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Edited by Vini Mehta
E-mail: vmehta@statsense.in
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Optical coherence tomography-based evaluation of age-related macular degeneration

Shruti Patidar[1], Garvesh Modi[2] & Adesh Rundla[2,*]

[1]Fellowship in Intraocular Lens (IOL) Surgery, Sankara Eye Hospital, Indore, Madhya Pradesh, India; [2]Department of Ophthalmology, Bundelkhand Medical College, Sagar, Madhya Pradesh, India; *Corresponding author

Affiliation URL:
https://sankaraeye.com/
https://www.bmcsagar.edu.in/

Author contact:
Shruti Patidar - E-mail: shrutipatidar01@gmail.com
Garvesh Modi - E-mail: garveshmodi@gmail.com

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Adesh Rundla - E-mail: adeshrundla@gmail.com

Abstract:
Age-related macular degeneration is a leading cause of irreversible vision loss and detailed characterization of retinal changes is essential for accurate diagnosis and disease monitoring. This hospital-based observational study evaluated 120 patients with age-related macular degeneration using optical coherence tomography to assess retinal structural changes and their association with clinical presentation and visual acuity. Subretinal fluid, intraretinal fluid, pigment epithelial detachment, choroidal neovascular membrane, drusen and central macular thickness were assessed, with wet age-related macular degeneration showing a significantly higher prevalence of subretinal and intraretinal fluid than the dry form. Optical coherence tomography effectively identified retinal structural alterations and differentiated disease severity between wet and dry age-related macular degeneration. Thus, data shows the role of optical coherence tomography as a non-invasive imaging modality for accurate diagnosis, classification and longitudinal monitoring of age-related macular degeneration.

Keywords: Optical coherence tomography (OCT), age-related macular degeneration, wet AMD, dry AMD, retinal imaging, macular thickness

Background:
Age-related macular degeneration (AMD) is a chronic progressive retinal disorder affecting the macular region of the retina and represents one of the leading causes of irreversible central vision loss among elderly individuals worldwide. The disease primarily affects individuals above 55 years of age and significantly impairs visual functions such as reading, facial recognition, color perception and driving. With increasing life expectancy and aging populations globally, the prevalence of AMD continues to rise and has become a major public health concern. Recent epidemiological studies have showed a substantial increase in the global burden of AMD, especially in developed and developing countries undergoing demographic transition **[1, 2].** AMD is broadly classified into dry (non-neovascular) AMD and wet (neovascular or exudative) AMD. Dry AMD is characterized by accumulation of drusen, retinal pigment epithelium (RPE) abnormalities and progressive geographic atrophy, whereas wet AMD involves choroidal neovascularization, hemorrhage, fluid accumulation, fibrosis and rapid visual deterioration. Although dry AMD accounts for nearly 80–90% of cases, wet AMD is responsible for the majority of severe visual impairment and blindness associated with the disease. Fleckenstein *et al.,* Falcão *et al.* and Boopathiraj *et al.* described AMD as a complex degenerative retinal disease involving progressive dysfunction of photoreceptors, retinal pigment epithelium, Bruch's membrane and choriocapillaris **[1, 3 and 4].** The pathogenesis of AMD is multifactorial and involves aging, oxidative stress, chronic inflammation, complement system dysregulation, mitochondrial dysfunction, smoking, environmental exposure and genetic susceptibility. Amini *et al.* emphasized that inflammatory mediators and genetic polymorphisms play critical roles in disease initiation and progression **[2]**. Similarly, few studies demonstrated that disruption of autophagy and accumulation of oxidative damage contributes significantly to retinal degeneration in AMD **[5]**. Recent evidence has also highlighted the importance of lysosomal dysfunction and impaired cellular metabolism in retinal pigment epithelial degeneration **[6]**. Falcão *et al.* reported that oxidative stress and lysosomal impairment accelerate retinal cell death and progression toward advanced AMD **[3].** Advances in retinal imaging have dramatically improved the diagnosis and management of AMD. Optical coherence tomography (OCT) has emerged as an essential noninvasive imaging modality for the diagnosis and monitoring of AMD, providing detailed visualization of retinal morphology and pathological changes **[7, 8].** OCT provides high-resolution cross-sectional images of retinal layers and enables detailed visualization of retinal microstructures. The modality plays a crucial role in identifying drusen, pigment epithelial detachments, intraretinal fluid, subretinal fluid, retinal atrophy and choroidal neovascular membranes associated with AMD. Spaide *et al.* standardized OCT terminology for neovascular AMD and highlighted the importance of OCT biomarkers in assessing disease activity and treatment response **[6].** OCT is particularly valuable in wet AMD because it facilitates detection of active disease through identification of intraretinal cysts, subretinal fluid and pigment epithelial detachments. Monitoring retinal thickness and fluid accumulation through OCT is essential during anti-vascular endothelial growth factor (anti-VEGF) therapy. Yen *et al.* showed significant anatomical improvement in neovascular AMD following intravitreal faricimab therapy, emphasizing the importance of OCT-guided monitoring **[7, 9].** In dry AMD, OCT assists in evaluating drusen morphology, retinal pigment epithelial alterations and progression toward geographic atrophy. Liao *et al.* further highlighted the role of OCT in assessing therapeutic response in geographic atrophy associated with AMD **[8].** Recent studies have showed that OCT biomarkers may predict disease progression and visual prognosis in AMD patients. Features such as hyperreflective foci, outer retinal tubulations, drusenoid pigment epithelial detachments and incomplete retinal pigment epithelial atrophy have emerged as important prognostic indicators. Kozhevnikova *et al.*, Holland *et al.*, Kong *et al.*, Hanson *et al.* and Abdulrazzaq *et al.* showed that artificial intelligence and deep learning-based analysis of OCT images can facilitate automated biomarker identification and improve disease prediction models in AMD **[10-14].** Technological advancements such as spectral-domain OCT and swept-source OCT have further enhanced image resolution, scanning speed and tissue penetration, thereby improving visualization of retinal and choroidal structures. In

