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Association of pre-transplant CT-derived perirenal fat measurements with post-transplant diabetes mellitus after kidney transplantation

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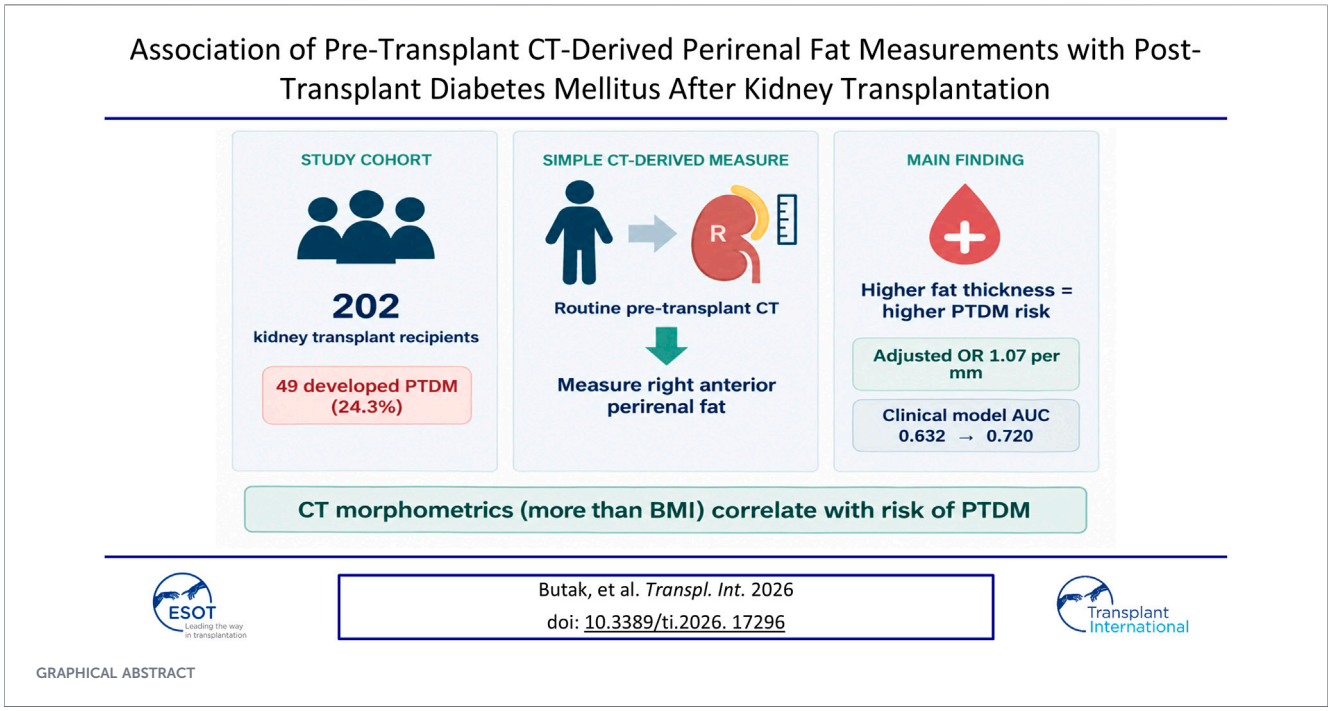
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Post-transplant diabetes mellitus (PTDM) is a common metabolic complication after kidney transplantation with important implications for patient and graft outcomes. We evaluated the association between pre-transplant computed tomography (CT)-derived adiposity measurements and the development of PTDM. We retrospectively studied adult kidney transplant recipients who underwent pre-transplant abdominal CT imaging. CT-derived adiposity measurements were obtained at standardized anatomical locations. Multivariable logistic regression models were constructed for each imaging parameter after adjustment for age, sex, and body mass index. Model discrimination was assessed using receiver operating characteristic analysis. Among all CT-derived adiposity measurements, right anterior perirenal fat thickness demonstrated the strongest independent association with PTDM (adjusted OR 1.07, 95% CI 1.03–1.12; P = 0.001). Right maximum perirenal fat thickness (adjusted OR 1.04, 95% CI 1.00–1.08; P = 0.028) and anterior subcutaneous fat thickness (adjusted OR 1.05, 95% CI 1.02–1.09; P = 0.005) were also independently associated with PTDM, whereas other CT-derived adiposity measurements were not. Pre-transplant right anterior perirenal fat thickness is independently associated with PTDM after kidney transplantation and improves prediction beyond conventional clinical risk factors. This simple CT-derived measurement may enhance pre-transplant metabolic risk assessment and warrants validation in prospective multicenter studies.

KEYWORDS
metabolic derangements, perirenal fat, post-transplant diabetes mellitus, transplant outcomes, visceral adiposity

Introduction

Post-transplant diabetes mellitus (PTDM) is one of the most common metabolic complications following kidney transplantation, affecting approximately 10%–30% of recipients depending on the study population and diagnostic criteria [1–4]. PTDM is diagnosed according to international consensus recommendations after excluding transient post-transplant hyperglycemia and is associated with increased cardiovascular events, infectious complications, reduced graft survival, and premature mortality [1–5]. Despite



advances in immunosuppressive therapy and perioperative management, PTDM remains an important determinant of long-term patient and allograft outcomes.

