Preoperative Computed Tomography-Derived Visceral Adipose Tissue Density Predicts Clinical Outcome of Laparoscopic Sleeve Gastrectomy in Morbid Obesity

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Abstract

Background: The influence of preoperative computed tomography (CT)-derived adipose tissue density on weight loss following bariatric surgery remains unclear. We investigated the clinical utility of CT density as a predictor of weight loss and type 2 diabetes mellitus (T2DM) remission post-bariatric surgery.

Materials and Methods: This study cohort comprised patients with morbid obesity with body mass index (BMI) > 35 kg/m^2 who underwent laparoscopic sleeve gastrectomy (LSG), and patients with early gastric cancer with BMI < 25 (lean) who underwent distal gastrectomy. Immune cell profiles in visceral adipose tissue (VAT) and peripheral blood were analyzed using flow cytometry.

Results: CT density in the group with morbid obesity (n=38) was lower than that in the lean group (n=37); $P < 0.05$. Changes in CT density of VAT (VAT-D) and subcutaneous adipose tissue (SAT-D) in the group with morbid obesity were positively correlated with postoperative weight loss. Lower preoperative VAT-D was associated with enhanced weight loss post-surgery. Among morbidly obese patients with T2DM, low VAT-D and SAT-D groups exhibited significantly less weight loss ($P < 0.05$). A lower preoperative VAT-D score was significantly associated with a reduced T2DM remission rate ($P < 0.05$) and fewer $CD56^{bright}$ natural killer (NK) cells in the VAT ($P < 0.05$). Receiver operating characteristic analysis indicated that preoperative VAT-D predicted T2DM remission with 73% specificity and 70% sensitivity. Other NK cell phenotypes were not associated with adipose tissue CT density.

Conclusion: Preoperative adipose tissue CT density predicts the effect of LSG on postoperative weight loss and T2DM improvement. CT density may reflect the local immunological status of the VAT, particularly the distribution of NK cell subsets. Further research is required to elucidate the mechanisms by which VAT-infiltrating immune cells influence clinical outcomes following bariatric surgery.

Keywords: Computed tomography, adipose tissue density, weight loss, type 2 diabetes mellitus, laparoscopic sleeve gastrectomy, obesity

Introduction

Obesity, a global epidemic affecting over 1 billion individuals, ranks among the top five risk factors for mortality and contributed to approximately 5 million deaths worldwide in 2019.[1] A recent study identified the body roundness index (BRI), a more specific anthropometric measure of visceral and total body fat percentage, as a mortality risk factor.[2]

Visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) increase with obesity. Visceral fat area (VFA) assessed via computed tomography (CT) or magnetic resonance imaging (MRI), serves as a clinical parameter of abdominal adiposity.[3] Alternatively, bioelectrical impedance analysis has been explored to evaluate

body fat composition.[4] With the expansion of basic research, the microenvironment of VAT in obesity is becoming increasingly understood. Adipocytes respond to this inflammatory environment by releasing cytokines from immune cells and undergoing morphological changes.[5] In obesity, immune cells such as macrophages, natural killer (NK) cells, and T cells accumulate in VAT, contributing to chronic inflammation.[6-8] Notably, pathways through which NK cells induce macrophages have been identified, highlighting their critical role in adipose tissue inflammation.[9] Given that chronic inflammation and adipocyte hypertrophy can alter tissue composition, these immune-mediated changes may be reflected in CT density. This suggests that CT imaging could serve as a non-invasive marker to assess the pathological status of adipose tissue.

Excessive adipose tissue deposition leads to dysfunction characterized by adipocyte hypertrophy, reduced angiogenesis, impaired vascular function, and decreased capillary density.[10-12] Among adipose tissue characteristics, adipocyte size and fibrosis are closely linked to glucose tolerance.[13] Specifically, larger adipocytes are positively correlated with insulin resistance, type 2 diabetes mellitus (T2DM), and macrophage infiltration and inversely associated with adiponectin secretion.[14, 15]

VAT can be estimated through anthropometric measurements or more accurately quantified using CT scans. The CT density of the adipose tissue (AT-D) reflects both the adipocyte size and extracellular matrix composition. Larger adipocytes are associated with increased infiltration of inflammatory immune cells, reduced vascular density, and lower AT-D.[16, 17] This state poses a high risk for hypoxia and inflammation, and is implicated in various diseases, including cardiovascular diseases, obesity, and cancer.[18, 19] Studies utilizing CT-based assessments of abdominal fat distribution have revealed associations between VAT, abdominal SAT, and various metabolic abnormalities.[20]

