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Integrated Multimodal OCT Imaging: A Non-Invasive Alternative for the Identification, Characterization, and Localization of Capillary Macroaneurysms (CMAs) in Diabetic Macular Edema

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Abstract

Background

To evaluate the utility of integrated multimodal OCT imaging—combining B-scan, "En face" reconstructions, and simultaneous color fundus photography—for the identification, characterization, and topographical localization of capillary macroaneurysms (CMAs) in diabetic macular edema (DME).

Methods

This observational study evaluated 104 eyes (52 patients) with DME using an integrated multimodal OCT protocol. Utilizing synchronous swept-source B-scans, structural "En face" OCT, and simultaneous color fundus photography from a single acquisition, we identified CMAs (defined as aneurysmal dilatations ≥ 150 µm). This integrated approach allowed for precise topographical localization relative to the fovea and characterization of their spatial relationship with exudative markers.

Results

The prevalence of CMAs was 61.6% in eyes with DME. Lesion diameters ranged from 150 to 290 µm. Qualitative analysis showed that 75% of CMAs were associated with hard exudates, typically located at the center of circinate rings. Topographically, 72% of CMAs were located ≥ 1000 µm from the foveal center, making them eligible for targeted focal laser treatment. DME associated with CMAs frequently presented an asymmetrical, eccentric, and polylobed morphology on thickness mapping.

Conclusions

Integrated multimodal OCT imaging is a highly effective, non-invasive method for diagnosing CMAs. This approach provides precise lesion mapping and serves as a reliable alternative to indocyanine green angiography, facilitating the planning of selective laser photocoagulation in accordance with recent consensus recommendations.

Background

Capillary macroaneurysms (CMAs), also referred to as telangiectatic capillaries, are aneurysmal dilatations within the retinal capillary networks with a diameter typically exceeding 150 µm [1, 2]. These lesions are identified in approximately two-thirds of cases involving chronic diabetic macular edema (DME) and retinal vein occlusions [2, 3, 4]. Clinically, CMAs are significant as they represent a source of resistance and dependency on anti-vascular endothelial growth factor (anti-VEGF) therapy; however, targeted focal laser photocoagulation of these specific lesions has proven highly effective [1, 3, 5, 6].

While indocyanine green angiography (ICGA) remains the gold standard for identifying CMAs, it is invasive and often inaccessible in many settings [2]. Integrated multimodal optical coherence tomography (OCT) imaging—combining the simultaneous acquisition and synchronous analysis of B-scan slices, "En face" structural images, and color fundus photography—represents a high-performance, non-invasive, and accessible alternative for precise identification, characterization, and topographical mapping of CMAs.

The objective of this study is threefold:

- Protocol standardization: to describe a standardized multimodal OCT protocol for the precise detection and localization of CMAs through synchronous imaging analysis.
- Prevalence assessment: to evaluate the prevalence of CMAs within a cohort of patients with DME using this non-invasive approach.
- Characterization: to analyze CMAs in terms of size, number, and foveal distance, while evaluating their spatial relationship with exudative biomarkers of DME.

Methods

We conducted a prospective observational study of 52 patients (104 eyes) followed for DME at the Ophthalmology Department of the Avicenne Military Hospital in Marrakech between September 2024 and December 2025. The study included both treatment-naïve patients and those previously treated with focal laser and/or intravitreal injections (IVI).

All patients underwent imaging using the DRI OCT Triton Plus (Topcon, Tokyo, Japan), a swept-source multimodal OCT platform. This technology utilizes a 1050 nm wavelength and an acquisition speed of 100,000 A-scans per second, ensuring optimal tissue penetration through edematous retina. Our protocol relied on a 6 x 6 mm 3D volume scan centered on the fovea. This module generates a high-density scan (512 A-scans x 512 B-scans), enabling synchronous structural analysis of B-scan slices, "En face" reconstructions, and simultaneous color fundus photography using IMAGEnet 6 software. Image analysis was performed by two independent readers.

Capillary macroaneurysms (CMAs) were defined as lesions with a diameter ≥ 150 µm, measured along the major axis on B-scan slices, including the lesional walls. Our detection protocol utilized a bidirectional correlation between B-scan slices and coronal "En face" reconstructions segmented at the levels of the superficial and deep capillary plexuses (specifically the inner nuclear and outer plexiform layers):

- B-scan to "En Face": suspect lesions identified during dynamic B-scan scrolling were measured to confirm CMA criteria. This mode allowed for the analysis of internal reflectivity, determination of depth within the capillary plexuses, and instantaneous localization on the corresponding "En face" image via an integrated cross-hair cursor system.

- "En Face" to B-scan: conversely, suspect "target-like" lesions visualized on the "En face" structural map were selected to immediately display the corresponding B-scan slice, facilitating morphological confirmation.

