Abdominal Lean Muscle Is Associated with Lower Mortality among Kidney Waitlist Candidates

Jayme E. Locke, MD MPH[1], **J. Jeff Carr, MD**[2], **Sangeeta Nair, DVM MS**[2], **James G. Terry, MS**[2], **Rhiannon D. Reed, MPH**[1], **Grant D. Smith**[1], **Dorry L. Segev, MD, PhD**[3], **Vineeta Kumar, MD**[1], and **Cora E. Lewis, MD MPH**[4]

[1]University of Alabama at Birmingham Comprehensive Transplant Institute, Birmingham, AL

[2]Department of Radiology and Vanderbilt Translational and Clinical Cardiovascular Research Center (VTRACC), Vanderbilt University School of Medicine, Nashville, TN

[3]Johns Hopkins University, Department of Surgery, Baltimore, MD

[4]University of Alabama at Birmingham, Division of Preventive Medicine, Birmingham, AL

Abstract

Morphometric assessments, such as muscle density and body fat distribution, have emerged as strong predictors of cardiovascular risk and post-operative morbidity and mortality. To date, no study has examined morphometric mortality risk prediction among kidney transplant (KT) candidates. KT candidates, waitlisted 2008–2009 were identified (n=96) and followed to the earliest of transplant, death, or administrative end of study. Morphometric measures, including abdominal adipose tissue, paraspinous and psoas muscle composition, and aortic calcification were measured from CTs. Risk of waitlist mortality was examined using Cox proportional hazards regression. On adjusted analyses, radiologic measures remained independently and significantly associated with lower waitlist mortality; the addition of radiologic measures significantly improved model predictive ability over models containing traditional risk factors alone (net reclassification index: 0.56, 95% CI: 0.31–0.75). Higher psoas muscle attenuation (indicative of leaner muscle) was associated with decreased risk of death (aHR: 0.93, 95% CI: 0.91–0.96, p< 0.001); and for each unit increase in lean paraspinous volume there was an associated 2% decreased risk for death (aHR: 0.98, 95%CI: 0.96–0.99, p=0.03). Radiologic measures of lean muscle mass, such as psoas muscle attenuation and paraspinous lean volume, may improve waitlist mortality risk prediction and candidate selection.

INTRODUCTION

There is a large unmet need for donor kidneys with over 100,000 patients currently waiting for a deceased donor kidney transplant, yet each year only 11,000 receive a transplant.[1] With annual death rates among waitlist registrants approaching 15%, many die before receiving a kidney transplant.[2]

Current kidney transplant selection practices involve a series of evaluations intended to assess perioperative morbidity and mortality, particularly cardiovascular risk, such that allocation of a scarce resource is optimized.[3,4] However, these assessments are costly and often imprecise, as waitlist mortality remains high in large part due to cardiovascular events. Identification of alternative methodologies for predicting morbidity and mortality among waitlisted ESRD patients is a priority. In fact, a 2012 US consensus conference convened to evaluate "Transplant Program Quality and Surveillance", including a review of the limitations of existing data on pre-transplant metrics and an evaluation of the needs for more accurate predictive tools for waitlist mortality. The conference concluded that more data on waiting list mortality risk and outcomes should be provided.[5]

Only 51% of dialysis patients are still alive three years after initiation of treatment for end-stage renal disease (ESRD), illustrating the extreme vulnerability of these patients compared to the general population.[6] Although comorbidity and disability are associated with mortality and hospitalization in ESRD,[6–11] their high prevalence in the ESRD population limits their ability to inform risk prediction.[7,8,12–14] Other metrics such as elevated cardiac troponin T (cTnT) have been studied to refine risk prediction in this population,[15–17] showing a 1.7-fold increased risk for mortality among waitlist candidates (hazard ratio (HR): 1.73; 95%CI: 1.25–2.39, p=0.01).[16] However, the test was associated with low sensitivity (70%) and specificity (69%), and is not routinely performed as part of the kidney transplant evaluation process.[16] Moreover, while novel, these additional metrics, such as cTnT, identified to date require additional testing, cost, and time, and as such, may not be practical additions to an already expensive and intense kidney transplantation evaluation process.