PTDM results from a complex interaction between preexisting metabolic susceptibility and transplant-related factors. Established risk factors include older age, obesity, family history of diabetes, hypertension, dyslipidemia, hepatitis C infection, and the diabetogenic effects of calcineurin inhibitors and corticosteroids [1, 2, 6–8]. Although these clinical characteristics identify patients at increased risk, accurately predicting PTDM before transplantation remains challenging. Moreover, body mass index (BMI), the most commonly used measure of obesity, does not adequately characterize body fat distribution or distinguish metabolically active visceral fat from lean tissue [9].

Accumulating evidence indicates that visceral adiposity is more strongly associated with insulin resistance and metabolic dysfunction than generalized obesity [10, 11]. Computed tomography (CT), routinely obtained during the evaluation of kidney transplant candidates at many transplant centers, provides an objective and reproducible method for quantifying regional adiposity without additional imaging or radiation exposure beyond standard pre-transplant assessment. Initial studies using CT-based analytic morphomics demonstrated that body composition is associated with the subsequent development of PTDM after kidney transplantation [12]. More recently, automated CT-derived body composition analysis has further improved the prediction of PTDM beyond conventional clinical variables, supporting the growing role of CT-based body composition analysis in pre-transplant metabolic risk assessment [13, 14]. However, these investigations have primarily focused on global visceral adiposity or automated body composition metrics rather than individual perirenal adiposity measurements.

To our knowledge, no study has comprehensively evaluated multiple CT-derived perirenal adiposity measurements and their independent association with PTDM after kidney transplantation. Therefore, we aimed to evaluate the association between multiple pre-transplant CT-derived perirenal adiposity measurements and the development of PTDM after kidney transplantation. We hypothesized that increased perirenal fat thickness would be independently associated with PTDM after adjustment for age, sex, and body mass index, and that it could serve as a simple, readily available imaging biomarker for pre-transplant metabolic risk stratification.

Materials and methods

Study design and patient population

We conducted a single-center retrospective cohort study of consecutive adult kidney transplant recipients who underwent transplantation at the Medical College of Wisconsin between January 1, 2012, and September 7, 2023. The study was approved by the Institutional Review Board of the Medical College of Wisconsin.

Patients were eligible for inclusion if they were 18 years of age or older, underwent kidney transplantation during the study period, had an available pre-transplant abdominal computed tomography (CT) scan (with or without contrast) performed no more than 18 months before transplantation, and had sufficient clinical follow-up to ascertain whether they developed post-transplant diabetes mellitus (PTDM) (Figure 1).

Patients were excluded if they had a diagnosis of diabetes mellitus before transplantation, underwent multi-organ transplantation, were younger than 18 years of age, lacked an

