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Screening potential of optical coherence tomography angiography for assessing metabolic risk prior to bariatric surgery

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Aim. To evaluate retinal microcirculation parameters using optical coherence tomography angiography (OCTA) in patients with metabolic syndrome (MS) prior to bariatric surgery and to assess their association with markers of metabolic risk.

Materials and methods. This study included 32 patients scheduled for bariatric surgery. Patients were divided into two groups: MS without type 2 diabetes mellitus (T2DM, n = 18) and MS with T2DM (n = 14). Demographic and clinical data, anthropometry, blood pressure, and metabolic laboratory parameters (fasting glucose, insulin, HbA1c, lipid profile) were recorded; insulin resistance (IR) was estimated using HOMA-IR. All participants underwent macular OCTA (6 × 6 mm scan; RTVue XR Avanti, Optovue). Vessel density in the superficial vascular plexus (SVP), deep capillary plexus (DCP) and the foveal avascular zone (FAZ) area was analyzed.

Results. Patients with MS and T2DM demonstrated significantly worse glycemic control and higher IR than those without T2DM ($p \leq 0.002$). OCTA revealed reduced vessel density (VD) in both the SVP (41.2 % vs 44.8 %; p = 0.004) and DCP (43.5 % vs 47.1 %; p = 0.006), and a larger FAZ area (0.39 mm^2 vs 0.31 mm^2; p = 0.008) in the T2DM group. Moderate correlations were observed between OCTA metrics and metabolic parameters: SVP and DCP VD negatively correlated with HOMA-IR (ρ = -0.56 and -0.53) and HbA1c (ρ = -0.49 and -0.46), whereas FAZ positively correlated with HOMA-IR (ρ = 0.51) and fasting glucose (ρ = 0.44). ROC analysis showed the highest discriminative performance for SVP VD (AUC = 0.82 for HOMA-IR ≥2.7; AUC = 0.80 for HbA1c ≥7.0 %).

Conclusions. In bariatric surgery candidates with MS, concomitant T2DM is associated with retinal microvascular impairment detectable by OCTA. Retinal parameters correlate with insulin resistance and glycemic control, supporting the potential role of retinal parameters as biomarkers of systemic microangiopathy. SVP vessel density shows the best screening performance for identifying high metabolic risk and may assist preoperative stratification.

Keywords: metabolic syndrome, insulin resistance, diabetes mellitus, retinal microcirculation, optical coherence tomography angiography, microvascular density, foveal avascular zone, bariatric surgery.

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Скринінговий потенціал оптичної когерентної томографічної ангіографії для оцінки метаболічного ризику перед баріатричною хірургією

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Мета роботи – оцінити параметри ретинальної мікроциркуляції за допомогою оптичної когерентної томографії-ангіографії (ОКТА) у пацієнтів із метаболічним синдромом (МС) перед баріатричною операцією та визначити їх зв'язок із маркерами метаболічного ризику.

Матеріали і методи. До дослідження залучені 32 пацієнти, яким заплановано баріатричне втручання. Пацієнтів поділено на дві групи: МС без цукрового діабету (ЦД) – 18 осіб та МС із ЦД – 14 обстежених. Оцінювали демографічні та клінічні дані, антропометрію, артеріальний тиск і метаболічні лабораторні показники (глюкоза натще, інсулін, HbA1c, ліпідний профіль); інсулінорезистентність визначали за індексом HOMA-IR. Усім пацієнтам виконано ОКТА макули (6 × 6 мм; RTVue XR Avanti, Optovue). Аналізували щільність судин (vessel density, VD) у поверхневому (SVP) і глибокому капілярному сплетеннях (DCP) та площу фовеальної аваскулярної зони (FAZ).

Результати. Пацієнти з МС і ЦД мали значно гірший глікемічний контроль і вищу інсулінорезистентність порівняно з пацієнтами без ЦД ($p \leq 0,002$). За даними ОКТА виявлено зниження VD у SVP (41,2 % проти 44,8 %, p = 0,004) і DCP (43,5 % проти 47,1 %, p = 0,006) та збільшення площі FAZ (0,39 $мм^2$ проти 0,31 $мм^2$, p = 0,008) у групі обстежених із ЦД. Встановлено помірні та сильні кореляції між параметрами ОКТА і метаболічними показниками: VD у SVP і DCP негативно корелювала з HOMA-IR (ρ = -0,56 і -0,53) та HbA1c (ρ = -0,49 і -0,46), а площа FAZ позитивно корелювала з HOMA-IR (ρ = 0,51) і глюкозою натще (ρ = 0,44). У результаті ROC-аналізу визначено найкращу дискримінативну здатність для VD у SVP (AUC = 0,82 для HOMA-IR ≥2,7; AUC = 0,80 для HbA1c ≥7,0 %).