Morphometric assessments, such as muscle density and visceral fat volume, have emerged as strong predictors of cardiovascular risk and post-operative morbidity and mortality.[18–21] Morphometric analyses do not require any additional testing, as these measurements are made using preoperative computed tomography (CT) imaging routinely obtained as part of many transplant center selection practices. To date, no study has examined morphometric risk prediction and mortality among waitlisted ESRD patients.[22,23] Given the significant knowledge gap regarding risk prediction among kidney waitlist candidates, we leveraged the second largest kidney transplant waiting list in the US and examined the relationship between morphometric measures and waitlist mortality.

PATIENTS AND METHODS

Data Source

The study used data from our center's transplant registry, which includes data on all kidney waitlisted candidates and transplant recipients at our center. The use of these data and a waiver of informed consent were approved by our Institutional Review Board (Protocol Number: X140509006).

Study Population

Adult kidney transplant candidates listed at UAB between 2008 and 2009 with CT imaging of their abdomen and pelvis performed at the time of evaluation were identified (n=320). Candidates whose CT scan quality permitted complete analysis of all morphometric measurements of interest were included (n=96).

Traditional Risk Factors

Patient characteristics traditionally associated with cardiovascular mortality were abstracted from the medical record. These traditional measures included age, race, BMI, length of time spent on dialysis, comorbidities such as diabetes, hypertension, and peripheral vascular disease (PVD), social history, and family history of diabetes, hypertension, and chronic kidney disease (CKD)/ESRD. These factors were abstracted from the record on or closest to the date of listing for transplant.

Morphometric Measures

The same methods employed for morphometric assessment of participants in the Coronary Artery Risk Development in Young Adults (CARDIA) study were used in this cohort. The base CT scanning protocol utilized in numerous large studies (Multi-Ethnic Study of Atherosclerosis, Framingham, Family Heart Study, Jackson Heart Study, and Epidemiology of Diabetes Interventions and Complications) and published by CARDIA was used.[24–26] Digital Imaging and Communications in Medicine (DICOM) images from CT were analyzed by skilled analysts, blinded to all clinical information, at Vanderbilt University on a dedicated imaging processing workstation with custom programmed subroutines (Osirix, Pixmeo Bernex, Switzerland) and a dedicated pen computing display (Cintiq, Wacom Technology Corporation Vancouver, WA). Abdominal adipose tissues were volumetrically measured from a block of slices centered at the L4–5 vertebral bodies extending for 30 mm in the z-axis (head-to-foot). Specific Hounsfield units (HU) thresholds are used to discriminate between fat (−190 to −30 HU) and muscle (−30 to −160). Trained analysts defined the boundaries of the air/skin, subcutaneous fat/muscular fascia and peritoneum creating anatomically defined regions of interest (ROI). For the entire abdomen (all tissue deep to the skin), the intra-abdominal space (tissue within the peritoneal cavity) and the subcutaneous space (tissue deep to the skin but superficial to the muscular fascia) the volume [mm3] and mean tissue attenuation [mean CT number] of adipose and lean tissue based on the specific CT number thresholds was calculated. The ratio of visceral to subcutaneous adipose tissue was calculated directly.

Additional segmentations of the psoas and paraspinous skeletal muscles were performed and corresponding volumes of fat and lean tissue calculated within a 30mm block of slices centered at L3–4. Calcified atherosclerotic plaque was measured in the infrarenal abdominal aorta and common iliac arteries and reported as an Agatston Score (Aquarius Workstation, TeraRecon, Foster City, CA), as previously described.[24,26,27]

Exploratory Data Analyses

Characteristics were compared by candidate status – death on the waiting list, transplantation, still waiting. Continuous variables were analyzed using Kruskal Wallis tests, and categorical variables were examined using chi-square tests of independence.

Outcome Ascertainment

The primary outcome was waitlist mortality. Death dates were abstracted from the medical record, obtained from the United Network for Organ Sharing, and supplemented by information from the Centers for Medicare and Medicaid Services and the Limited Access Death Master File available from the National Technical Information Service. Exposure time began at time of waitlisting to the earlier of patient death, transplantation, or administrative end of study (July 1, 2015).