However, few studies have documented CT density in patients undergoing bariatric surgery for severe obesity. Postoperative increases in the CT density of the VAT (VAT-D) and SAT (SAT-D) after bariatric surgery have been associated with greater weight and total fat loss.[21, 22] Specifically, these studies primarily focused on changes in

CT density after surgery as a retrospective marker of treatment response. Conversely, preoperative CT density may reflect the baseline adipose tissue quality, including cellular composition and inflammatory status. Therefore, preoperative VAT-D and SAT-D might provide valuable insights into individual variability in treatment responses, and serve as novel predictive markers for postoperative outcomes.

Predictive scoring systems such as the ABCD[23] and DiaRem scores,[24] are widely utilized to evaluate T2DM remission in obese individuals after bariatric surgery. Nevertheless, to date, no study has identified a single preoperative predictor of weight loss and T2DM remission following bariatric surgery in patients with morbid obesity. This study aimed to investigate whether preoperative abdominal adipose tissue distribution and CT density are correlated with postoperative weight loss and glycemic metabolic outcomes in patients with morbid obesity undergoing laparoscopic sleeve gastrectomy (LSG). The study offers valuable insights into a novel approach for predicting clinical outcomes of bariatric surgery, particularly regarding metabolic improvement and diabetes remission.

Materials and Methods

Study design

Between March 2015 and January 2024, 38 patients who underwent LSG after preoperative weight loss for patients with morbid obesity (obese) and 37 patients without morbid obesity (lean) who underwent laparoscopic gastrectomy for early gastric cancer at Hiroshima University Hospital, Japan, were included in the study. The group with obesity met the following criteria for LSG, as defined by the Japanese guidelines for the Management of Obesity Disease 2022: morbid obesity (BMI > 35 kg/m^2), age 18–65 years, and medical treatment for >6 months, with insufficient control of one or more comorbidities (T2DM, hypertension, hyperlipidemia or obstructive sleep apnea). Exclusion criteria were secondary obesity due to pituitary or endocrine disorders, poorly controlled psychiatric disorders or alcohol dependence, and failure to lose 5% of the preoperative body weight after 6 months of nutritional intervention using infant formula (Microdiet, Sunny Health Co. Ltd., Tokyo, Japan) taken at least once per day.[25] The lean group served as a control and comprised a population with BMI < 25 kg/m^2,

and T1 early gastric cancer without lymph node metastasis. The immune cells in their VAT and peripheral blood appeared unaffected by gastric cancer. The study was approved by the Institutional Review Board of Hiroshima University Hospital (E2016-0611-03), and the study protocol complied with the provisions of the 1995 Helsinki Declaration (revised in Brazil in 2013).[26] Written informed consent was obtained from all patients at the first visit. The participants' medical records included information on age; sex; T2DM; hypertension; hyperlipidemia; body weight; BMI; white blood cell (WBC) count; neutrophil, lymphocyte, and monocyte counts; and markers of low-grade systemic inflammation, such as C-reactive protein (CRP) levels. Visceral fat area (VFA) and subcutaneous fat area (SFA) were determined by body fat scanning during the initial examination. Body composition at the initial visit and 12 months post-surgery was measured using a bioelectrical impedance analysis device (InBody 770; InBody Co., Ltd., Seoul, South Korea).

The percentage weight change at each time point was defined according to Equations 1 and 2.[27]

Total weight loss (TWL) (%): [(initial weight (kg) – weight at 12 months after surgery (kg))/initial weight (kg)] × 100 (1)

Excess weight loss (EWL) (%): [(initial weight (kg) – weight at 12 months after surgery (kg))/(initial weight (kg) – ideal weight (based on a BMI of 22 kg/m^2) (kg))] × 100 (2)

Remission of type 2 diabetes mellitus

Glycemic remission and improvement were assessed based on the international diabetes remission criteria proposed by Riddle et al.[28] Complete remission was defined as having normal glucose metabolism values (HbA1c <6%, fasting blood glucose (FBG) <100 mg/dL) without the use of antidiabetic medications. Partial remission was defined as sub-diabetic hyperglycemia (HbA1c 6–6.4%, FBG 100–125 mg/dL) in the absence antidiabetic medications. Improvement was defined as statistically significant reduction in HbA1c and FBG that did not meet the criteria for remission, or the decrease in antidiabetic medications requirement (discontinuation of insulin or

one oral agent, or 1/2 reduction in dose). Unchanged was defined as the absence of remission or improvement. Recurrence was defined as an FBG or HbA1c within the diabetic range (>126 mg/dL and >6.5%, respectively) or the need for antidiabetic medication after any period of complete or partial remission.