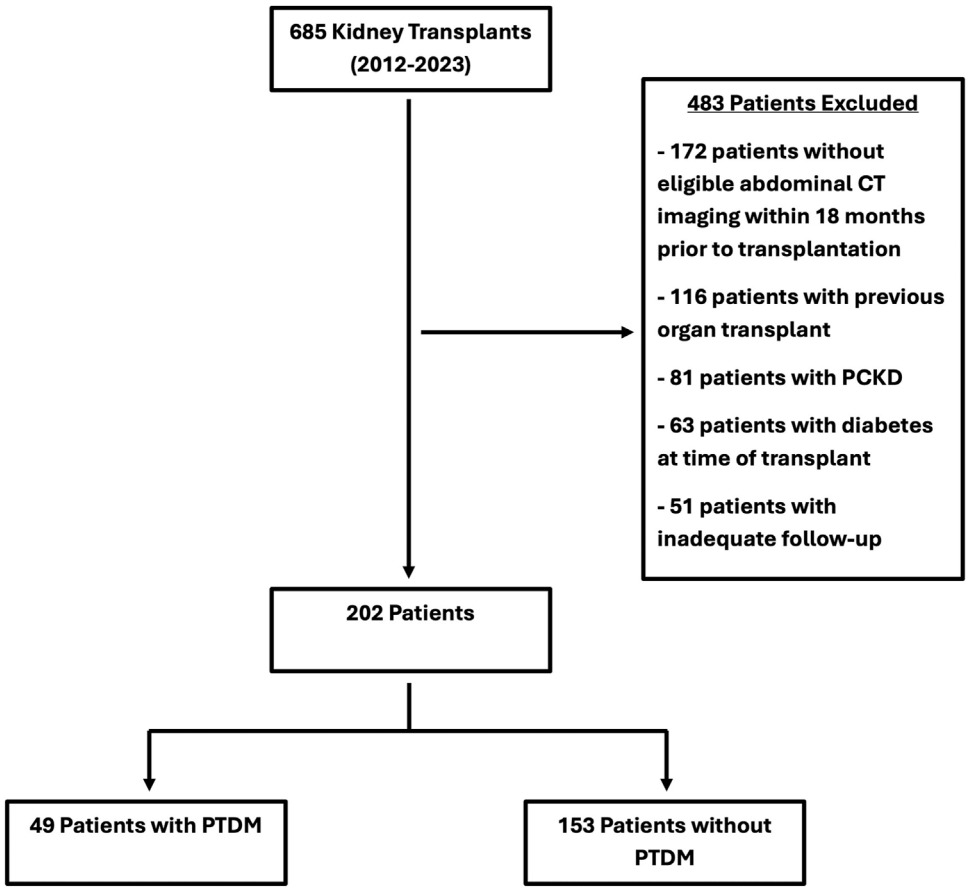


FIGURE 1
Patient selection flow diagram showing cohort eligibility and reasons for exclusion. CT, computed tomography; PCKD, polycystic kidney disease; PTDM, post-transplant diabetes mellitus.

eligible pre-transplant CT examination, or had incomplete clinical or imaging data. Recipients with a history of organ transplantation or polycystic kidney disease were also excluded. After application of the inclusion and exclusion criteria, 202 patients comprised the final study cohort.

Radiological measurements

Pre-transplant abdominal CT examinations performed within 18 months before kidney transplantation were reviewed. Perirenal fat measurements were obtained on axial CT images using the method described by Chen et al. [15]. For each native kidney, anterior, lateral, and posterior perirenal fat thicknesses were measured as the shortest perpendicular distance from the renal capsule to the adjacent fascia or surrounding visceral structures (Figure 2). Maximum perirenal fat thickness was defined as the greatest perpendicular distance between the renal capsule and the surrounding fascia on the same axial image.

Additional CT-derived anthropometric measurements were obtained to characterize overall body habitus and adiposity. These included anterior subcutaneous fat thickness, body depth, cross-sectional body area, and abdominal circumference. Anterior subcutaneous fat thickness was measured as the perpendicular distance between the skin surface and the anterior abdominal wall musculature at the level of the L4 vertebra. Body depth was defined as the maximum anteroposterior distance between the anterior and posterior skin surfaces on the same axial image. Cross-sectional body area and abdominal circumference were determined by tracing the external body contour on the axial CT image at the level of the L4 vertebra using the institutional image analysis software. All linear measurements were recorded in millimeters, whereas cross-sectional body area was recorded in square millimeters.

Definition of PTDM

PTDM was diagnosed according to the international consensus recommendations using the diagnostic criteria for diabetes mellitus after exclusion of transient post-transplant hyperglycemia. PTDM was defined by one or more of the following: fasting plasma glucose ≥126 mg/dL, 2-h plasma glucose ≥200 mg/dL during an oral glucose tolerance test, hemoglobin A1c ≥ 6.5%, or random plasma glucose ≥200 mg/dL in the presence of classic symptoms of hyperglycemia.

Early postoperative hyperglycemia alone was not classified as PTDM. In the absence of unequivocal symptomatic hyperglycemia, abnormal diagnostic results were confirmed on a separate occasion. Early diagnoses were reviewed against subsequent clinical assessments to confirm persistent diabetes.

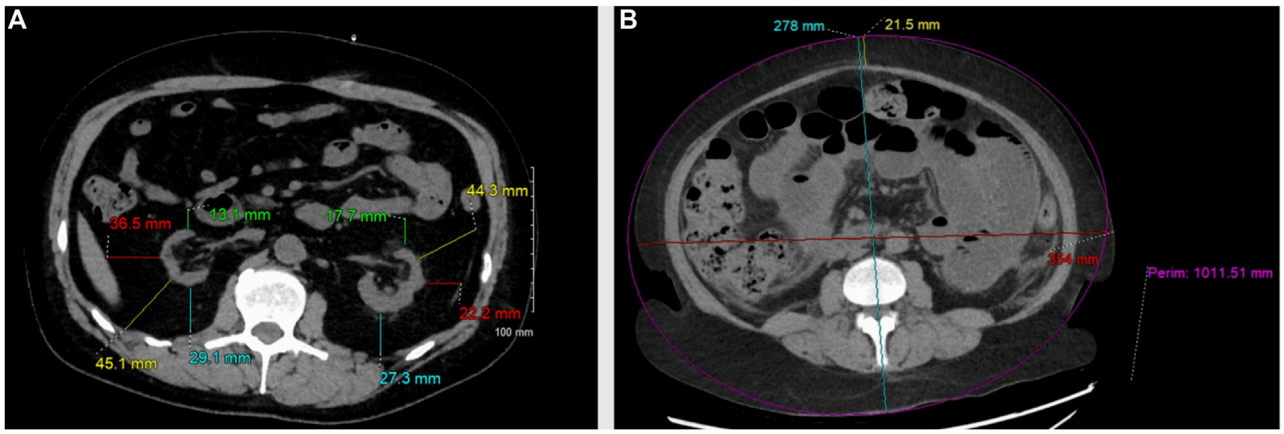


FIGURE 2
Representative axial computed tomography (CT) image demonstrating fat measurements. **(A)** Anterior (green), lateral (red), posterior (blue), and maximum (yellow) perirenal fat thicknesses. **(B)** Body width (red), body depth (blue), abdominal circumference (purple), and anterior subcutaneous fat (yellow) at the level of the L4 vertebra.