Survival Analyses

Risk of mortality was examined using multivariable Cox proportional hazards regression. Factors found to be significant on univariate analyses, as well as traditional factors known to be associated with cardiovascular mortality, were considered for model development, with the most parsimonious model chosen by minimizing Akaike's Information Criterion. Analysis considering transplantation as a competing risk was performed using the Fine and Gray method, and inferences were confirmed (Supplemental Table 1).[28] All analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC), Stata version 14 (StataCorp, College Station, TX), and R version 3.2.5 (R Foundation for Statistical Computing, Vienna, Austria).

Model discrimination and calibration

The discriminative ability of the standard Cox model was calculated with Harrell's C index. To assess calibration of the model, we stratified patients by quantile of risk and compared observed and expected waitlist mortality using the Groennesby and Borgan score test.[29,30] To assess improvements in discrimination between a model containing only traditional risk factors with a model containing both traditional and morphometric factors, we used an extension of the Net Reclassification Improvement (NRI) index from R package survIDINRI, estimating NRI using 200 resampling perturbations and assessing the values at 3 years post-listing for transplant.[31,32]

Sensitivity Analyses

Additional models were built, including models chosen by backwards, forwards, and stepwise selection and factors significant at an alpha of < 0.10 on univariate analyses. Active status on the waitlist was considered, and results were found to be similar to the competing

risks model (Supplemental Table 2). Models considering other traditional risk factors were generated (Supplemental Table 3). Inferences of the reported parsimonious model were confirmed.

RESULTS

Kidney Transplant Candidate Characteristics

The cohort at time of being added to the waitlist had a median age of 50.7 years (IQR: 40.1–58.0), 57% male, 52% African American, 52% were blood group O, and the median time spent on dialysis prior to evaluation for transplant was 0.63 years (interquartile range (IQR): 0.0–2.30). Comorbid conditions were common, including diabetes 44%, hypertension 90%, coronary artery disease 39%, and PVD 4%. Nine percent of the cohort was infected with hepatitis C, and 22% had a history of prior transplant. After a median of 3.9 years of follow-up (IQR: 1.3–6.1), 39 patients died while waiting, 26 patients were transplanted (13 received deceased donor transplants and 13 living donor transplants), and 31 were still awaiting kidney transplant. Among those transplanted, median waiting time was 0.9 years (IQR: 0.3–3.1).

Waitlist Mortality

We explored traditional risk factors known to be associated with increased risk for cardiovascular morbidity and mortality (Table 1). Candidates that died while waiting were older than those who achieved transplant or remained on the waitlist (54.5 yrs vs. 47.6 yrs vs. 44.9 yrs, respectively, p=0.01) and had longer median time on dialysis prior to evaluation compared to those who achieved transplant (1.1yrs vs. 0.13yrs, p< 0.001). BMI $\geq$ 30kg/m^2 was more common among those remaining alive on the waitlist (60% vs. 31% for those transplanted and 28% for those who died while waiting, p=0.02). Additionally, African American candidates were more likely to die (54%) or remain on the waitlist (71%) than be transplanted (27%, p=0.004).

We also explored previously reported morphometric measures associated with increased risk for cardiovascular morbidity and mortality (Table 2). Total abdominal, visceral and subcutaneous fat volumes showed no association with waitlist mortality although abdominal fat attenuation was slightly higher in those that died on the WL. Skeletal muscle composition of the paraspinous and psoas muscles was strongly associated with waitlist mortality in unadjusted analyses. Lean and total muscle attenuation were each lower in those who died than either those transplanted or still awaiting transplant for both the paraspinous and psoas muscles. These lower attenuations were consistent with higher fat volume to total muscle volume ratios in those who died compared to those who were transplanted or were still alive awaiting transplant. Abdominal aortoiliac calcified plaque prevalence and calcified plaque burden (higher Agatston scores) were higher in those who died awaiting transplant.