CT imaging

CT imaging was performed using a 16-detector row CT scanner (Canon, Tokyo, Japan). Patients were placed in a supine position with both arms stretched above the head to prevent beam-hardening artifacts. The umbilical fat area assessed by CT correlated with the total abdominal fat mass, including VAT and SAT.[29] A single CT slice was obtained at the umbilical level (L3–L5 with a 5-mm slice thickness (130 kVp; 150–300 mA). Abdominal cross-sectional areas (cm^2) and mean Hounsfield unit (HU) for VAT and SAT were measured using semi-automated tracings with density thresholds between -250 and -50 HU. All participants underwent a single-slice scan preoperatively and 1 year postoperatively. CT images were analyzed using SYNAPSE VINCENT (Fujifilm Medical Co., Ltd., Tokyo, Japan). The change in CT density of adipose tissue (ΔAT-D) was defined as the difference between the postoperative (1-year) and preoperative mean CT density for VAT and SAT.

Sampling and preparation

The stromal vascular fraction (SVF) was extracted from VAT immediately after its removal. VAT was collected from patients who underwent greater omentum LSG for morbid obesity or laparoscopic gastrectomy for early gastric cancer. Following removal from the patient in the operating room, the VAT was immediately placed in phosphate-buffered saline (PBS) with bovine fetal serum (BFS; 50 mg/mL in PBS) and transported to the laboratory on ice. Interstitial tissues in the adipose tissue, such as blood vessels and hematomas, were removed and thoroughly washed with PBS. The tissue was minced, mashed, and digested with collagenase type I (Wako, 1.0 mg mL in BFS-PBS) for 75 min at 37℃, and shaken at a rate of 100 reciprocations per minute. Twenty milliliters of BFS-PBS and type I collagenase were added to 5 g of well-minced VAT in conical tubes. After collagenase digestion, the SVF was filtered through a 100 μm cell strainer and a 35 μm cell strainer. SVF cells were suspended in complete RPMI, and cell counts were determined.[30]

Flow cytometry

Flow cytometry was conducted using a FACSCanto II (BD Biosciences, Mountain View, CA, USA), and the data were analyzed using FlowJo software (Tree Star Software, San Carlos, CA, USA). SVF cells were immediately stained post-purification with the following monoclonal antibodies: fluorescein isothiocyanate-conjugated anti-CD56, allophycocyanin-conjugated anti-CD3, phycoerythrin-conjugated anti-NKp46, phycoerythrin-conjugated anti-CD69, phycoerythrin-conjugated anti-NKG2D, and phycoerythrin-conjugated anti-CD158a (BD Pharmingen, San Diego, CA, USA). The SVF was then incubated with antibodies for 30 min at 4°C in the dark. Dead cells were excluded from the analysis using 7-AAD (7-aminoactinomycin D, BD Pharmingen) or propidium iodide staining. Due to limited cell numbers, it was not feasible to measure all surface markers in all samples. Gating of lymphocytes and NK cells in VAT and peripheral blood was performed, as shown in Supplementary Figure 1.

Statistical analysis

Data are presented as the median (interquartile range). Linear regression analysis was utilized to evaluate adipose tissue CT density and the effects on weight loss in the obese group. Continuous variables were compared using an unpaired Student's *t*-test. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the sensitivity and specificity of the VAT-D, ABCD, and DiaRem scores in predicting diabetes remission in the cohort of patients with morbid obesity and comorbid T2DM. All statistical analyses were performed using JMP, version 18 (SAS Institute, Cary, NC, USA). Statistical significance was set at $P < 0.05$.

Results

A comparison of the patient backgrounds and initial examination data between the obese and lean groups is presented in Table 1. These results aligned with those of previous reports.[16, 20] Notably, AT-D was significantly lower in the obese group than in the lean group (Table 1; VAT-D, $P < 0.01$; SAT-D; $P < 0.01$). The obese group had a higher rate of T2DM complications than the lean group, and laboratory data revealed higher levels of glucose

and lipid metabolism markers. Furthermore, CRP levels and WBC counts were higher in the obese group, consistent with previous reports[21] (Table 1).