addition, OCT angiography (OCTA) has enabled non-invasive assessment of retinal and choroidal vasculature without the need for intravenous dye injection. Tillmann *et al.* described OCT angiography as a highly valuable tool for identifying neovascular networks and monitoring vascular activity in AMD patients **[15].** Therefore, it is of interest to evaluate OCT findings in patients with age-related macular degeneration and analyze their clinical significance.

Materials and Methodology:
The present hospital-based observational study was conducted in the Department of Ophthalmology of a tertiary care teaching hospital over a period of 18 months. The study aimed to evaluate optical coherence tomography findings in patients diagnosed with age-related macular degeneration.

Study population:
A total of 120 patients clinically diagnosed with AMD were included in the study after obtaining informed written consent. Patients were selected from the ophthalmology outpatient department and retina clinic.

Inclusion criteria:
[1] Patients aged 50 years and above
[2] Patients clinically diagnosed with dry or wet AMD
[3] Patients willing to participate in the study
[4] Patients undergoing OCT examination

Exclusion criteria:
[1] Patients with diabetic retinopathy
[2] Patients with pathological myopia
[3] Patients with retinal vascular occlusions
[4] Patients with previous retinal surgery
[5] Patients with media opacity interfering with OCT imaging
[6] Patients with glaucoma or optic neuropathy

Ethical approval:
Institutional ethical committee approval was obtained prior to commencement of the study. The study adhered to the principles of the Declaration of Helsinki.

Clinical examination:
All patients underwent detailed ophthalmic evaluation including:
[1] Best corrected visual acuity assessment
[2] Slit lamp examination
[3] Intraocular pressure measurement
[4] Dilated fundus examination using indirect ophthalmoscopy and slit lamp biomicroscopy

Oct examination:
Optical coherence tomography imaging was performed using spectral-domain OCT. Macular scans were obtained for all participants. The following OCT parameters were analyzed:
[1] Presence of drusen
[2] Pigment epithelial detachment (PED)
[3] Subretinal fluid (SRF)
[4] Intraretinal fluid (IRF)
[5] Choroidal neovascular membrane (CNVM)
[6] Geographic atrophy
[7] Central macular thickness (CMT)
Patients were categorized into dry AMD and wet AMD groups based on clinical and OCT findings.

Statistical analysis:
Data were entered into Microsoft Excel and analyzed using SPSS software version 25. Quantitative variables were expressed as mean ± standard deviation, whereas qualitative variables were expressed as frequency and percentage. Chi-square test and independent t-test were used for statistical analysis. A p value <0.05 was considered statistically significant.