On unadjusted analyses, longer time on dialysis was significantly associated with mortality (HR: 1.12, 95%CI: 1.01–1.23, p=0.03), as was older candidate age (HR: 1.04, 95%CI: 1.01–1.08, p=0.007). Additionally, candidate BMI $\geq$ 30kg/m^2 was associated with a 2.38-fold lower risk of death (HR: 0.42; 95%CI: 0.21–0.85, p=0.02). Total abdominal fat attenuation

was significantly lower among waitlist candidates who died compared to those transplanted (−85.3 HU vs. −88.9 HU); and for each HU decrease in total abdominal fat attenuation there was an associated 3% increased risk of waitlist mortality (HR: 1.03, 95%CI: 1.00–1.05, p=0.02). Several abdominal muscle measures correlated with waitlist mortality. Psoas lean volume (22.1cm^3 vs. 31.4cm^3, p=0.01) and attenuation (35.3 HU vs. 44.9 HU, p<0.001) were significantly lower among candidates who died waiting compared to those transplanted. Greater psoas lean muscle mass was associated with decreased risk of waitlist mortality (volume HR: 0.93, 95%CI: 0.90–0.97, p<0.001; attenuation HR: 0.92, 95%CI: 0.89–0.95, p<0.001). Similar trends were observed with measures of paraspinous lean volume and attenuation. Abdominal aortic calcification (AAC) Agatston score was significantly higher among waitlist candidates who died compared to those transplanted (866 Agatston units (AU) vs. 100 AU); and prevalent AAC was associated with a 2.64-fold increased risk of waitlist mortality (HR: 2.64, 95%CI: 1.11–6.31, p=0.03) (Table 3).

After adjusting for multiple factors, including both traditional and morphometric measures, radiologic measures remained the strongest independent risk factors associated with waitlist mortality. Specifically, for each HU increase in psoas muscle attenuation (indicative of leaner muscle mass) there was an associated 7% decreased risk of death (adjusted HR: 0.93, 95%CI: 0.91–0.96, p< 0.001) (Table 4 & Figure 1). For each HU increase in total fat attenuation (or abdominal fat infiltration), there was an associated 3% increased risk of waitlist mortality (aHR: 1.03, 95%CI: 1.00–1.06, p=0.02), and for each HU increase in paraspinous muscle lean volume there was an associated 2% decreased risk of death (aHR: 0.98, 95%CI: 0.96–0.99, p=0.03).

When the discriminative ability of a model containing only the traditional risk factors was compared to that including both the traditional and the morphometric factors, the model including both was shown to have an NRI of 0.555 (95%CI: 0.31–0.75, p < 0.001), indicating that the predictive ability of the model for waitlist mortality was improved significantly by including radiologic measures.

DISCUSSION

In this single center study of kidney transplant waitlist candidates, we found that morphometric measures of lean abdominal mass as measured by CT imaging were independently associated with waitlist mortality. Specifically, higher psoas muscle attenuation or greater lean muscle mass was protective, such that for each HU increase in attenuation there was a 7% decrease in risk of death. Additionally, greater volume of the lean paraspinous muscle was associated with a 2% lower risk of death, and higher fat attenuation was associated with a 3% increased risk. These findings were independent of factors traditionally known to be associated with increased risk of waitlist mortality including candidate age and length of time on dialysis, and suggest that morphometric measures of sarcopenia using radiologic imaging may improve kidney waitlist mortality risk prediction and candidate selection.

Sarcopenia describes the lean mass reduction typically seen with aging and is a component of frailty.[33,34] It is estimated that 42% of dialysis patients meet criteria for frailty, and among

those dialysis patients older than 50 years the incidence is greater than 50%.[10,35] Frailty in the dialysis population is associated with a 2.6-fold increased risk of mortality and a 1.43-fold increased risk of hospitalization independent of age, comorbidity or disability.[35,36] Sarcopenia increases progressively along with loss of renal function in chronic kidney disease,[37] and represents a significant component of the increased mortality risk seen among frail dialysis patients. In particular, morphometric measures including mid arm muscle circumference (lean mass surrogate) and triceps skin-fold thickness (fat mass surrogate) have been associated with all-cause mortality in hemodialysis patients.[38,39] With an NRI of 0.555 for a model with morphometric factors compared to traditional factors alone, our findings also suggest that measurements such as lean muscle mass and volume are strongly associated with mortality risk and lend further support for incorporation of morphometric measures into mortality risk prediction tools for ESRD waitlist candidates.