Clinical variables

Recipient demographic and clinical characteristics were obtained from the electronic medical record, including age, sex, body mass index (BMI), donor type, induction immunosuppression, maintenance immunosuppression, and other transplant-related variables. Clinical characteristics were compared between recipients who developed PTDM and those who did not.

Statistical analysis

Continuous variables are presented as median (interquartile range) or mean ± standard deviation, as appropriate, and categorical variables are presented as frequencies and percentages. Baseline characteristics were compared between patients who developed PTDM and those who did not, using the appropriate univariate statistical tests.

Variables that were statistically significant in the univariate analysis were entered into multivariable logistic regression models to identify independent predictors of PTDM. Each CT-derived adiposity parameter was evaluated in a separate multivariable logistic regression model adjusted for age, sex, and BMI, irrespective of its univariate statistical significance. Odds ratios (ORs) with 95% confidence intervals (CIs) were reported.

The discriminatory performance of individual CT-derived adiposity measurements and multivariable models was evaluated using receiver operating characteristic (ROC) curve analysis. The area under the ROC curve (AUC) with 95% confidence intervals was calculated using bootstrap resampling. Statistical significance was defined as a two-sided P value <0.05. All statistical analyses were performed using standard statistical software.

Results

A total of 202 kidney transplant recipients met the study inclusion criteria. Among these, 49 patients (24.3%) developed post-transplant diabetes mellitus (PTDM), whereas 153 (75.7%) remained free of PTDM during follow-up (Figure 1). The mean follow-up duration was 68.8 ± 39.3 months for the overall cohort. Mean follow-up was similar between recipients who developed PTDM and those who did not (71.7 ± 37.3 vs. 67.9 ± 39.9 months, $P = 0.54$).

Baseline clinical characteristics

Baseline demographic and clinical characteristics are summarized in Table 1. Patients who developed PTDM were older at the time of transplantation than those who did not develop PTDM (54.2 ± 11.9 vs. 49.0 ± 13.8 years, $P = 0.011$). Pre-transplant hemoglobin A1c was also significantly higher among recipients who subsequently developed PTDM (5.19% ± 0.31% vs. 4.99% ± 0.40%, $P = 0.022$). No significant differences were observed between groups with respect to sex, body mass index (BMI), ethnicity, hypertension, dyslipidemia, coronary artery disease, smoking history, dialysis duration, cause of end-stage renal disease, donor type, induction immunosuppression, maintenance immunosuppression, or follow-up duration (Table 1). Residual confounding related to tacrolimus exposure and cumulative glucocorticoid doses cannot be excluded, as these were not incorporated into the models.

CT-derived adiposity measurements

Comparisons of CT-derived adiposity measurements are presented in Table 2. Recipients who developed PTDM demonstrated significantly greater left anterior perirenal fat thickness (14.07 ± 11.15 vs. 10.35 ± 8.51 mm, $P = 0.042$), left maximum perirenal fat thickness (33.22 ± 12.47 vs. 27.44 ± 12.05 mm, $P = 0.007$), right anterior perirenal fat thickness (15.81 ± 9.76 vs. 9.59 ± 9.20 mm, $P < 0.001$), right maximum perirenal fat thickness (32.46 ± 12.52 vs. 26.26 ± 11.75 mm, $P = 0.004$), and anterior subcutaneous fat thickness (28.00 ± 12.87 vs. 22.48 ± 12.17 mm, $P = 0.012$). Left lateral and left posterior perirenal fat measurements demonstrated borderline statistical significance

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TABLE 1 Baseline Recipient and Transplant Characteristics According to Post-Transplant Diabetes Mellitus Status. PTDM, post-transplant diabetes mellitus.