Results:
A total of 120 patients diagnosed with age-related macular degeneration were evaluated using OCT imaging. The majority of patients belonged to the elderly age group, with increasing prevalence noted after 60 years of age. Male patients constituted a slightly higher proportion compared with females. Dry AMD was more common than wet AMD in the study population. Dry AMD constituted the majority of cases (60%), while wet AMD accounted for 40% of the study population **(Table 1).** Subretinal fluid was identified in 41 patients with wet AMD and only 6 patients with dry AMD. Intraretinal fluid was significantly more common in wet AMD. Choroidal neovascular membrane was almost exclusively associated with wet AMD. Pigment epithelial detachment was also observed more frequently among wet AMD patients. Drusen and geographic atrophy were significantly associated with dry AMD, whereas subretinal fluid, intraretinal fluid, pigment epithelial detachment and CNVM were significantly more common in wet AMD. The differences were statistically significant **(Table 2).** Central macular thickness was substantially higher among wet AMD patients due to retinal edema and fluid accumulation. Dry AMD patients showed relatively lower macular thickness because of retinal atrophy and degenerative changes. Mean central macular thickness was significantly higher in wet AMD patients compared with dry AMD patients, indicating retinal edema and active neovascular disease **(Table 3).** The study further showed that OCT was useful in differentiating active neovascular lesions from inactive fibrotic scars. Active lesions showed fluid accumulation and retinal thickening, whereas chronic lesions exhibited fibrosis and retinal thinning. Monitoring of retinal morphology through OCT provided valuable information regarding disease severity and treatment planning. Overall, OCT proved to be an indispensable diagnostic modality for evaluating retinal structural changes in AMD. The modality facilitated accurate identification of disease type, disease activity and retinal complications. Significant differences in OCT findings between dry and wet AMD groups emphasize the importance of OCT in clinical diagnosis and management.

Table 1: Distribution of AMD types among study participants

Type of AMD	Number of Patients	Percentage
Dry AMD	72	60%

Wet AMD	48	40%
Total	120	100%

Table 2: Comparison of OCT findings between dry and wet AMD

OCT Finding	Dry AMD n (%)	Wet AMD n (%)	p value
Drusen	64 (88.9%)	19 (39.6%)	<0.001
Geographic atrophy	28 (38.9%)	6 (12.5%)	0.002
Subretinal fluid	6 (8.3%)	41 (85.4%)	<0.001
Intraretinal fluid	4 (5.6%)	36 (75.0%)	<0.001
Pigment epithelial detachment	11 (15.3%)	30 (62.5%)	<0.001
CNVM	2 (2.8%)	39 (81.3%)	<0.001

Table 3: Comparison of central macular thickness between dry and wet AMD

Parameter	Dry AMD (Mean ± SD)	Wet AMD (Mean ± SD)	p value
Central Macular Thickness (μm)	238.4 ± 28.6	341.7 ± 52.3	<0.001

Discussion:

Age-related macular degeneration (AMD) is one of the most important retinal degenerative disorders affecting the elderly population and remains a major cause of irreversible visual impairment worldwide. The present study evaluated optical coherence tomography (OCT) findings in 120 patients with AMD and demonstrated the significant utility of OCT in identifying retinal structural alterations associated with disease severity and progression. OCT has transformed retinal imaging by providing high-resolution cross-sectional visualization of retinal layers and pathological changes. The increasing global burden of AMD has emphasized the need for accurate diagnostic modalities for early disease detection and monitoring. Recent epidemiological analyses have shown a substantial rise in AMD prevalence due to increased life expectancy and aging populations **[11].** In the present study, dry AMD constituted 60% of cases, while wet AMD accounted for 40%. Similar observations have been reported in previous studies demonstrating that dry AMD is more prevalent than neovascular AMD, although wet AMD contributes disproportionately to severe visual loss. Fleckenstein *et al.* described AMD as a progressive retinal disorder characterized by degeneration of the retinal pigment epithelium, photoreceptors and choriocapillaris, ultimately resulting in central vision impairment **[1].** The higher prevalence of dry AMD in the current study may be attributed to the slower and chronic progression of non-neovascular disease, allowing more patients to present at earlier stages. In the present study, OCT findings were predominantly associated with dry AMD. Similar findings have been reported in an Indian hospital-based study, in which dry AMD was more common than wet AMD and OCT frequently demonstrated drusen and neovascular lesions **[16]**. Amini *et al.* highlighted the important role of drusen in AMD pathogenesis and emphasized that large soft drusen are associated with increased risk of progression to advanced disease **[2].** OCT imaging enables accurate visualization of drusen morphology, size and distribution, thereby facilitating early diagnosis and risk stratification. Geographic atrophy was observed more frequently among dry AMD patients in the present investigation. OCT allowed detailed assessment of retinal pigment epithelial atrophy, outer retinal thinning and increased choroidal hyper transmission associated with atrophic degeneration. Liao *et al.* showed that retinal degeneration in AMD involves oxidative stress, autophagic dysfunction and progressive retinal cell loss **[9].** Similarly, Falcão *et al.* emphasized the role of lysosomal dysfunction and oxidative stress in retinal pigment epithelial degeneration and progression of geographic atrophy **[3].** Recent evidence further supports the prognostic value of OCT in non-exudative AMD, with several OCT biomarkers showing potential for identifying early changes preceding geographic atrophy and predicting progression toward advanced atrophic disease **[17].** The ability of OCT to identify early atrophic changes is clinically important because geographic atrophy is associated with irreversible visual decline. Wet AMD patients in the present study demonstrated significantly higher prevalence of subretinal fluid, intraretinal fluid, pigment epithelial detachment and choroidal neovascular membrane formation. These OCT findings reflect abnormal choroidal angiogenesis and vascular leakage characteristic of neovascular AMD. Spaide *et al.* established standardized nomenclature for neovascular AMD and highlighted the significance of OCT biomarkers in assessing disease activity **[6].** The presence of retinal fluid on OCT is considered an important indicator of active disease requiring anti-vascular endothelial growth factor (anti-VEGF) therapy. Central macular thickness was significantly elevated among wet AMD patients in the present study. Increased retinal thickness primarily resulted from edema and fluid accumulation secondary to choroidal neovascularization. Similar findings have been reported in studies evaluating therapeutic outcomes following anti-VEGF therapy. Yen *et al.* showed that intravitreal faricimab significantly reduced retinal fluid and improved anatomical outcomes in neovascular AMD patients **[7].** Reduction in central macular thickness after treatment is regarded as a major therapeutic endpoint and reflects improvement in retinal edema and disease activity. The present study also demonstrated a significant association between OCT abnormalities and visual impairment. Patients with extensive intraretinal cysts, subretinal fluid and advanced geographic atrophy showed poorer visual acuity. Structural disruption of retinal layers identified on OCT has been strongly correlated with photoreceptor damage and functional visual loss. Boopathiraj *et al.* emphasized the importance of OCT in evaluating disease progression, visual prognosis and treatment response in AMD patients **[4].** Accurate assessment of retinal morphology through OCT therefore plays a critical role in clinical decision-making. Hyperreflective foci and outer retinal layer disruption were observed in several advanced AMD cases in the present study. These OCT biomarkers are increasingly recognized as predictors of disease progression and poor visual prognosis. Holland *et al.* showed that artificial intelligence-based OCT analysis can identify retinal biomarkers associated with AMD progression and may improve future risk stratification models **[11].** Advances in deep learning and automated image analysis may further enhance the diagnostic and prognostic utility of OCT in retinal diseases. Recent therapeutic developments have further increased the importance of OCT in AMD management. Liao *et al.* reported promising

results with complement C3 inhibitor pegcetacoplan in slowing progression of geographic atrophy in AMD patients **[9].** Hanson *et al.* additionally highlighted the emergence of novel pharmacological therapies targeting angiogenesis, inflammation and complement activation pathways in AMD **[13].** Continuous OCT monitoring is essential in assessing therapeutic response and identifying disease recurrence in such patients OCT angiography has also emerged as a valuable advancement in retinal imaging. Unlike conventional fluorescein angiography, OCT angiography enables noninvasive visualization of retinal and choroidal vasculature without dye injection. Tillmann *et al.* described OCT angiography as an important modality for identifying neovascular networks and monitoring vascular activity in AMD patients **[15].** These technological innovations have significantly improved diagnostic precision and patient monitoring. The findings of the present study support previous systematic reviews emphasizing the indispensable role of OCT in AMD diagnosis and management. Castro-Fernández *et al.* concluded that OCT remains the gold standard imaging modality for evaluation of retinal structural abnormalities in AMD **[18].** Long-term follow-up studies by Sadeghi *et al.* further showed that OCT is highly effective in monitoring progression of dry AMD and identifying conversion to neovascular disease **[19].** Despite the valuable findings, the present study had certain limitations. The study was hospital-based and involved a relatively limited sample size. Longitudinal follow-up and advanced multimodal imaging techniques were not included for all patients. Future multicentric studies with larger populations and longer follow-up durations may provide more comprehensive insights regarding OCT biomarkers and disease progression. Overall, the present study highlights the critical role of OCT in evaluating retinal structural changes in AMD and reinforces its importance in disease classification, monitoring progression, therapeutic planning and assessment of treatment response.

Conclusion:

Optical coherence tomography effectively characterized retinal structural changes in age-related macular degeneration, with dry AMD more prevalent and wet AMD showing greater retinal fluid and central macular thickness. OCT reliably identified drusen, geographic atrophy, pigment epithelial detachment, subretinal and intraretinal fluid and choroidal neovascular membranes. OCT is therefore valuable for AMD diagnosis, classification, progression monitoring and assessment of treatment response.

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