Our study is unique in that it used novel methods for assessing mortality risk among kidney waitlist candidates. To date no study of kidney waitlist candidates has used CT-derived morphometric measures of sarcopenia to assess risk of waitlist mortality. ESRD patients undergoing evaluation for transplant listing often undergo cross-sectional imaging during the evaluation process to evaluate vascular anatomy, which can be used to assess sarcopenia. Measurements of psoas muscle density and paraspinous lean volume are precise and reproducible and can be obtained at no extra cost and add no additional time to an often laborious evaluation process. Interestingly, other studies have examined various non-radiologic measures of frailty and sarcopenia in the kidney waitlist candidate population and have demonstrated increased mortality risk with increasing frailty and progressive sarcopenia; yet none of those measures have garnered widespread acceptance by the transplant community and are not routinely incorporated into current evaluation practices or standards. Many of those measures, including measures of sarcopenia such as mid-arm muscle circumference and triceps skin-fold thickness, are subjective and susceptible to provider error, as the methods lack the necessary consistency and precision to be reliably included in risk prediction tools. In contrast, CT-derived morphometric measures introduce objective measures of sarcopenia, and as suggested by our results, may prove to be better risk prediction tools for waitlist mortality.

Inferences based on the results of our study must take into account several limitations specific to single center retrospective studies. Alternative provider-based measures of sarcopenia, such as gait, grip strength, mid-arm muscle circumference or triceps skin-fold thickness, were not measured as a part of our center's evaluation process. As a result, a direct comparison of the predictive ability of radiographic and provider-based measures of sarcopenia could not be studied. Additionally, this study was designed as a pilot project. Due to resource constraints and variability of CT image quality, we were only able to obtain complete morphometric data on 96 patients, thus introducing the possibility for selection bias. Larger studies will be necessary to confirm our findings.

To date, this is the first study to examine the association between radiographic morphometric measures of sarcopenia and kidney waitlist mortality. Our findings suggest that muscle size and density are independently associated with kidney waitlist mortality, and that higher lean muscle mass may be protective. Radiologic measures of sarcopenia, such as psoas muscle

attenuation and paraspinous lean volume, may help to improve waitlist mortality risk adjustment and prediction and candidate informed consent.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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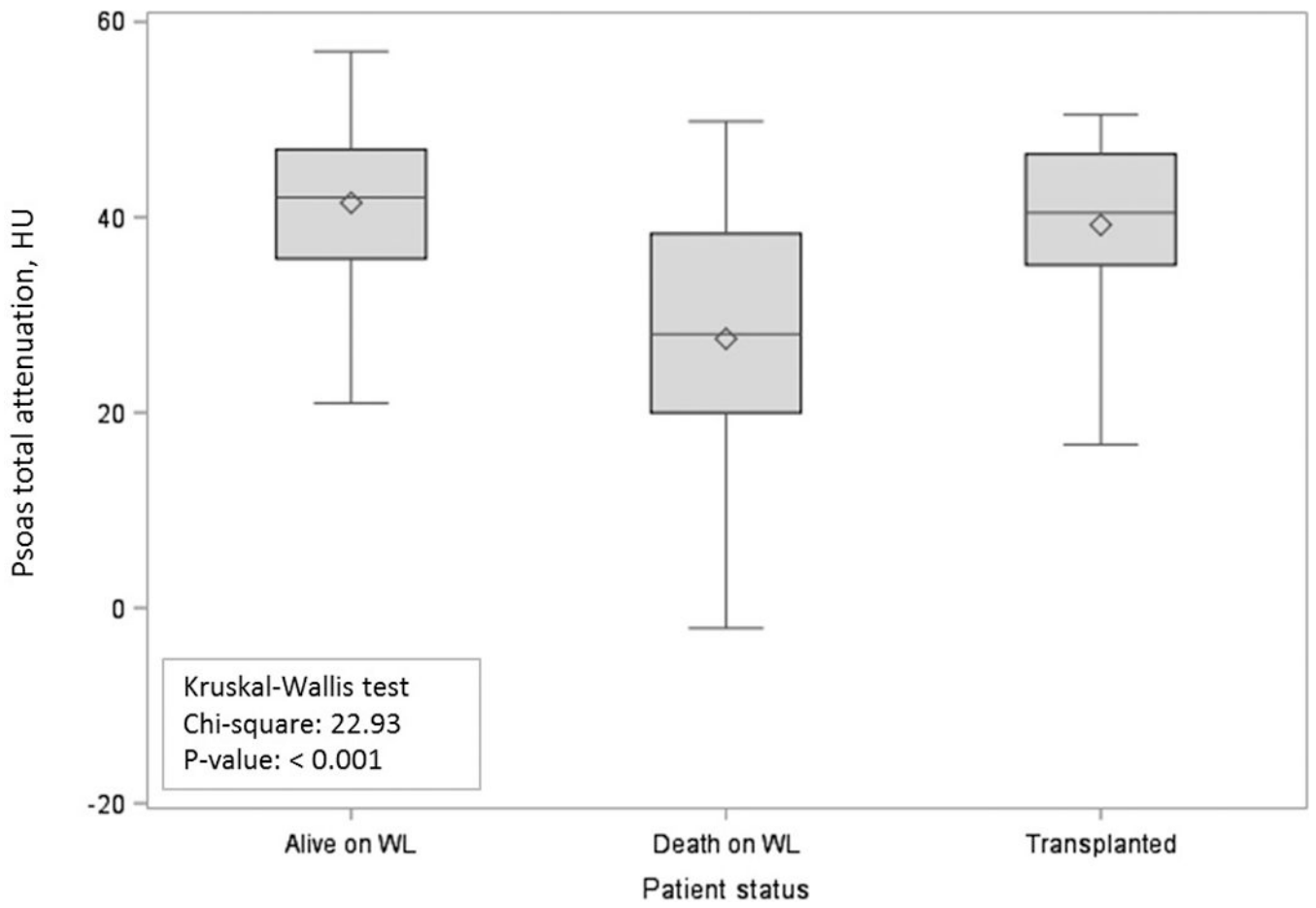
Figure 1.
Total psoas attenuation in Hounsfield units by candidate status.