Variable	No PTDM (n = 153)	PTDM (n = 49)	P value
Age at transplantation, years	49.0 ± 13.8	54.2 ± 11.9	0.011
Male sex, n (%)	65 (42.5)	24 (49.0)	0.528
Body Mass index, kg/m^2	27.3 ± 5.3	28.8 ± 5.6	0.128
Non-hispanic ethnicity, n (%)	137 (89.5)	45 (91.8)	0.787
Hypertension, n (%)	137 (89.5)	46 (93.9)	0.574
Prediabetes, n (%)	3 (2.0)	2 (4.3)	0.340
Dyslipidemia, n (%)	54 (35.5)	24 (50.0)	0.105
Coronary artery disease, n (%)	14 (9.4)	5 (10.4)	0.784
Smoking history, n (%)			0.977
• Never	92 (60.1)	29 (59.2)	
• Former	54 (35.3)	18 (36.7)	
• Current	7 (4.6)	2 (4.1)	
Pretransplant hemoglobin A1c, %	4.99 ± 0.40	5.19 ± 0.31	0.022
Dialysis duration, days	1,469 ± 1,198	1,516 ± 1,123	0.835
Cause of end-stage renal disease, n (%)			0.173
• Hypertensive nephrosclerosis	47 (31.1)	24 (49.0)	
• Glomerular/Immune disease	69 (45.7)	16 (32.7)	
• Obstructive/Urologic disease	6 (4.0)	2 (4.1)	
• Cystic kidney disease	1 (0.7)	1 (2.0)	
• Other/Unknown	28 (18.5)	6 (12.2)	
Living donor transplantation, n (%)	43 (28.1)	14 (28.6)	1.000
Induction immunosuppression, n (%)			0.559
• Thymoglobulin	111 (73.0)	35 (71.4)	
• Basiliximab	38 (25.0)	14 (28.6)	
• Steroid only/Other	3 (2.0)	0	
Tacrolimus-based maintenance immunosuppression at 3 months, n (%)	142 (93.4)	47 (95.9)	0.734

($P = 0.054$ and $P = 0.053$, respectively), whereas body depth, cross-sectional body area, abdominal circumference, and right lateral and posterior perirenal fat measurements were not significantly different between groups.

Univariate logistic regression analysis

Univariate logistic regression analysis identified several imaging parameters associated with PTDM (Table 3). Among the clinical variables, increasing age (OR 1.03 per year, 95% CI 1.00–1.06; $P = 0.020$) and higher pre-transplant hemoglobin A1c (OR 4.26, 95% CI 1.02–17.74; $P = 0.046$) were significantly associated with PTDM, whereas sex, BMI, and dyslipidemia were not.

Among CT-derived adiposity measurements, right anterior perirenal fat thickness demonstrated the strongest association with PTDM (OR 1.07 per mm, 95% CI 1.03–1.11; $P < 0.001$). Left anterior perirenal fat thickness, left posterior perirenal fat thickness, left maximum perirenal fat thickness, right maximum perirenal fat thickness, and anterior subcutaneous fat thickness were also significantly associated with PTDM in univariate analyses.

Multivariable logistic regression analysis

Multivariable logistic regression models adjusted for recipient age, sex, and BMI are summarized in Table 4. Right anterior perirenal fat thickness remained independently associated with PTDM after adjustment (adjusted OR 1.07, 95% CI 1.03–1.12; $P = 0.001$). Right maximum perirenal fat thickness (adjusted OR 1.04, 95% CI 1.00–1.08; $P = 0.028$) and anterior subcutaneous fat thickness (adjusted OR 1.05, 95% CI 1.02–1.09; $P = 0.005$) also remained independently associated with PTDM. None of the left-sided perirenal adiposity measurements, body depth, cross-sectional body area, or abdominal circumference remained statistically significant after adjustment. Although different between those

TABLE 2 Pretransplant CT-Derived Adiposity Measurements According to Post-Transplant Diabetes Mellitus Status. PTDM, post-transplant diabetes mellitus.

Variable	No PTDM	PTDM	P value
Left anterior perirenal fat thickness (mm)	10.35 ± 8.51	14.07 ± 11.15	**0.042**
Left lateral perirenal fat thickness (mm)	18.28 ± 12.61	22.05 ± 10.84	0.054
Left posterior perirenal fat thickness (mm)	13.90 ± 9.59	17.31 ± 10.46	0.053
Left maximum perirenal fat thickness (mm)	27.44 ± 12.05	33.22 ± 12.47	**0.007**
Right anterior perirenal fat thickness (mm)	9.59 ± 9.20	15.81 ± 9.76	**<0.001**
Right lateral perirenal fat thickness (mm)	13.58 ± 11.37	17.08 ± 12.91	0.102
Right posterior perirenal fat thickness (mm)	13.56 ± 9.64	16.44 ± 9.44	0.077
Right maximum perirenal fat thickness (mm)	26.26 ± 11.75	32.46 ± 12.52	**0.004**
Anterior subcutaneous fat thickness (mm)	22.48 ± 12.17	28.00 ± 12.87	**0.012**
Body depth (mm)	242.2 ± 48.5	252.1 ± 43.7	0.193
Cross-sectional body area (mm^2)	82,551 ± 27,496	84,378 ± 26,112	0.732
Abdominal circumference (mm)	945.1 ± 159.7	951.6 ± 135.3	0.828

Bold values indicate statistical significance ($P < 0.05$).

TABLE 3 Univariate Logistic Regression Analysis of Clinical and CT-Derived Adiposity Measurements Associated with Post-Transplant Diabetes Mellitus. CI, confidence interval.