Висновки. У кандидатів на баріатричну операцію з МС наявність супутнього ЦД асоціюється з порушенням ретинальної мікроциркуляції, що виявлено за допомогою ОКТА. Параметри ретинальної мікроциркуляції корелюють з інсулінорезистентністю та глікемічним контролем, підтверджуючи потенційну роль параметрів сітківки як біомаркерів системної мікроангіопатії. VD у SVP має найкращу здатність виявляти високий метаболічний ризик і може бути корисною для передопераційної стратифікації.

Ключові слова: метаболічний синдром, інсуліно-резистентність, цукровий діабет 2 типу, ретинальна мікроциркуляція, оптична когерентна томографія-ангіографія, щільність судин, фовеальна аваскулярна зона, баріатрична хірургія.

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Metabolic syndrome (MS) and type 2 diabetes mellitus (T2DM) remain among the leading contributors to cardiovascular morbidity and mortality and confer a high risk of perioperative complications in patients with morbid obesity who are planning bariatric surgery [1,2]. In the setting of insulin resistance (IR), chronic hyperglycemia, and dyslipidemia, systemic endothelial dysfunction and microangiopathy develop, which may be subclinical and are not always reflected by standard laboratory parameters alone. In this context, the identification of noninvasive markers capable of capturing the status of systemic microcirculation and supporting preoperative risk stratification is of particular relevance.

The retina represents a unique "window" into the microvasculature owing to the possibility of direct in vivo visualization of the capillary network. Optical coherence tomography angiography (OCTA) enables quantitative assessment of retinal vascular density, providing sensitive detection of early perfusion abnormalities. Published data indicate that OCTA metrics can serve as quantitative indicators of capillary dropout and the progression of diabetic microvascular damage [3,4].

Concurrently, accumulating data suggest that retinal microvascular alterations may occur before the onset of clinically manifest retinopathy and even at stages of disordered glucose metabolism that do not meet the diagnostic criteria for diabetes. In studies focusing on prediabetes and abnormal glucose metabolism, differences in macular vessel density (VD) and/or characteristics of the foveal avascular zone (FAZ) compared with healthy controls have been described [5], supporting the sensitivity of OCTA to early metabolically induced microvascular disturbances. Data from patients with diabetes but without clinical retinopathy further demonstrate that VD in both the superficial vascular plexus (SVP) and the deep capillary plexus (DCP) may be reduced, and that metabolic factors can modify these parameters, underscoring the potential of OCTA as an early biomarker of microvascular dysfunction [6,7].

Evidence pertaining to obesity and IR is also growing. Studies assessing retinal microcirculation in individuals with obesity have demonstrated the presence of microvascular changes, supporting the systemic nature of microangiopathy in obesity [8,9]. Moreover, several reports directly link indices of IR to manifestations of retinal vascular dysfunction, highlighting the potential diagnostic value of IR indices (HOMA-IR) in predicting retinal microvascular impairment [10].

For the bariatric cohort with MS, a key question is whether retinal OCTA parameters are informative specifically at the stage of preoperative screening. Some prospective studies indicate that patients with severe obesity already exhibit signs of retinal microvascular impairment prior to surgery, and that improvements in perfusion parameters may occur following bariatric treatment over time [11,12]. This provides a rationale for interpreting OCTA not only as an ophthalmic assessment tool but also as a potential marker of systemic metabolic risk along the bariatric surgery care pathway.

Aim

To evaluate retinal microcirculation parameters using OCTA in patients with metabolic syndrome prior to bariatric surgery and to assess their association with markers of metabolic risk.

Materials and methods

The study included 32 patients who were scheduled for bariatric surgery and were referred by bariatric surgeons for preoperative ophthalmologic evaluation due to the presence of MS and/or T2DM. Patients were divided into two groups based on the presence of T2DM: Group 1 included 18 patients with MS without T2DM; Group 2 included 14 patients with MS and T2DM.