For the identification and characterization of CMAs, our approach leverages the software integration of the platform, enabling synchronized multimodal analysis. Selecting a lesion within the 'En face' module instantly projects its exact position onto the color fundus photograph by the intersection of the XY reference axes (Fig. 3). This system also facilitates the overlay of structural 'En face' OCT images and retinal thickness maps directly onto the fundus image. This multimodal co-registration thus guarantees:"

The integrated nature of the platform allowed for the synchronized spatial registration of identified CMAs onto the simultaneous color fundus photograph. Selecting a lesion within the 'En face' module instantly projects its exact position onto the fundus photograph via the intersection of the XY reference axes (Fig. 3). This system also enables the overlay of structural 'En face' OCT images and retinal thickness maps directly onto the color fundus image. This multimodal co-registration thus guarantees:

- High-precision topographical mapping and the establishment of reliable markers for CMAs on the fundus image.
- Rigorous measurement of the distance between each identified CMA and the foveal center.
- Detailed spatial analysis of the relationship between CMAs and exudative biomarkers, such as hard exudates, cystic spaces, and localized areas of retinal thickening.

Results

The cohort consisted of 52 patients (32 men and 20 women), all with type 2 diabetes, with a mean age of 67 years (range: 55–82 years). Of the 104 eyes included, 73 presented with DME according to ETDRS criteria. At least one CMA was identified in 61.6% of eyes with DME (Table 1).

Within the 6 x 6 mm macular scan volume, the number of CMAs per eye ranged from 1 to 11. the largest lesion reached a vertical diameter of 290 µm. Topographically, 72% of CMAs were located ≥ 1000 µm from the foveal center, making them eligible for targeted conventional laser photocoagulation. An association between CMAs and hard exudates was observed in 75% of eyes with DME (Table 2).

Qualitative analysis revealed that these CMAs:

- Preferentially occupy the center of circinate exudate rings (Fig. 6A).
- Are frequently positioned in close proximity to intraretinal cystic spaces in cystoid DME phenotypes (Fig. 6B).
- Often colocalize with areas of maximum retinal thickening on the thickness mapping (Fig. 6C).

Finally, DME associated with the presence of CMAs exhibited a characteristic asymmetrical, eccentric, and polylobed morphology on thickness mapping (Fig. 6C).

Discussion

Capillary macroaneurysms (CMAs), or telangiectatic capillaries (TelCaps), are voluminous aneurysmal dilatations (diameter ≥ 150 µm) arising within the retinal capillary networks [1, 2]. Frequently associated with chronic macular edema (ME) in diabetic retinopathy and retinal vein occlusions, they must be distinguished from arterial macroaneurysms. The latter occur on first- or second-order arterioles and are typically associated with systemic hypertension [2, 3, 5, 6]. CMAs are a frequent source of resistance to intravitreal injections (IVIs); however, targeted focal laser photocoagulation of these lesions can optimize DME management [1, 3, 5, 6].

On fundus examination, CMAs may appear as dark red or pinkish lesions, sometimes surrounded by a whitish cuff and often centered within circinate exudate rings [8]. Indocyanine green angiography (ICGA) is considered the gold standard for identification, revealing well-defined hypercyanescent spots that characteristically persist into the late phases [1, 2, 3, 7]. Conversely, fluorescein angiography (FA) is often hindered by early dye leakage [7], and OCT-angiography (OCT-A) is frequently limited by the slow flow within these lesions [1].

Recent advances in OCT have significantly improved the sensitivity for CMA detection [4]. In routine practice, identification relies on a dynamic analysis of B-scan slices, revealing ovoid structures with a vertical major axis, characterized by a hyperreflective wall, a hyporeflective lumen, and posterior shadowing. The 150 µm threshold is essential to distinguish them from standard microaneurysms, as photocoagulation of smaller lesions has not demonstrated significant clinical benefit [1, 3].

While OCT B-scans are highly sensitive for identification, "En face" imaging is essential for precise topographical localization. In the Imaging-Guided Targeted Laser (IGTL) procedure described by Pâques et al., frontal localization relies on ICGA [1], an invasive and often inaccessible exam in Morocco. In this context, "En face" structural OCT represents a promising alternative. This approach uses transverse reconstructions of B-scans to visualize retinal layers frontally (C-scans). On images segmented at the superficial and deep capillary plexuses, CMAs present a "target-like" appearance, with a hyperreflective rim and a hyporeflective center.

Unlike some OCT devices that generate "En face" reconstructions from standard structural scans, obtaining these images on the Topcon DRI OCT Triton Plus platform technically requires the OCT-A module, regardless of flow data. Our acquisition protocol (6×6 mm 3D macula, 512×512 scans) offers a lateral resolution of 20 µm, ensuring sensitive detection while covering the entire ETDRS grid. The analysis benefits from integrated automatic segmentation, generating "En face" images specifically targeting the inner nuclear layer (INL) and outer plexiform layer (OPL)—the zones where the capillary plexuses harboring CMAs are located.