We examined the relationship between AT-D and BMI in each group. AT-D correlated with body weight and BMI in the lean group (VAT-D: $r = -0.611$, $P < 0.01$; SAT-D: $r = -0.367$, $P < 0.05$) (Figure 1b, d). In contrast, no such correlation was observed in the obese group (Figure 1a, 1c). Additionally, we examined changes in AT-D in participants with morbid obesity. AT-D at 1 year postoperatively was significantly higher than that measured preoperatively (Supplementary Table 1, $P < 0.05$). Moreover, greater weight loss was associated with a larger increase in AT-D post-surgery, as reported previously (Supplementary Table 2).

Additional analyses were conducted to examine the association between CT density and postoperative weight loss. The obese group was further divided into two groups: low group (VAT-L and SAT-L) with AT-D lower than the median (median VAT-D; -100.4 HU, median SAT-D: -105.4 HU) and high group (VAT-H and SAT-H) with AT-D exceeding the median (Table 2). Although no significant correlation was observed between VAT-D or SAT-D and postoperative weight loss (Supplementary Figure 2), the VAT-L group tended to experience less weight loss (Figure 2a–2c; weight loss, $P = 0.58$; %TWL, $P = 0.06$; %EWL, $P = 0.08$). No significant differences were found in the SAT-D analysis (Figure 2d–2f; weight loss, $P = 0.68$; %TWL, $P = 0.70$; %EWL, $P = 0.61$).

Subsequently, the analysis was restricted to patients with T2DM, who were considered to be more systemically affected by inflammation among severely obese individuals. The median CT density (median VAT-D; -100.4 HU, median SAT-D; -104.9 HU) of the T2DM group was determined to establish low and high groups (DM(+)VAT-L, DM(+)VAT-H, DM(+)SAT-L, and DM(+)SAT-L) (Table 3). Regarding the baseline characteristics, the DM(+)VAT-L group exhibited a larger total fat area (TFA) than the DM(+)VAT-H group. This difference is potentially attributable to the taller stature and greater body weight observed in the DM(+)VAT-L group, suggesting a distinct body composition profile. Among morbidly obese patients with T2DM, analysis of the association between postoperative weight loss and CT density revealed a positive correlation between VAT-D,

%TWL, %EWL (Figure 3b, 3c; %TWL: $r = 0.507$, $P < 0.05$, and %EWL: $r = 0.486$, $P < 0.05$). In addition, we observed significantly less weight loss in the DM(+)VAT-L group (Figure 4b, 4c; %TWL; $P < 0.01$, %EWL; $P < 0.05$). In contrast, this investigation revealed no correlation between SAT-D and postoperative weight loss even when the analysis was restricted to patients with T2DM (Figure 3d–3f, 4d–4f). No obvious difference in weight loss occurred in the non-T2DM group based on the CT density in either the VAT or SAT (data not shown).

Next, we evaluated the relationship between CT density and the inflammatory response, glucose tolerance, and lipid metabolic function using blood test data. In the group with morbid obesity, the WBC count was significantly higher in the SAT-L group than in the SAT-H group (Table 2), as previously reported.[31, 32] Further evaluation of the obese subgroup with comorbid T2DM showed significantly higher WBC count and CRP in the DM(+)SAT-L group than in the DM(+)SAT-H group (Table 3). However, VAT-D revealed no significant association with blood test data, including HbA1c. In the assessment of diabetes remission in the T2DM group, a lower proportion of patients in the DM(+)VAT-L group experienced complete remission, characterized by the elimination of diabetes medications and improvement in glucose tolerance, compared to the DM(+)VAT-H group ($P < 0.05$) (Table 4). The same analysis for the DM(+)SAT-D group revealed no significant differences (Table 4). To assess the predictive capability of VAT-D for postoperative diabetes remission, we compared its performance with established scoring systems, such as the ABCD and DiaRem scores, which are typically used to predict diabetes remission following bariatric surgery. ROC analysis for complete diabetes remission indicated that VAT-D, when used as a cutoff parameter, achieved a sensitivity of 70% and a specificity of 73.3% (Figure 5a). In contrast, within the same cohort, the ABCD score achieved a sensitivity of 55.6% and a specificity of 84.6% at a cutoff value of 8, whereas the DiaRem score demonstrated a sensitivity of 66.7% and a specificity of 78.6% at a cutoff value of 4 (Figure 5b, c). These findings indicate that the VAT-D exhibits comparable sensitivity and specificity to the ABCD and DiaRem scores, suggesting its potential utility as a predictor of diabetes remission following bariatric surgery.