In Group 1, the median age was 46.0 [41.0; 52.0] years (range 34–59); females accounted for 12 (66.7 %) and males for 6 (33.3 %). In Group 2, the median age was 52.0 [47.0; 58.0] years (range 39–62); females accounted for 8 (57.1 %) and males for 6 (42.9 %). Intergroup differences in age ($p = 0.08$) and sex ($p = 0.63$) were not statistically significant.

The study was conducted in accordance with the principles of the Declaration of Helsinki. All participants provided written informed consent. The protocol was approved by the local Ethics Committee of Zaporizhzhia State Medical and Pharmaceutical University, (Protocol No. 7 of 12.05.2026).

Inclusion criteria were age ≥30 years; confirmed MS according to IDF criteria [13]; and the ability to obtain high-quality OCTA scans. Exclusion criteria included concomitant ocular diseases that could independently affect retinal microcirculation; ocular media opacities preventing acquisition of high-quality scans; high myopia / ocular globe anomalies affecting OCTA reliability; and OCTA scans with pronounced motion artifacts or segmentation errors that could not be corrected.

Preoperatively, demographic and clinical variables were recorded, including age, sex, BMI, waist circumference, blood pressure, as well as comorbid conditions and current therapy (antihypertensive, hypoglycemic, etc.). Metabolic status was assessed using standard laboratory parameters: fasting glucose, fasting insulin, HbA1c, and lipid profile (triglycerides, HDL). The HOMA-IR index was calculated using the formula: HOMA-IR = (fasting insulin [μIU/mL] × fasting glucose [mmol/L]) / 22.5.

All patients underwent a standard ophthalmologic examination and OCTA using the RTVue XR OCT Avanti device (Optovue, Inc., Fremont, CA) with a 6 × 6 mm scan protocol in the macular area. Automated segmentation with manual verification of layer boundaries was applied for analysis; scans with significant motion artifacts, decorrelation noise, or incorrect segmentation were excluded. The following OCTA parameters were evaluated: VD in the SVP and DCP, and FAZ area. Additional image quality indices were used as scan acceptability criteria. Analysis was performed for one eye per patient to avoid statistical dependence of data. If both eyes met quality criteria, the eye with higher scan quality was included.

Statistical analysis was performed using Statistica 10. Quantitative variables were expressed as median [IQR], and categorical variables as n (%). Between-group comparisons were conducted using nonparametric tests (Mann–Whitney U) for quantitative variables. Correlations between OCTA parameters and metabolic variables were analyzed using Spearman's method (Spearman's ρ). Effect size measures (r for Mann–Whitney or ρ for correlations) were additionally reported to allow more accurate interpretation of results in small samples. The screening performance of OCTA parameters for identifying patients at high metabolic risk was

evaluated using ROC analysis, with calculation of AUC and 95 % confidence intervals, determination of optimal cutoff values based on the Youden index, and corresponding sensitivity and specificity. Two-sided p values <0.05 were considered statistically significant.

Results

Patients with MS and concomitant T2DM (Group 2) demonstrated a markedly worse glycemic profile compared with patients without T2DM (Group 1). Fasting glucose levels in Group 2 were significantly higher, reaching 8.9 [7.6; 10.4] mmol/L, whereas in Group 1 they were 5.6 [5.2; 6.1] mmol/L ($p < 0.001$, $r = 0.68$). Similarly, HbA1c was elevated in Group 2 – 7.8 [7.1; 8.6] % versus 5.9 [5.6; 6.2] % in Group 1 ($p < 0.001$, $r = 0.72$), reflecting chronically poorer glycemic control in patients with T2DM. The HOMA-IR index was also significantly higher in Group 2 – 5.1 [4.3; 6.2] compared with 2.9 [2.3; 3.6] in Group 1 ($p = 0.002$, $r = 0.61$), indicating more pronounced IR in patients with T2DM.

Regarding anthropometric parameters, BMI tended to be higher in Group 2 – 41.8 [38.5; 45.2] kg/m^2 versus 39.6 [36.9; 42.7] kg/m^2 in Group 1; however, this difference did not reach statistical significance ($p = 0.11$, $r = 0.29$). A similar trend was observed for waist circumference, which was 122 [116; 130] cm in Group 2 and 118 [110; 124] cm in Group 1 ($p = 0.14$, $r = 0.26$).

In Group 2, a statistically significant reduction in VD was observed in both the SVP and DCP compared to Group 1 *(Fig. 1)*. VD SVP was lower in Group 2 (41.2 % [39.6; 43.1]) than in Group 1 (44.8 % [42.9;46.3]; $p = 0.004$, $r = 0.51$). VD DCP was also significantly reduced in Group 2 (43.5 % [41.7; 45.2]) compared with Group 1 (47.1 % [45.3; 48.9]; $p = 0.006$, $r = 0.48$).