Table 1

Traditional risk factors of waitlist candidates by candidate status at time of listing.

Parameter	Total (n=96) N(%)	Transplanted (n=26) N(%)	Died on Waitlist (n=39) N(%)	Still Waiting (n=31) N(%)	p
Age, median (IQR)	50.7 (40.1–58.0)	47.6 (36.3–60.5)	54.5 (47.2–61.1)	44.9 (38.7–51.8)	**0.01**
Male sex	55 (57)	18 (69)	19 (49)	18 (58)	0.26
Race					
Non African American	46 (48)	19 (73)	18 (46)	9 (29)	**0.004**
African American	50 (52)	7 (27)	21 (54)	22 (71)	
BMI (kg/m^2), median (IQR)	28.0 (24.0–33.4)	26.5 (24.0–30.0)	27.1 (22.0–32.0)	31.5 (27.0–35.0)	0.07
BMI 30	37 (39)	8 (31)	11 (28)	18 (60)	**0.02**
Time on dialysis (yrs), median (IQR)	0.63 (0.0–2.3)	0.13 (0.0–0.7)	1.10 (0.3–4.3)	0.92 (0.0–2.5)	**0.002**
On dialysis	69 (72)	13 (50)	33 (85)	23 (74)	**0.009**
Blood type					
A	26 (27)	6 (23)	12 (31)	8 (26)	0.58
B	16 (17)	3 (12)	7 (18)	6 (19)	
AB	4 (4)	0 (0)	3 (8)	1 (3)	
O	50 (52)	17 (65)	17 (44)	16 (52)	
Diabetes					
Type I	9 (9)	5 (19)	3 (8)	1 (3)	0.25
Type II	33 (34)	6 (23)	16 (41)	11 (36)	
None	54 (56)	15 (58)	20 (51)	19 (61)	
Hypertension	86 (90)	24 (92)	33 (85)	29 (95)	0.49
Coronary artery disease	37 (39)	8 (31)	16 (41)	13 (43)	0.63
Peripheral vascular disease	4 (4)	0 (0)	4 (10)	0 (0)	0.06
Hepatitis C	9 (9)	1 (4)	6 (15)	2 (7)	0.27
Prior transplant	21 (22)	2 (8)	12 (31)	7 (23)	0.08
Ever smoked	52 (57)	14 (56)	23 (62)	15 (52)	0.69