In our cohort, the combined and synchronous analysis of B-scans and "En face" structural images revealed a CMA prevalence comparable to historical data obtained via ICGA [2, 4], thereby confirming the high sensitivity of this non-invasive method. Beyond simple identification, this integrated multimodal analysis allows for rigorous spatial localization and detailed characterization of the perilesional environment. It accurately documents the intimate relationship between these vascular anomalies and specific exudative biomarkers including lipid exudation, intraretinal cystic spaces, and localized retinal thickening. These anatomical correlations confirm the direct causal link between the identified CMAs and the adjacent macular edema. Ultimately, this multimodal approach optimizes the management of CMA-related DME, in accordance with the latest French Delphi consensus recommendations. These guidelines advocate for targeted focal laser photocoagulation of lesions located ≥ 1000 µm from the foveal center when associated with perifocal thickening, particularly in cases where exudates threaten central vision [9].

To our knowledge, while the utility of "En face" imaging is documented, few studies describe a standardized protocol for the combined and synchronous analysis of B-scans and "En face" images for CMA identification and localization. This protocol allows for the morphological identification of CMAs to be correlated with exudative DME biomarkers and their exact spatial projection onto fundus photography without invasive angiography, providing the high-precision mapping indispensable for selective photocoagulation.

Despite the relevance of this protocol, our study has limitations. First, the relatively small cohort size limits the statistical power of our observations. Furthermore, CMA identification relied exclusively on structural analysis based on size criteria. Finally, detection sensitivity may be compromised by media opacities, major retinal layer disorganization, or massive DME. Additional prospective studies with larger cohorts are necessary to establish formal consensus criteria for CMA diagnosis via integrated multimodal OCT.

Conclusions

Our study demonstrates that integrated multimodal OCT imaging—which synchronizes B-scan slices, structural "En face" reconstructions, and simultaneous color fundus photography—constitutes a non-invasive, reproducible, and high-performance alternative for the management of CMA-related DME. This approach facilitates the precise morphological identification of CMAs, their characterization in direct correlation with concomitant macular edema, and their exact topographical localization via spatial co-registration. Consequently, this protocol transforms the OCT platform from a standard diagnostic modality into a definitive planning roadmap for focal laser photocoagulation in accordance with current consensus recommendations.

Abbreviations

Anti-VEGF: Anti-Vascular Endothelial Growth Factor

CMA: Capillary Macroaneurysm

DME: Diabetic Macular Edema

ETDRS: Early Treatment Diabetic Retinopathy Study

FA: Fluorescein Angiography

FAZ: Foveal Avascular Zone

ICGA: Indocyanine Green Angiography

IGTL: Imaging-Guided Targeted Laser

INL: Inner Nuclear Layer

IVI: Intravitreal Injection

ME: Macular Edema

OCT: Optical Coherence Tomography

OCT-A: Optical Coherence Tomography Angiography

OPL: Outer Plexiform Layer

SS-OCT: Swept-Source Optical Coherence Tomography

TelCap: Telangiectatic Capillary

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the tenets of the Declaration of Helsinki. The study protocol was reviewed and approved by the Ethics Committee of the Avicenne Military Hospital, Marrakech, Morocco. Due to the observational and non-invasive nature of the imaging protocol, the requirement for written informed consent was waived by the committee.

Consent for publication

Not applicable as the study is observational and images are anonymized to ensure patient privacy.

Availability of data and materials

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

No funding was received for this study.

Authors' contributions

EAL: Project design, imaging protocol, and manuscript drafting. **FB**, **IE**, and **AL1**: Clinical examinations and data collection. **AL2** and **SB**: OCT acquisitions and image analysis. **FEA**: Study supervision and final critical revision. All authors have read and approved the final manuscript.

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Tables

Table 1 and 2 are available in the Supplementary Files section.