The FAZ area was larger in patients with T2DM (0.39 [0.35; 0.43] mm^2) compared with the non-T2DM group (0.31 [0.28; 0.36] mm^2; $p = 0.008$, $r = 0.46$).

To assess the relationship between retinal microcirculation parameters and systemic metabolic indices, a correlation analysis was performed *(Table 1)*.

Moderate correlations were identified between retinal microcirculation parameters and markers of metabolic control.

VD SVP was negatively correlated with HOMA-IR ($p = 0.002$) and HbA1c levels ($p = 0.006$). Similar associations were observed for DCP ($p < 0.05$). FAZ area showed a positive correlation with HOMA-IR ($p = 0.004$) and fasting glucose levels ($p = 0.01$). Waist circumference and triglyceride levels demonstrated weak but statistically significant correlations with reduced VD SVP ($p < 0.05$).

Given the strongest and statistically significant correlations between OCTA parameters and indices of IR and glycemic control, HOMA-IR (≥2.7) and HbA1c (≥7.0 %) were selected as key integral markers of metabolic risk for further evaluation of screening performance *(Fig. 2)*.

VD SVP demonstrated the highest discriminative performance among the analyzed OCTA parameters, with an area under the ROC curve (AUC) of 0.82 (95 % CI: 0.67–0.93; $p = 0.001$). The optimal cutoff value, determined using the Youden index, was SVP < 42.5 %, providing a sensitivity of 78 % and a specificity of 80 % for identifying patients with high HOMA-IR.

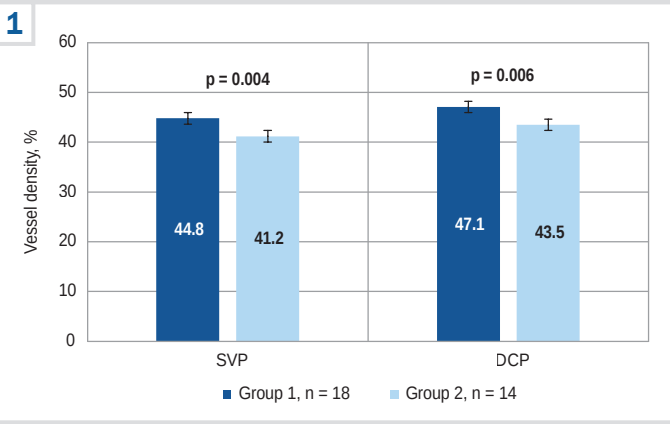

Fig. 1. Comparison of retinal plexus vessel density between patient groups. Statistical significance was defined as $p \leq 0.01$.

Table 1. Associations of OCTA-derived retinal microcirculation parameters with markers of metabolic control in the study cohort (n = 32)

OCTA parameter	Metabolic parameter	Spearman's ρ	p-value
Vessel density SVP, %	HOMA-IR	-0.56	0.002**
Vessel density SVP, %	HbA1c, %	-0.49	0.006**
Vessel density SVP, %	Fasting glucose, mmol/L	-0.41	0.02*
Vessel density SVP, %	Waist circumference, cm	-0.35	0.04*
Vessel density SVP, %	Triglycerides, mmol/L	-0.38	0.03*
Vessel density DCP, %	HOMA-IR	-0.53	0.003**
Vessel density DCP, %	HbA1c, %	-0.46	0.01**
Vessel density DCP, %	Fasting glucose, mmol/L	-0.39	0.03*
Vessel density DCP, %	Waist circumference, cm	-0.28	0.12
Vessel density DCP, %	Triglycerides, mmol/L	-0.30	0.09
FAZ area, mm^2	HOMA-IR	0.51	0.004**
FAZ area, mm^2	HbA1c, %	0.40	0.02*
FAZ area, mm^2	Fasting glucose, mmol/L	0.44	0.01**
FAZ area, mm^2	Waist circumference, cm	0.27	0.13
FAZ area, mm^2	Triglycerides, mmol/L	0.29	0.10

Statistical significance was defined as $p \leq 0.05$ (*) and $p \leq 0.01$ (**).

The FAZ area also showed significant predictive ability for IR, with an AUC of 0.79 (95 % CI: 0.63–0.91; $p = 0.003$). A FAZ threshold > 0.36 mm^2 corresponded to a sensitivity of 74 % and a specificity of 77 %.