Parameter	Total (n=96)	Transplanted (n=26)	Died on Waitlist (n=39)	Still Waiting (n=31)	
	N(%)	N(%)	N(%)	N(%)	p
Alcohol use	15 (16)	6 (23)	5 (13)	4 (13)	0.56
Family history of diabetes	34 (35)	9 (35)	15 (39)	10 (32)	0.86
Family history of hypertension	39 (41)	8 (31)	19 (49)	12 (39)	0.34
Family history of CKD	36 (38)	11 (42)	15 (39)	10 (32)	0.73
QTC, median (IQR)	461 (433–481)	444 (416–469)	466 (441–481)	464.5 (438–485)	0.13
Ejection fraction, median (IQR)	55.0 (51–61)	55.0 (52–61)	55.5 (51–63)	55.0 (51–60)	0.91
Albumin, median (IQR)	3.50 (3.1–3.8)	3.70 (3.3–3.8)	3.30 (3.1–3.7)	3.50 (2.9–3.7)	0.14
HDL cholesterol, median (IQR)	42.0 (32–55)	37.0 (28–55)	48.0 (39–63)	39.0 (33–51)	0.06
LDL cholesterol, median (IQR)	78.0 (59–101)	80.5 (68–117)	71.0 (53–94)	80.0 (54–111)	0.23
Triglycerides, median (IQR)	124.0 (85–204)	112.0 (78–188)	120.5 (73–205)	129.0 (100–204)	0.57
Serum total protein, median (IQR)	7.0 (6.4–7.7)	6.8 (6.3–7.2)	7.1 (6.3–8.0)	7.3 (6.5–7.5)	0.41
Fasting blood glucose, median (IQR)	107.5 (93–155)	111.5 (99–155)	111.0 (88–158)	103.0 (92–155)	0.82

Table 2

Distribution of morphometric risk factors for mortality among waitlist candidates by candidate status.

Parameter	Total (n=96)	Transplanted (n=26)	Died on Waitlist (n=39)	Still Waiting (n=31)	p
Abdominal fat measures					
Total abdominal measures					
Abdomen total volume, cm3	2222.5 (1681.0, 2812.7)	2086.1 (1680.7, 2563.5)	2017.4 (1605.8, 2936.2)	2596.7 (1935.0, 2879.2)	0.18
Total fat volume, cm3	1098.7 (712.8, 1843.9)	1098.7 (724.1, 1277.5)	959.3 (673.6, 1963.4)	1605.2 (909.4, 1852.0)	0.3
Total fat attenuation, HU	−88.9 (−94.8, −78.9)	−88.9 (−94.7, −77.0)	−85.3 (−91.4, −76.8)	−92.6 (−97.7, −87.0)	**0.04**
Total muscle volume, cm3	864.8 (749.7, 977.5)	907.7 (779.4, 1087.8)	834.7 (683.6, 929.5)	864.8 (750.1, 1057.9)	0.11
Total muscle attenuation, HU	30.9 (26.1, 34.7)	30.4 (26.3, 33.3)	28.1 (23.1, 36.3)	31.9 (28.1, 34.9)	0.19
Visceral					
Fat volume, cm3	297.6 (139.6, 468.2)	335.5 (136.8, 444.9)	282.6 (126.1, 394.1)	359.2 (140.9, 633.0)	0.3
Fat attenuation, HU	−81.5 (−90.3, −73.5)	−83.6 (−90.4, −73.7)	−77.2 (−89.1, −72.5)	−86.8 (−93.0, −73.6)	0.49
Subcutaneous					
Subcutaneous fat volume, cm3	706.2 (398.2, 1063.8)	636.3 (383.9, 767.3)	515.2 (339.5, 1121.1)	828.8 (510.2, 1154.1)	0.13
Subcutaneous fat attenuation, HU	−94.5 (−101.6, −84.9)	−94.3 (−101.9, −80.4)	−92.8 (−96.6, −79.7)	−97.0 (−102.9, −91.1)	0.08
Abdominal muscle measures					
Paraspinous					
Total volume, cm3	71.6 (63.9, 81.3)	70.3 (64.9, 81.5)	68.0 (62.4, 74.9)	77.6 (71.1, 83.6)	**0.03**
Total attenuation, HU	27.4 (12.2, 40.3)	32.9 (28.4, 43.0)	14.8 (3.4, 28.6)	30.9 (17.7, 41.5)	**<0.001**
Fat volume, cm3	6.0 (3.4, 9.8)	4.0 (3.2, 5.3)	8.9 (4.3, 14.5)	5.7 (3.1, 8.6)	**<0.001**
Fat attenuation, HU	−60.4 (−64.8, −56.8)	−59.6 (−65.8, −56.9)	−60.9 (−64.1, −55.9)	−60.7 (−67.3, −56.8)	0.71
Muscle lean volume, cm3	64.2 (55.9, 74.3)	64.9 (59.3, 74.4)	57.3 (51.6, 64.3)	70.9 (63.5, 79.0)	**0.001**
Muscle lean attenuation, HU	35.2 (23.8, 45.2)	40.6 (34.4, 47.6)	25.6 (19.4, 34.8)	38.0 (24.7, 46.6)	**<0.001**