Figures

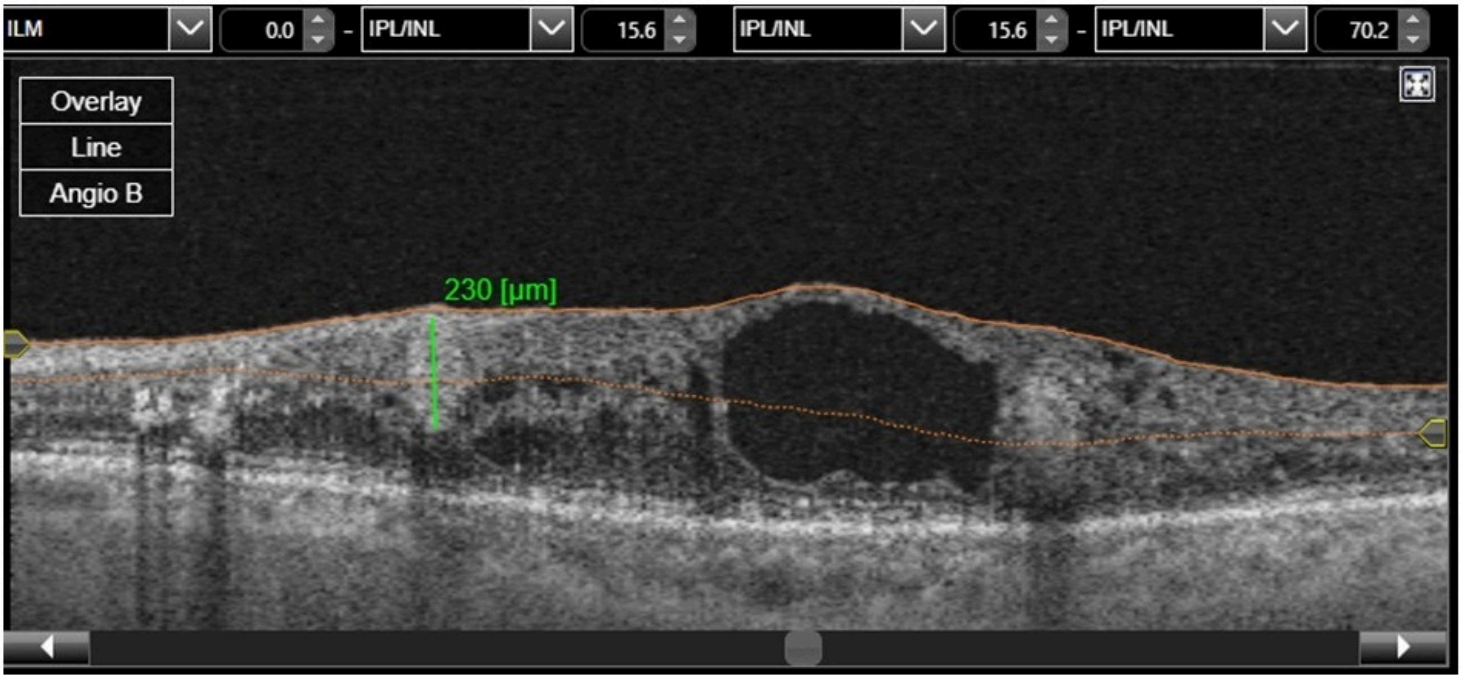


Figure 1

(Materials and Methods). Structural analysis and identification of CMAs on OCT B-scans: Dynamic analysis of the 6×6 mm macular volume identifies an ovoid lesion with a vertical major axis, a hyperreflective wall, a hyporeflective lumen, and posterior shadowing. A diameter measurement ≥150 µm confirms the diagnosis of a capillary macroaneurysm (CMA).

