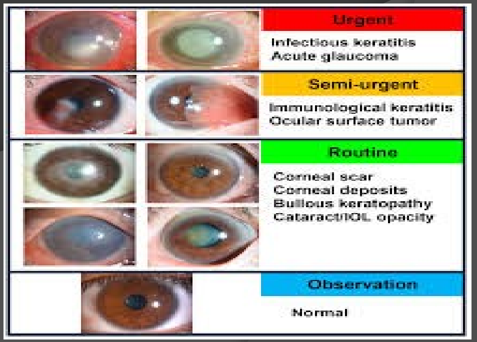
Infectious Keratitis: Background

- Infectious keratitis (IK) is corneal infection by bacteria, fungi, viruses or protozoa, causing pain, photophobia, redness, and ulcers .
- It is a significant global health issue **(5th leading cause of blindness)**.
- Delays in correct diagnosis can lead to vision loss.
- Distinguishing etiology **(bacterial** vs **fungal** vs **viral)** usually requires culture, which is slow and often in-conclusive.
- Clinical signs overlap among pathogens.
- Rapid, accurate tools are needed for appropriate treatment.

AI in Keratitis Diagnosis

- AI models have been developed to assist IK diagnosis. For example, one study trained various CNNs on slit-lamp images: the best model (EfficientNet B3) had 70.3% accuracy (sens 74%, spec 64%) .
- Another DL model on confocal microscopy achieve sensitivity 91.9%, specificity 98.3% for general keratitis detection .
- AI has been applied to sub-type identification: models achieved 80–98% accuracy in distinguishing infectious vs non-infectious keratitis, and bacterial vs fungal IK .
- These results approach clinician-level performance, suggesting AI could aid **early triage**.



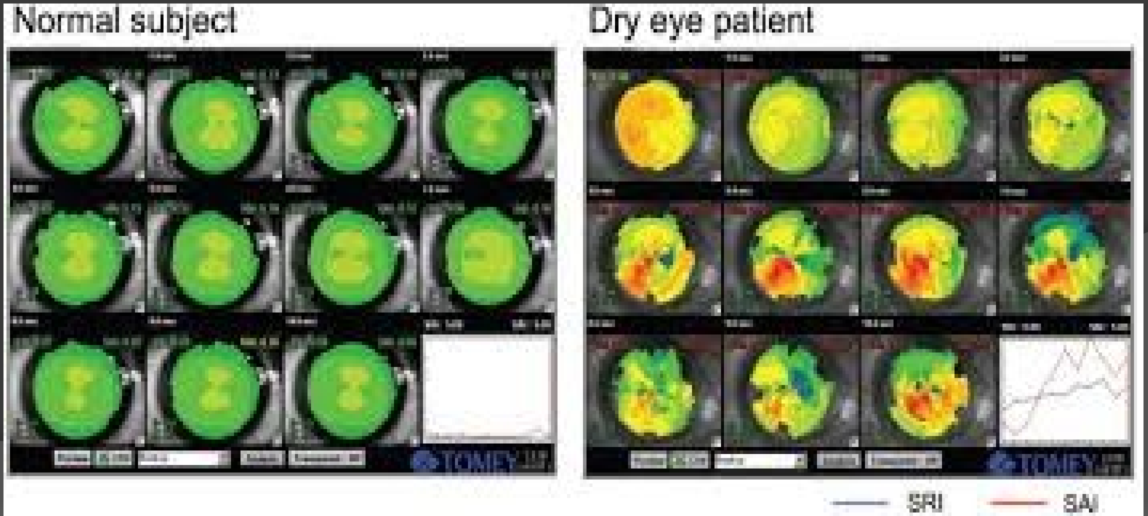


Dry Eye Disease: Background

- Dry eye is a chronic condition of the tear film and ocular surface, leading to irritation, fluctuating vision, and inflammation .
- It is highly prevalent (especially in older adults) and multi-factorial (tear deficiency, meibomian gland dysfunction, environment) .
- Patients suffer from discomfort, light sensitivity, and reduced quality of life.
- Diagnosis is challenging due to variable symptoms and lack of a single definitive test .
- Standard exams include tear breakup time (TBUT), Schirmer's test, corneal staining, and meibography.
- AI offers the potential for objective, quantitative assessment of these factors.