In an immunological analysis, mononuclear cells from VAT were extracted and analyzed. No differences in the percentages of NK, T, or NKT cells (Figure 6a–c), and in the phenotype of inflammatory markers of NK cells between the DM(+)VAT-H and DM(+)VAT-L groups were observed (Figure 6f, g). However, when the percentage of NK cells divided by $CD56^{bright}$ and $CD56^{dim}$ was evaluated, the DM(+)VAT-L group possessed more $CD56^{bright}$ NK cells than the DM(+)VAT-H group (Figure 6; $P < 0.05$).

Discussion

In the present study, low CT density of VAT was associated with suboptimal weight loss outcomes and reduced T2DM remission following LSG in patients with morbid obesity. CT-based adipose tissue analysis typically focuses on fat area or volume and has garnered considerable attention as a non-invasive, straightforward tool for evaluating obesity-related conditions such as T2DM and hyperlipidemia.[33, 34] Recently, AT-D emerged as a valuable predictor of long-term prognosis in various contexts, including cancer treatment outcomes and routine health assessments.[35, 36] These studies commonly employed CT imaging at the umbilical level, a methodology similarly adopted in this study. The umbilical region is widely recognized as a site closely linked to fat mass,[29, 37] making it a reliable reference point for abdominal CT imaging.

Several studies have reported a correlation between AT-D and body weight or BMI, attributing this relationship to the strong association between CT density and adipocyte hypertrophy.[36, 38, 39] However, in the present study, in participants with obesity with BMI > 35 kg/m^2, neither VAT-D nor SAT-D demonstrated a correlation with body weight or BMI. This observation supports the hypothesis that adipocyte hypertrophy reaches a physiological limit beyond a certain threshold of obesity, beyond which further enlargement is minimal or absent.[12] Few studies have specifically investigated individuals with a BMI exceeding 35, a group distinct from lean individuals in terms of adipose tissue composition and inflammatory processes. Our findings highlight that the significance of CT density in patients with morbid obesity differs markedly from that in lean populations underscoring the necessity to distinguish the metabolic and immunological profiles of these groups to better understand obesity-related pathophysiology. Our study is the first to demonstrate that the association between AT-D and BMI is preserved

only in individuals with a BMI ≤ 25, and becomes statistically insignificant in those with a BMI > 35. This novel finding highlights a critical shift in adipose tissue behavior in the context of extreme obesity and underscores the potential of AT-D as a distinct marker that reflects qualitative, rather than quantitative, adipose tissue changes in severely obese populations.

Changes in AT-D have been implicated in weight loss outcomes of bariatric surgery in morbid obesity. Torriani et al. reported a negative correlation between VAT-D and CRP levels in patients with morbid obesity, highlighting a significant increase in CT density 1 year post-bariatric surgery.[21] Similarly, Ozeki et al. found that postoperative weight loss in patients with morbid obesity without T2DM was associated with changes in both VAT-D and SAT-D.[22] In our study, greater postoperative weight loss following LSG was correlated to increased AT-D, consistent with previous findings.[21, 22] We investigated whether the preoperative CT density in the obese group could predict postoperative weight loss outcomes. In patients with T2DM, lower preoperative VAT-D was associated with significantly less weight loss after LSG, as indicated by %TWL and %EWL. These findings suggest that preoperative VAT-D may serve as a weight-loss predictor following LSG. Although the DM(+)VAT-L group had a larger TFA than the DM(+)VAT-H group, this possibly reflected differences in body size rather than fat quality. Consequently, the diminished weight loss in the VAT-L group is better explained by the lower VAT-D, supporting its role as a marker of adipose tissue quality and predictor of postoperative effects.