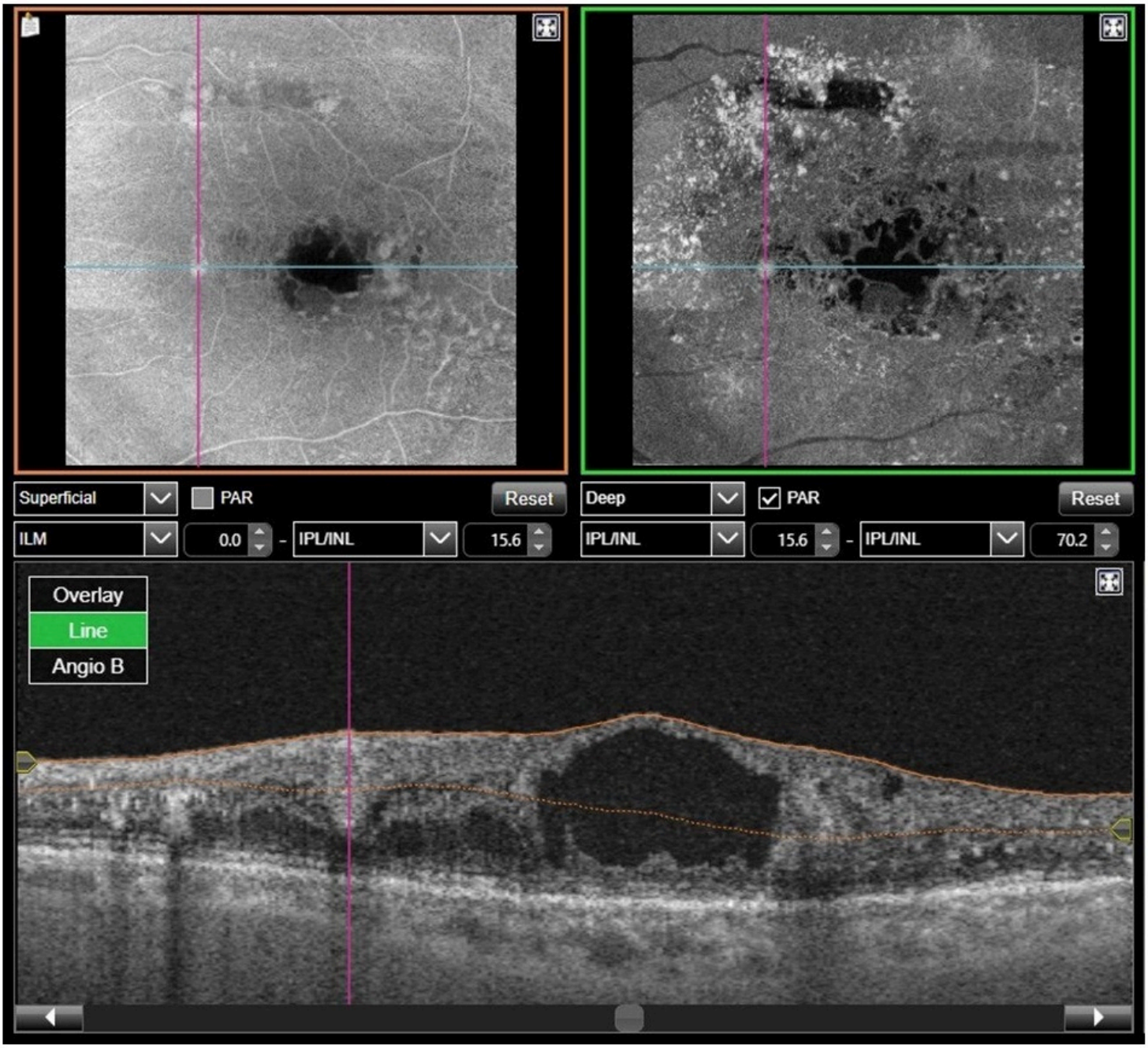


Figure 2

(Materials and Methods). Integrated multimodal OCT analysis and bidirectional synchronous navigation between B-scan slices and structural "En face" images segmented at the levels of the superficial and deep capillary plexuses: The selection of a CMA on a B-scan slice instantly projects the intersection of the navigation axes (cross-hair cursor) precisely onto the lesion within the coronal images. Conversely, selecting a "target-like" lesion on the "En face" structural map triggers the synchronous display of the corresponding B-scan slice, facilitating morphological confirmation of its nature.