Variable	Odds ratio (95% CI)	P value
Age at transplantation (per year)	1.03 (1.00–1.06)	**0.020**
Male sex	1.30 (0.68–2.48)	0.426
Body Mass index (per kg/m^2)	1.05 (0.99–1.11)	0.117
Dyslipidemia	1.81 (0.94–3.50)	0.075
Pretransplant hemoglobin A1c (per 1%)	4.26 (1.02–17.74)	**0.046**
Left anterior perirenal fat thickness (per mm)	1.04 (1.01–1.08)	**0.024**
Left lateral perirenal fat thickness (per mm)	1.03 (1.00–1.05)	0.072
Left posterior perirenal fat thickness (per mm)	1.03 (1.00–1.07)	**0.045**
Left maximum perirenal fat thickness (per mm)	1.04 (1.01–1.07)	**0.007**
Right anterior perirenal fat thickness (per mm)	1.07 (1.03–1.11)	**<0.001**
Right lateral perirenal fat thickness (per mm)	1.02 (1.00–1.05)	0.083
Right posterior perirenal fat thickness (per mm)	1.03 (1.00–1.07)	0.080
Right maximum perirenal fat thickness (per mm)	1.04 (1.01–1.07)	**0.004**
Anterior subcutaneous fat thickness (per mm)	1.03 (1.01–1.06)	**0.011**

Bold values indicate statistical significance ($P < 0.05$).

who did and did not develop PTDM, pre-transplant HbA1c was not included in the multivariate analysis as only 85 patients (42%) of the cohort had data for this value.

Predictive performance

Receiver operating characteristic (ROC) analyses are presented in Table 5. Right anterior perirenal fat thickness alone demonstrated good discrimination for PTDM (AUC 0.699), outperforming BMI alone (AUC 0.573) and anterior subcutaneous fat thickness alone (AUC 0.628). The baseline clinical model incorporating age, sex, and BMI yielded an AUC of 0.632. The addition of right anterior perirenal fat thickness improved the predictive performance of the clinical model, increasing the AUC to 0.720, whereas the addition of anterior subcutaneous fat thickness resulted in a more modest improvement (AUC 0.689) (Figure 3).

TABLE 4 Multivariable logistic regression analysis evaluating the association between CT-Derived adiposity measurements and post-transplant diabetes mellitus after adjustment for age, sex, and body mass index.

CT-derived adiposity measurement	Adjusted OR (95% CI)	P value
Left anterior perirenal fat thickness	1.03 (0.99–1.07)	0.151
Left lateral perirenal fat thickness	1.01 (0.98–1.05)	0.543
Left posterior perirenal fat thickness	1.02 (0.98–1.07)	0.291
Left maximum perirenal fat thickness	1.03 (1.00–1.07)	0.075
Right anterior perirenal fat thickness	1.07 (1.03–1.12)	**0.001**
Right lateral perirenal fat thickness	1.01 (0.98–1.05)	0.416
Right posterior perirenal fat thickness	1.02 (0.98–1.07)	0.316
Right maximum perirenal fat thickness	1.04 (1.00–1.08)	**0.028**
Anterior subcutaneous fat thickness	1.05 (1.02–1.09)	**0.005**
Body depth	1.00 (0.99–1.01)	0.955
Cross-sectional body area	1.00 (1.00–1.00)	0.958
Abdominal circumference	1.00 (0.995–1.005)	0.885

Bold values indicate statistical significance ($P < 0.05$).

TABLE 5 Receiver operating characteristic analysis of clinical and CT-Derived adiposity measurements for predicting post-transplant diabetes mellitus.

Model	AUC (95% bootstrap CI)
Body Mass index alone	0.573 (0.503–0.670)
Right anterior perirenal fat thickness alone	0.699 (0.617–0.793)
Anterior subcutaneous fat thickness alone	0.628 (0.542–0.723)
Clinical model (age, sex, and body Mass index)	0.632 (0.567–0.732)
Clinical model + right anterior perirenal fat thickness	0.720 (0.652–0.819)
Clinical model + anterior subcutaneous fat thickness	0.689 (0.622–0.784)

Discussion

In this single-center retrospective cohort study, we evaluated the association between pre-transplant CT-derived adiposity measurements and the development of post-transplant diabetes mellitus (PTDM) after kidney transplantation. Our principal finding was that right anterior perirenal fat thickness demonstrated the strongest independent association with PTDM after adjustment for recipient age, sex, and body mass index (BMI). The right maximum perirenal fat thickness and anterior subcutaneous fat thickness also remained independently associated with PTDM after multivariable adjustment, although right anterior perirenal fat thickness demonstrated the greatest discriminatory ability for PTDM. Furthermore, incorporation of right anterior perirenal fat thickness into a clinical prediction model improved discrimination, increasing the area under the receiver operating characteristic curve (AUC) from 0.632 to 0.720. Collectively, these findings suggest that a simple measurement obtained from routine pre-transplant CT imaging may improve identification of kidney transplant recipients at increased risk for PTDM beyond conventional clinical risk factors.