T2DM, a well-documented obesity-related condition, has also been linked to AT-D. Enlarged adipocytes in the VAT resulting from intracellular triglyceride accumulation are known to induce insulin resistance.[14, 40] Additionally, T2DM is linked to impaired angiogenic function in adipose tissue,[20] suggesting that CT density may serve as a clinically relevant marker of metabolic dysfunction. In the present study, a lower preoperative VAT-D score in the T2DM group was associated with poorer diabetes remission, highlighting its potential role as a predictor of postoperative glycemic outcomes. Furthermore, ROC analysis demonstrated that VAT-D displayed comparable sensitivity and specificity to established predictive models such as the ABCD and DiaRem scores, which are widely utilized to assess the likelihood of diabetes remission following bariatric surgery.[23, 24] These

findings suggest that VAT-D may reflect qualitative changes in adipose tissue associated with postoperative metabolic improvement. Previous studies have demonstrated that morbid obesity and T2DM both significantly affect VAT structure and function.[14, 15, 40] This observation potentially elucidates the rationale behind the more pronounced association between VAT-D and clinical outcomes in patients with diabetes than in non-diabetic patients observed in this study. Given these findings, VAT-D may serve as a valuable and practical predictor of treatment response in morbidly obese patients with T2DM undergoing bariatric surgery, providing additional insights beyond conventional scoring systems.

The association between the VAT-D and clinical data suggests a potential link between VAT-D and chronic inflammation in obesity. Obesity induces mild, subacute chronic inflammation in various tissues and organs, including adipose tissue, liver, pancreas, and vasculature, through cytokine-mediated immune cell accumulation.[41, 42] Chronic inflammation is known to contribute to metabolic disorders such as insulin resistance.[43, 44] Inflammatory processes promote adipocyte hypertrophy, impaired angiogenesis, and hypoxia.[17] As adipocytes enlarge with increased lipid content, inflammatory immune cell infiltration intensifies, vascular density diminishes, and CT density decreases.[17] It has been previously reported that adipocyte size and fibrosis, which constitute AT-D, are associated with inflammatory cytokines.[45, 46] Since our previous research demonstrated a link between the proportion of $CD56^{bright}$ NK cells in VAT and the preoperative weight loss in patients with morbid obesity,(30) we investigated the association between VAT-D and VAT NK cells in this study. Our findings indicate that lymphocyte fractions and NK cell phenotypes are not directly associated with AT-D. However, we observed that a lower VAT-D corresponded to a higher proportion of $CD56^{bright}$ NK cells in the VAT, a subtype that specializes in cytokine production. Although the present study was confined to the examination of NK cell surface markers, subsequent analyses of specific NK cell functions, such as interferons and the production of other cytokines, may offer more detailed evidence regarding the relationship between VAT-D and LSG postoperative outcomes. These findings suggest that $CD56^{bright}$ NK cells play a role in the immune and metabolic mechanisms underlying bariatric surgical outcomes.

The limitation of this study is its small sample size, which constrained the analysis of lymphocytes in VAT due to limited sample availability. Addressing this limitation requires larger multicenter studies with more diverse populations to validate our findings. Expanding the scope to include a broader range of lymphocyte phenotypes and their functional roles in VAT may provide a more comprehensive understanding of the immunological mechanisms underlying the effects of bariatric surgery. In addition, incorporating advanced imaging techniques and detailed metabolic profiling may further elucidate the relationship between VAT quality, immune cell composition, and postoperative therapeutic outcomes.

This study is the first to demonstrate that VAT-D, as assessed using preoperative CT, is an independent predictor of treatment outcomes, including weight loss and T2DM remission, in patients with morbid obesity undergoing bariatric surgery. These findings highlight the potential clinical utility of VAT-D as a simple, non-invasive imaging biomarker that reflects adipose tissue quality beyond conventional anthropometric measures such as BMI. In addition, this study provides novel insights into the potential link between VAT-D and the immune microenvironment of VAT, particularly NK cells, further emphasizing the biological significance of adipose tissue composition in metabolic recovery. Notably, VAT-D can facilitate the decision-making process regarding the selection of surgical procedures for bariatric surgery. Among the common bariatric procedures such as LSG and Roux-en-Y gastric bypass, VAT-D may offer additional insight into the selection of the most appropriate approach for individual patients. Further research is warranted to validate VAT-D in larger cohorts and clarify its link to immune factors such as VAT NK cells. Incorporating VAT-D into clinical practice may support effective, personalized treatment strategies for severe obesity.

Conclusions

The CT density of VAT was associated with the immune cell composition within the VAT and clinical outcomes of bariatric surgery. Our findings suggest that CT density could serve as a non-invasive and practical predictor of treatment outcomes in patients with morbid obesity, providing valuable insights into the chronic inflammation of

VAT. Further research is warranted to explore the clinical applicability and potential for integration into standard practice.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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