AI in Dry Eye : Diagnosis

- AI has been used to analyze meibography (infrared images of eyelid glands). With 95.6% accuracy in grading MG drop-out , significantly better than human raters.
- DL on confocal images can diagnose obstructive MGD: with 92.1% sensitivity and 98.8% specificity
- These AI systems provide rapid, objective scoring of gland health, aiding dry eye diagnosis and grading.



AI in Tear Film and Corneal Analysis

- DL can detect tear film break-up spots on fluorescein videos to screened dry eye with 83% sensitivity and 95% specificity .
- DL can use video of blinking and TBUT to diagnose dry eye (accuracy 83%), demonstrating automated blink analysis as a new method.
- Also, AI use AS-OCT images to segment tear meniscus height, reducing analysis time dramatically (100× faster than manual).
- It achieved 84.6% accuracy for dry eye detection, out-performing traditional slit-lamp staining tests.
- **Overall, AI enables rapid, quantitative analysis of tear film and corneal features, potentially yielding more reliable dry eye diagnostics**.

Predictive Modeling with AI

- AI uses baseline data (imaging, patient factors) to forecast outcomes (disease progression, treatment response).
- AI models can learn from cohorts to predict recurrence (e.g. pterygium) or severity (e.g. keratoconus).
- This approach shifts care from reactive to pro-active, allowing pre-emptive measures.

AI in Treatment Planning

- AI has the potential to **inform personalized therapy** by quantifying disease severity and predicting outcomes.
- This means using AI-derived metrics (gland loss score, topography irregularity) to guide treatment intensity.
- For instance:
  - A higher AI-detected pterygium severity score might indicate earlier surgery.
  - A high-risk keratoconus progression score might prompt prophylactic CXL.

Limitations and Challenges

- **Data limitations:** Many AI studies use limited, single-center datasets. Models may not generalize to diverse populations or imaging systems . External validation on varied data is essential.

- **Model interpretability:** Deep learning models are often “black boxes.” Clinicians must understand the basis of AI recommendations (e.g., highlight image areas driving a diagnosis) to trust them.

- **Workflow integration:** Practical deployment requires seamless integration with existing imaging platforms. Clinician training and user-friendly interfaces are needed for adoption.

- **Ethical/regulatory issues:** Patient privacy (image data security), informed consent for AI use, and responsibility for errors must be addressed.

Clinical Integration and Tele-medicine

- **Tele-health:** AI can empower non-specialists to screen OSD remotely.

- **Screening programs:** Mobile clinics could use AI to triage dry eye or MGD from captured images, referring only positive cases to ophthalmologists. This extends specialist reach to underserved areas.
- **Pilot studies** are underway to test such integration, assessing both efficacy and user acceptability.
- **AI tools should fit into clinical workflow**. Examples: AI-enabled slit-lamp attachments, cloud-based analysis portals, or smartphone apps for preliminary screening

Future Directions

- **Larger, diverse datasets:**

  - Multicenter collaborations will improve model robustness.
- **Multi-modal AI:**

  - Combining imaging with patient history, biomarkers, and wearable sensors could yield more accurate predictions.
- **Real-time AI:**

  - Advances in computing may allow live AI feedback (during surgery or examinations).
  - Surgeons could use AI overlays on the microscope to highlight pathology.
- **Wearables and mobile health:**

  - Wearable devices (smart contacts, glasses) may monitor eye parameters (humidity, blink completeness), with AI algorithms detecting early dryness or inflammation.
- **Regulatory and reimbursement frameworks:**

  - As evidence grows, governments will define standards for AI validation.
  - Ophthalmology societies may provide guidelines on clinical use of AI tools.

Conclusions

- Recent research shows AI can accurately detect and classify ocular surface diseases, achieving high accuracy.
- AI offers objective, reproducible assessments, potentially improving early diagnosis and standardizing care.
- In underserved settings, AI-based screening could expand access to eye care.
- However, challenges in data quality, validation, and integration remain.
- Collaborative efforts between clinicians and AI specialists are needed to ensure safe, effective adoption.
- Ophthalmologists should stay informed about AI advances.
  - By standardizing assessments, AI can help ensure patients receive the **right intervention at the right time.**


THANK
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