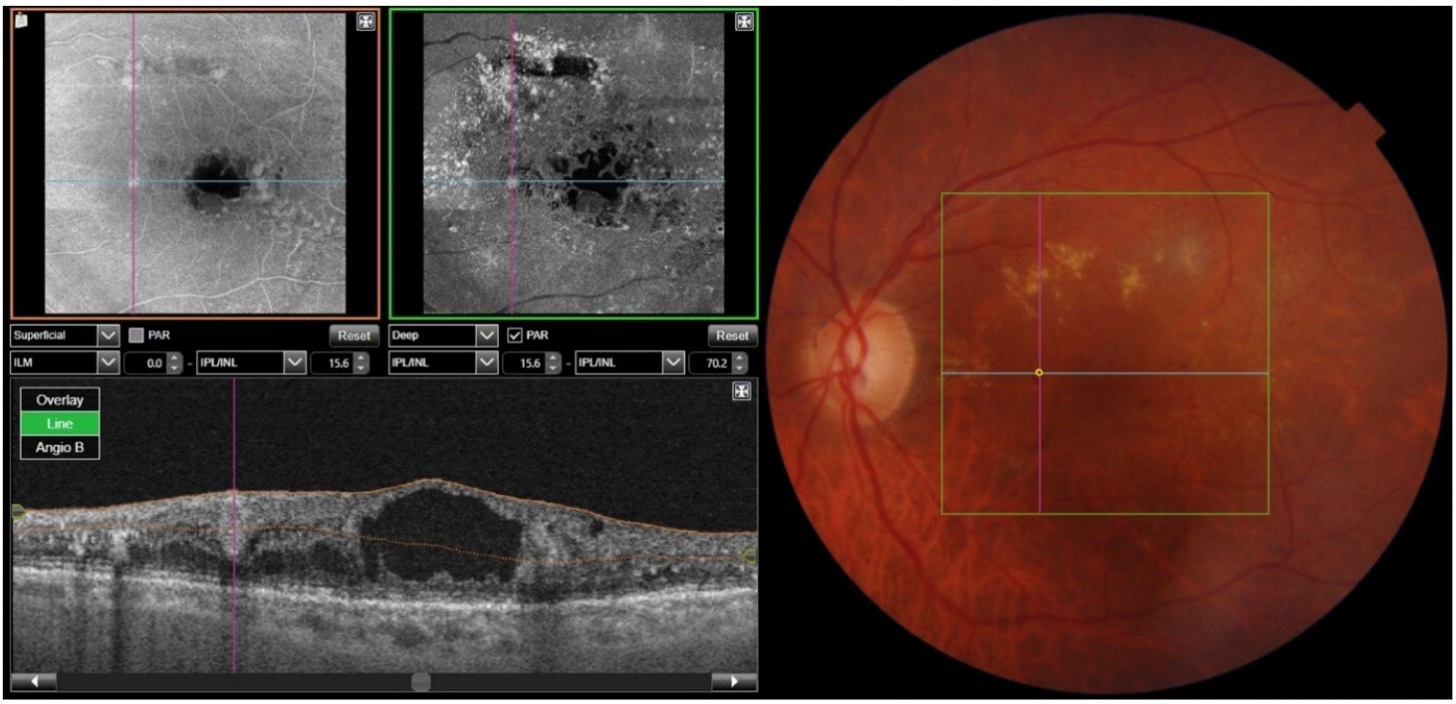


Figure 3

(Materials and Methods). Integrated Multimodal OCT-fundus correlation: Simultaneous display of the 3D macular volume (6×6 mm OCT) correlating the B-scan slice passing through the lesion, the corresponding "En face" images —segmented at the capillary plexus levels— and the color fundus photograph —. The lesion is precisely localized and marked on the fundus photograph at the intersection of the synchronized navigation axes. (B)