These findings are clinically important because they suggest that regional fat distribution assessed on routine pre-transplant CT captures aspects of metabolic risk that are not adequately reflected by conventional clinical characteristics. Although established risk factors such as advanced age, obesity, impaired glucose metabolism, and diabetogenic immunosuppressive agents are routinely considered during transplant evaluation, they incompletely explain why some recipients develop PTDM, whereas others with similar clinical profiles do not. This highlights the need for complementary approaches that better characterize an individual's metabolic risk before transplantation. Our findings suggest that simple CT-derived adiposity measurements may provide clinically relevant information beyond traditional risk factors and improve pre-transplant metabolic risk stratification [2, 3, 6, 7].

Our findings build upon a growing body of literature demonstrating the value of CT-based body composition analysis for metabolic risk assessment in kidney transplantation. Early work by Cron et al. demonstrated that pre-transplant CT-derived morphometric measurements were associated with the subsequent development of PTDM after kidney transplantation. More recently, Kim et al. showed that automated deep learning-

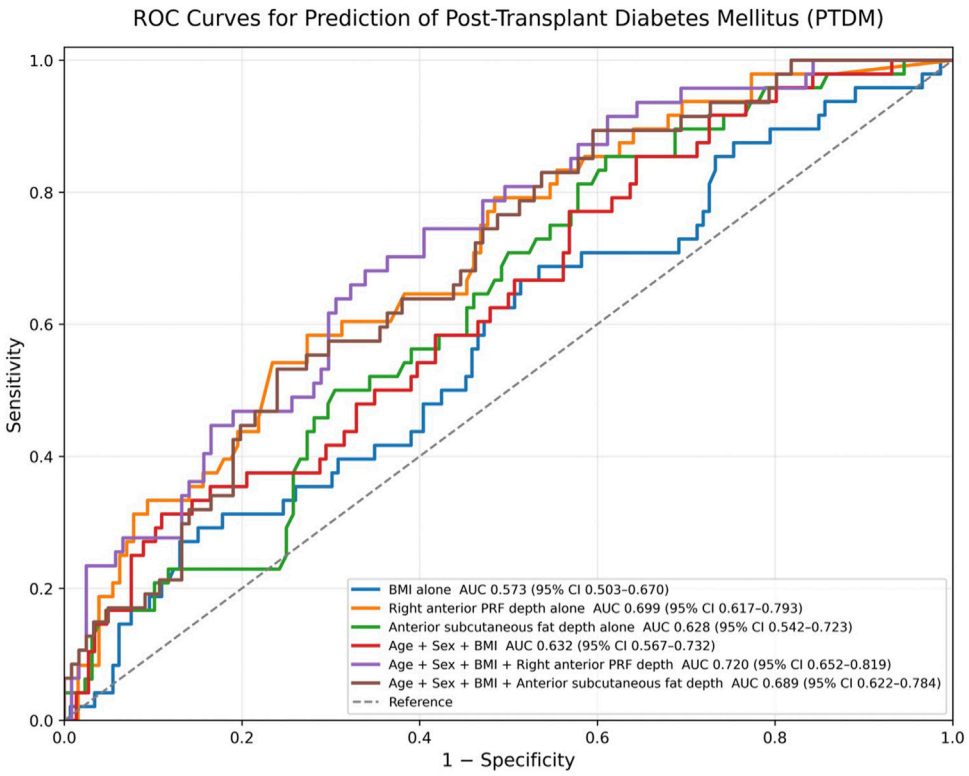


FIGURE 3
Receiver operating characteristic (ROC) curves for prediction of post-transplant diabetes mellitus (PTDM). ROC curves comparing the discriminative performance of body mass index (BMI) alone, right anterior perirenal fat thickness alone, anterior subcutaneous fat thickness alone, a clinical model incorporating recipient age, sex, and BMI, and clinical models with the addition of right anterior perirenal fat thickness or anterior subcutaneous fat thickness. Incorporation of right anterior perirenal fat thickness into the clinical model improved discrimination for PTDM (AUC, 0.720; 95% CI, 0.652–0.819) compared with the clinical model alone (AUC, 0.632; 95% CI, 0.567–0.732). Confidence intervals were estimated using bootstrap resampling. The diagonal dashed line represents discrimination expected by chance (AUC = 0.50).

based quantification of visceral adiposity improved prediction beyond conventional clinical variables, while Budhiraja et al. further demonstrated that integrating CT-derived body composition features with clinical characteristics enhanced predictive performance [12–14]. Collectively, these studies support the concept that body composition analysis provides clinically relevant information beyond traditional anthropometric measurements and underscore the potential role of CT in improving pre-transplant metabolic risk assessment.

However, our study differs from previous investigations in several important respects. Whereas previous studies have primarily evaluated global visceral adiposity or relied on automated body composition analysis, we comprehensively assessed multiple manually measured perirenal fat parameters obtained from routine pre-transplant CT examinations. Right anterior perirenal fat thickness emerged as the most informative parameter, demonstrating the strongest and most consistent independent association with PTDM after adjustment for recipient age, sex, and BMI. More importantly, these measurements can be obtained from routinely acquired pre-transplant CT scans without specialized software, automated segmentation, or artificial intelligence-based image analysis, making this approach practical and applicable in everyday clinical practice.