For VD DCP, discriminative performance was moderate, with an AUC of 0.75 (95 % CI: 0.58–0.89; $p = 0.01$). The optimal cutoff of DCP < 45.0 % yielded a sensitivity of 70 % and a specificity of 73 %.

In addition, the ability of OCTA parameters to predict poor glycemic control (HbA1c) was evaluated. Similarly, SVP showed the highest prognostic value (AUC = 0.80; 95 % CI: 0.64–0.92; $p = 0.002$), whereas FAZ and DCP demonstrated moderate discriminative ability (AUC = 0.77 and 0.73, respectively; both $p < 0.05$).

Discussion

In our study of patients with MS preparing for bariatric surgery, the presence of concomitant T2DM was shown to be associated with more pronounced retinal microcirculatory dysfunction, manifested by reduced VD in the SVP and DCP and enlargement of the FAZ area. Importantly,

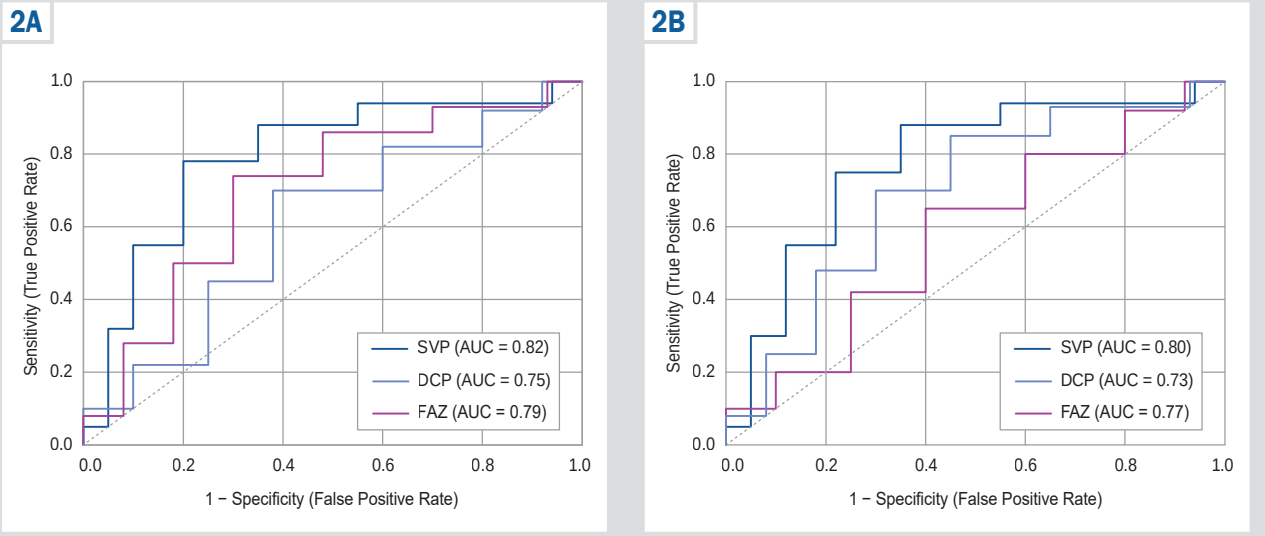

Fig. 2. ROC curves of OCTA-derived retinal microcirculation parameters. **A:** relative to HOMA-IR; **B:** relative to HbA1c.

these changes were detected at the stage of preoperative screening, suggesting that they may reflect a subclinical microvascular phenotype potentially relevant for systemic risk stratification. It should be emphasized that MS and morbid obesity represent multifactorial conditions. Retinal microvascular alterations observed in our cohort may reflect the combined influence of hyperglycemia, IR, arterial hypertension, dyslipidemia, and other systemic factors. Given the cross-sectional design of the study, causal relationships cannot be established, and OCTA changes should be interpreted as associative markers rather than specific effects of obesity or MS per se.

The observed intergroup differences in OCTA parameters are consistent with existing evidence indicating that early microvascular alterations can be detected by OCTA in patients with T2DM even in the absence of clinically apparent diabetic retinopathy (DR). In particular, studies in large cohorts of patients with T1DM or T2DM without signs of DR have reported reduced VD in the SVP and DCP compared with controls, while FAZ characteristics may vary depending on diabetes duration and type [14]. Moreover, microvascular perfusion deficits in T2DM without retinopathy have been shown to localize to the parafoveal region, with several reports highlighting the particular vulnerability of the DCP [15]. These observations are pathophysiologically concordant with our finding of reduced VD DCP in the T2DM group.