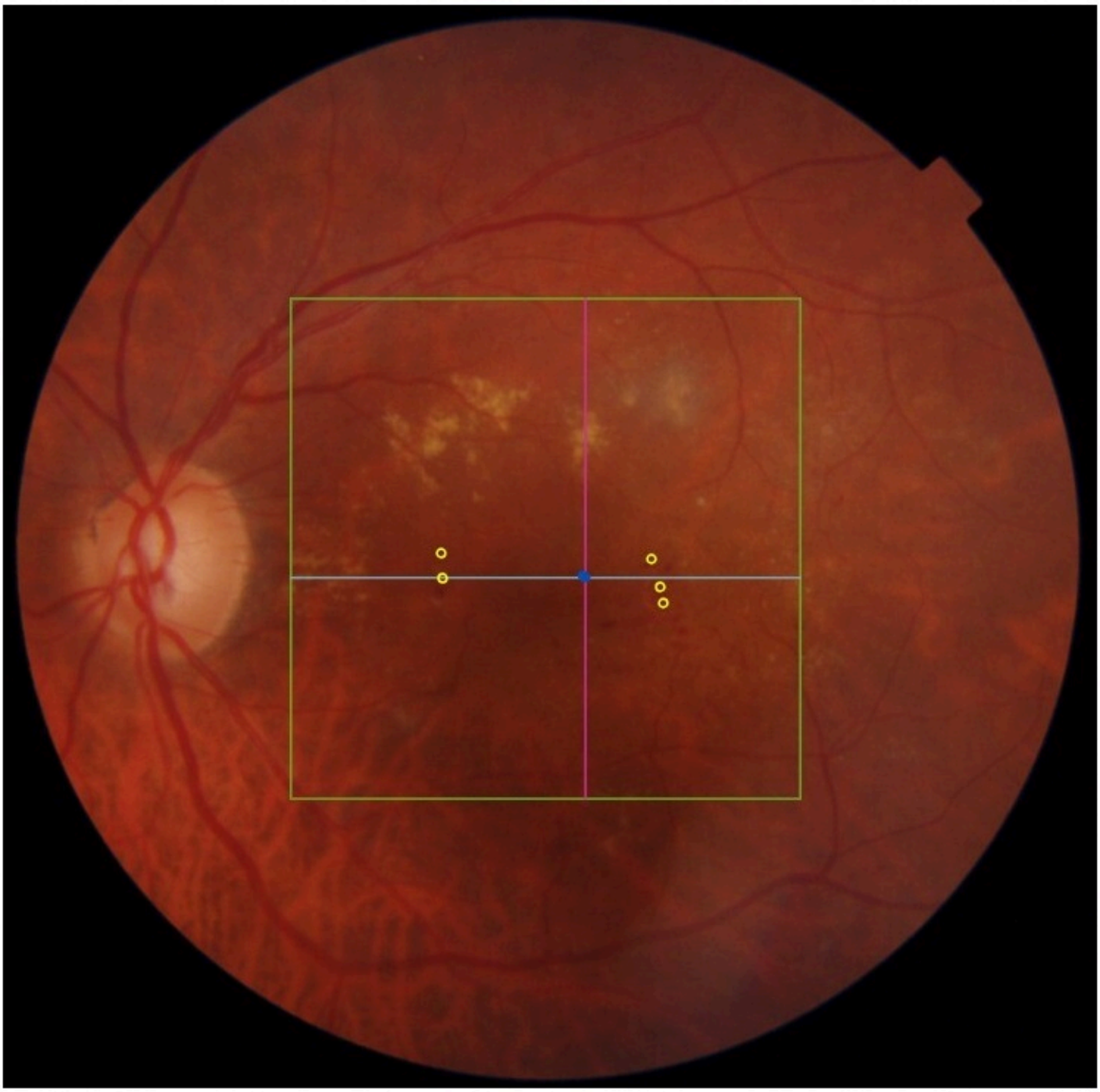


Figure 4

(Materials and Methods). Retinographic transposition of CMAs: High-precision color fundus photograph transposition with reliable marking of all CMAs (yellow circles) identified within the macular OCT scan volume and the foveal center (blue disk). This mapping provides a definitive guide for targeted photocoagulation planning.

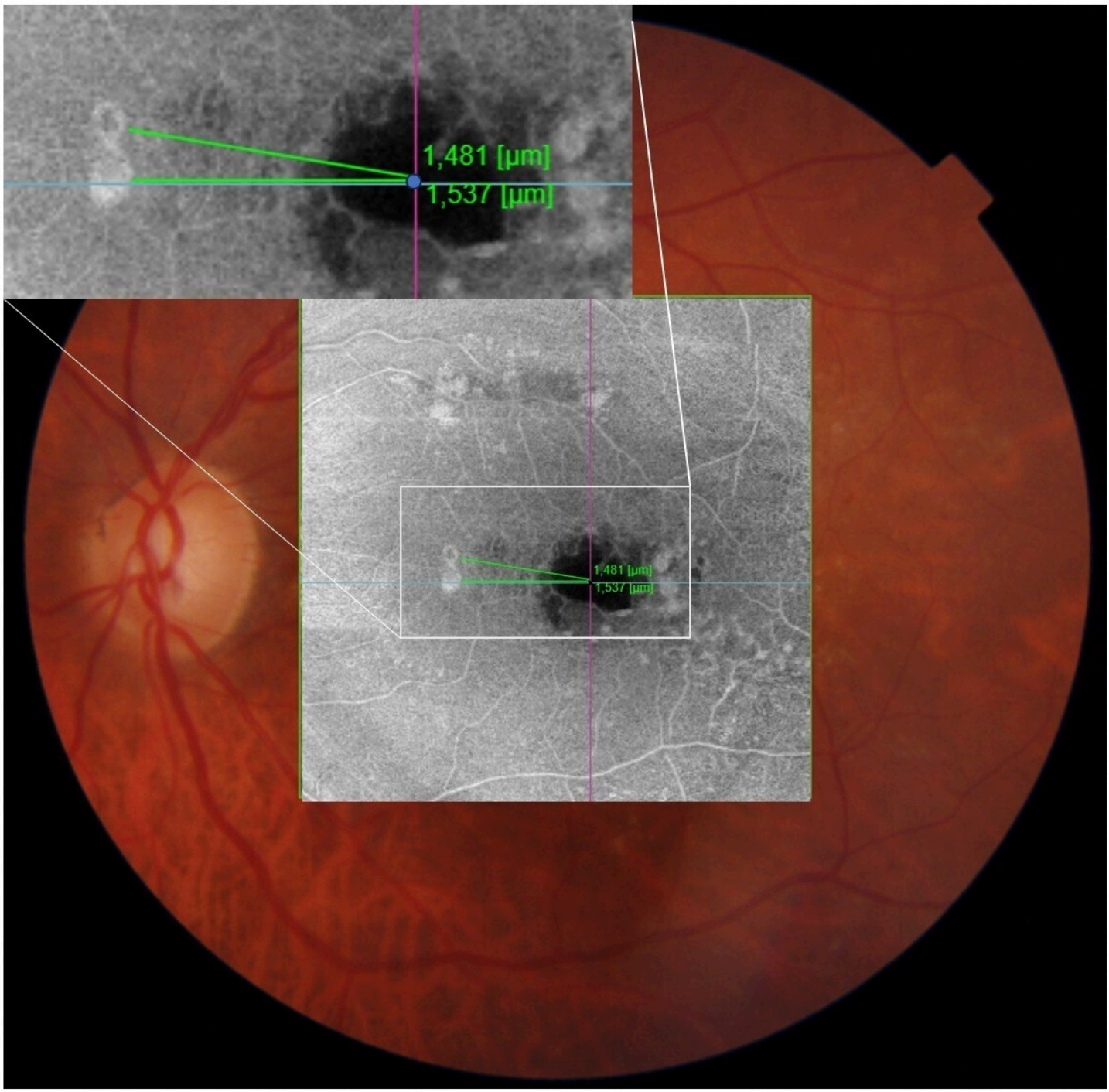


Figure 5

(Materials and Methods). Multimodal integration and spatial characterization of CMAs: Rigorous measurement of the distance between each CMA and the foveal center is performed on the structural "En face" OCT overlaid with the color fundus photograph. This metric parameter is crucial for ensuring safe selective photocoagulation by guaranteeing an optimal safety distance from the foveal avascular zone (FAZ).