An important observation emerging from our analyses was the limited predictive value of BMI. Although obesity is a well-established risk factor for PTDM and BMI has consistently been identified as an independent predictor in previous studies, BMI was not significantly associated with PTDM in our cohort, whereas several CT-derived adiposity measurements demonstrated significant associations. One possible explanation is that recipients with pre-existing diabetes were excluded and kidney transplant candidates undergo careful pre-transplant evaluation, resulting in a relatively narrow BMI distribution. Consequently, BMI may have had limited ability to distinguish recipients at different levels of metabolic risk despite substantial variation in regional fat distribution.

Beyond the relatively narrow BMI distribution observed in our cohort, BMI itself may be an imperfect surrogate for metabolic risk in kidney transplant candidates. As a global anthropometric measure, BMI does not distinguish lean body mass from adipose tissue or characterize regional fat distribution. In contrast, perirenal fat measurements obtained from routine pre-transplant CT imaging directly quantify ectopic adipose tissue, which may more accurately reflect the metabolic abnormalities underlying PTDM. Consistent with this concept, right anterior perirenal fat thickness demonstrated better discrimination than BMI alone (AUC 0.699 vs. 0.573) and further improved the predictive performance of a clinical model incorporating

age, sex, and BMI (AUC increased from 0.632 to 0.720). Together, these findings suggest that assessment of regional fat distribution may identify kidney transplant recipients at increased metabolic risk despite similar BMI values.

Having established the predictive value of right anterior perirenal fat thickness, it is worth considering the biological basis for this association. Perirenal adipose tissue is increasingly recognized as a metabolically active ectopic fat depot that secretes adipokines, inflammatory cytokines, and other bioactive mediators implicated in insulin resistance, chronic inflammation, and glucose dysregulation. Consequently, increased perirenal fat accumulation may reflect an adverse metabolic milieu that predisposes kidney transplant recipients to the development of PTDM. Although the predominance of right-sided measurements observed in our study remains unexplained, it may reflect anatomical differences, variability in fat distribution, or measurement-related factors. Further mechanistic and imaging studies are needed to clarify the biological basis of this laterality and determine whether it represents a true physiological phenomenon or a reproducible imaging characteristic [10, 11].

These findings have several important clinical implications. Because abdominal CT imaging is routinely performed during the evaluation of many kidney transplant candidates, assessment of right anterior perirenal fat thickness can be incorporated into the pre-transplant evaluation without additional imaging, radiation exposure, or cost. The measurement is straightforward, requires minimal additional effort, and can be readily obtained from standard CT images. Identification of recipients at increased risk for PTDM before transplantation may facilitate individualized patient counseling, closer post-transplant glucose surveillance, early lifestyle interventions, and consideration of strategies to minimize diabetogenic immunosuppression when clinically appropriate. If validated in larger prospective multicenter studies, incorporation of this simple measurement into routine pre-transplant assessment may improve individualized metabolic risk stratification and help guide preventive strategies following kidney transplantation. Additionally, future studies comparing perirenal fat with traditional anthropometric measures, such as waist and hip circumference, may further refine their individual or combined predictive value for PTDM.

Despite the use of standardized CT measurements and a carefully defined cohort of kidney transplant recipients, our findings should be interpreted in light of several limitations. First, this was a retrospective single-center study, which may limit the generalizability of our findings. Second the modest sample size and 49 PTDM events limit the precision and robustness of the multivariable estimates. Model discrimination was evaluated in the development cohort and may therefore be optimistic. Independent validation is required before clinical implementation. Third, although our models adjusted for important clinical confounders, residual confounding from unmeasured variables cannot be excluded. Finally, the predictive performance of our findings requires external validation in larger prospective multicenter cohorts before routine clinical implementation.

Conclusion

Right anterior perirenal fat thickness was independently associated with the development of PTDM after kidney transplantation and improved the prediction of PTDM beyond conventional clinical risk factors. Because this simple measurement can be readily obtained from routine pre-transplant CT imaging without additional imaging, radiation exposure, cost, or specialized software, it represents a practical approach to enhancing pre-transplant metabolic risk assessment. Prospective multicenter studies are warranted to externally validate these findings and determine whether the incorporation of right anterior perirenal fat thickness into clinical risk assessment improves individualized risk stratification and supports targeted preventive strategies for kidney transplant recipients.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Medical College of Wisconsin IRB (PRO00052951). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

WB – Concept/design, data analysis, drafting of article, data collection. JM – Concept/design, data collection, data analysis/interpretation. SM – Data collection and analysis. CC – Data collection and analysis. JC – Data collection and analysis. BR – Critical review of article. MC – Critical review of article. TD – Approval of article, concept/design, data interpretation, critical revision of article. EA - Approval of article, concept/design, data interpretation, critical revision of article. All authors contributed to the article and approved the submitted version.

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