A key result of our study is the identification of moderate to strong correlations between retinal microcirculation parameters and markers of metabolic control. Negative associations of VD in the SVP and DCP with HOMA-IR and HbA1c, as well as positive correlations between FAZ area and HOMA-IR and fasting glycemia, support the concept of the "retina as a biomarker of systemic microangiopathy." Notably, similar associations between OCTA metrics and insulin-related indices have been reported by E. Y. Choi et al., who demonstrated correlations between FAZ parameters and perfusion/microcirculation indices with IR markers in patients with T2DM without retinopathy using 6 × 6 mm scans [16]. Taken together, these data reinforce the notion that metabolic dysfunction, particularly IR and glycemic control, may be a key driver of retinal microvascular remodeling in candidates for bariatric surgery.

Our findings are also in line with studies evaluating OCTA in patients with severe obesity. Specifically, Dogan et al. reported that in patients with obesity (BMI ≥ 35 kg/m^2) scheduled for bariatric surgery, macular VD SVP and DCP was lower than in normal-weight controls, and negative correlations with BMI were observed [17]. Collectively, these results support the hypothesis that obesity and its associated metabolic disturbances (IR, hyperglycemia) may establish a baseline microvascular "background" that becomes evident in OCTA metrics even before the development of overt ophthalmic complications.

From a practical perspective, ROC analysis in our study demonstrated good to moderate discriminative performance of OCTA parameters, particularly SVP, for identifying patients with high HOMA-IR and poor glycemic control. This aligns with contemporary reviews that consider OCTA a noninvasive tool for detecting early microvascular changes in diabetes and metabolic conditions, with VD (SVP/DCP) and FAZ metrics proposed as potential risk biomarkers [18,19]. In the context of preoperative preparation for bariatric surgery, this approach may add value as an objective component of systemic risk stratification and as a rationale for more intensive correction of metabolic abnormalities prior to intervention. However, OCTA parameters cannot replace established metabolic and cardiovascular risk assessment tools.

Several limitations should be acknowledged, including the small sample size and the cross-sectional design, which preclude causal inferences. In addition, postoperative changes were not assessed, whereas some studies have analyzed retinal vascular parameters after bariatric surgery and demonstrated that certain microvascular characteristics may change over time or depend on local autoregulatory mechanisms [11,20,21]. Nevertheless, the focus on preoperative assessment represents a strength of our study, as it closely reflects a real-world clinical screening scenario.

Conclusions

1. Patients with MS and T2DM have a significantly worse metabolic profile, as evidenced by higher fasting glucose levels (8.9 mmol/L vs 5.6 mmol/L; p < 0.001), HbA1c (7.8 % vs 5.9 %; p < 0.001), and HOMA-IR (5.1 vs 2.9; p = 0.002) compared with patients without T2DM.

2. The presence of T2DM is associated with pronounced retinal microcirculatory dysfunction, including reduced VD in the SVP (41.2 % vs 44.8 %; p = 0.004) and DCP (43.5 % vs 47.1 %; p = 0.006), as well as enlargement of the FAZ area (0.39 mm^2 vs 0.31 mm^2; p = 0.008).

3. OCTA parameters are closely associated with insulin resistance and glycemic control: VD SVP and DCP negatively correlate with HOMA-IR (ρ = -0.56 and -0.53; p ≤ 0.003) and HbA1c (ρ = -0.49 and -0.46; p ≤ 0.01), whereas FAZ area positively correlates with HOMA-IR (ρ = 0.51; p = 0.004) and fasting glucose (ρ = 0.44; p = 0.01).

4. VD SVP demonstrates the highest screening performance for identifying high metabolic risk, with an AUC of 0.82 (95 % CI: 0.67–0.93; p = 0.001) for HOMA-IR ≥2.7 and an AUC of 0.80 (95 % CI: 0.64–0.92; p = 0.002) for HbA1c ≥7.0 %.

Prospects for further research. Future prospective studies with larger sample sizes are warranted, incorporating standardized control of potential confounders (blood pressure, lipid levels, diabetes duration, therapy) and long-term postoperative follow-up to determine whether OCTA parameters reflect the prognosis of metabolic response to bariatric surgery and/or the risk of systemic complications.

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