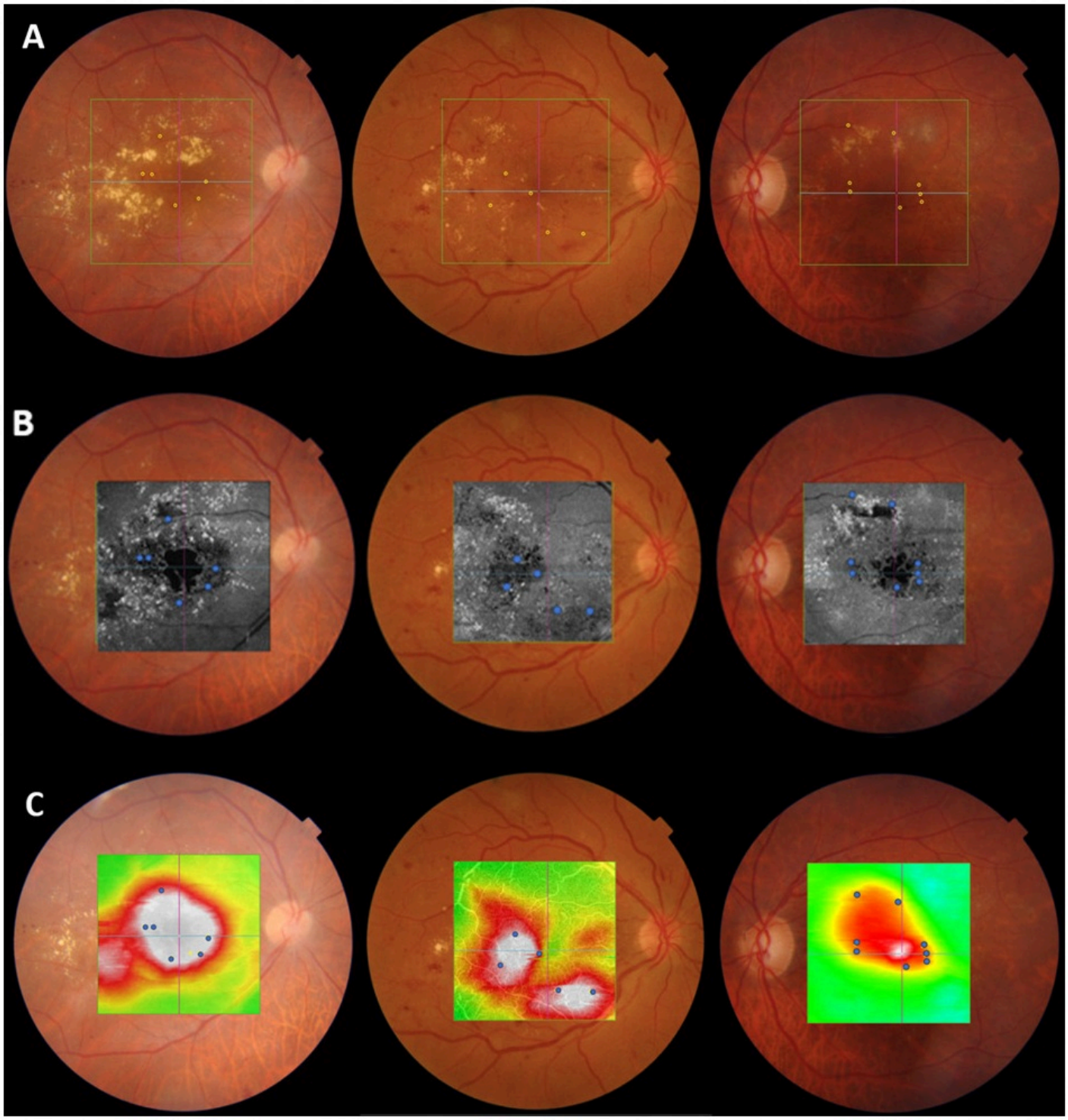


Figure 6

(Results). Multimodal integration and characterization of CMAs in relation to exudative biomarkers of DME: Detailed spatial analysis of the correlations between CMAs and various exudative biomarkers: hard exudates (A), intraretinal cystic spaces (B), and areas of retinal thickening (C). This analysis confirms a direct causal relationship between the identified CMAs and the adjacent macular edema.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.jpeg
- Table2.jpeg