Parameter	Total (n=96)	Transplanted (n= 26)	Died on Waitlist (n= 39)	Still Waiting (n= 31)	p
Ratio of fat to total volume	0.09 (0.05, 0.14)	0.06 (0.05, 0.08)	0.13 (0.06, 0.21)	0.09 (0.04, 0.11)	**< 0.001**
Ratio of lean to total volume	0.91 (0.86, 0.95)	0.94 (0.92, 0.95)	0.87 (0.79, 0.94)	0.91 (0.89, 0.96)	**< 0.001**
Psoas					
Total volume, cm3	30.2 (22.6, 36.7)	32.3 (24.4, 36.7)	25.0 (19.5, 35.2)	31.1 (26.7, 38.5)	**0.04**
Total attenuation, HU	37.6 (27.7, 44.3)	40.5 (35.1, 46.5)	28.0 (20.0, 38.3)	42.0 (35.7, 46.9)	**< 0.001**
Fat volume, cm3	1.3 (0.6, 1.8)	1.2 (0.5, 1.5)	1.5 (0.9, 2.9)	1.0 (0.5, 1.6)	**0.02**
Fat attenuation, HU	−56.1 (−59.8, −52.2)	−57.1 (−60.5, −51.9)	−55.6 (−60.9, −52.6)	−56.0 (−59.1, −50.8)	0.69
Muscle lean volume, cm3	28.9 (21.5, 35.2)	31.4 (22.5, 35.3)	22.1 (17.7, 34.6)	30.1 (26.2, 37.7)	**0.01**
Muscle lean attenuation, HU	41.1 (34.9, 47.0)	44.9 (38.5, 49.1)	35.3 (28.8, 42.6)	45.0 (39.6, 50.3)	**< 0.001**
Ratio of fat to total volume	0.04 (0.02, 0.07)	0.03 (0.01, 0.05)	0.06 (0.03, 0.11)	0.03 (0.01, 0.04)	**< 0.001**
Ratio of lean to total volume	0.96 (0.93, 0.98)	0.97 (0.95, 0.99)	0.94 (0.89, 0.97)	0.97 (0.96, 0.99)	**< 0.001**
Abdominal aortic calcification					
AAC, total, Agatston units	561.1 (0.0, 3159.6)	100.0 (0.0, 1486.8)	866.0 (292.8, 6145.3)	206.0 (0.0, 2042.6)	**0.02**
Aortic calcium visualized, N (%)	66 (689)	16 (62)	33 (85)	17 (55)	**0.02**

Table 3

Unadjusted risk of waitlist mortality.

Parameter	HR	95% CI	p-value
Traditional			
Age (per 1-year increase)	1.04	1.01–1.08	0.007
African American race	0.72	0.38–1.36	0.31
BMI $\geq$ 30 kg/m^2	0.42	0.21–0.85	0.02
Dialysis time (per 1-year increase)	1.12	1.01–1.23	0.03
On dialysis	2.40	1.01–5.73	0.05
Morphometric			
Total abdominal fat attenuation, HU	1.03	1.00–1.05	0.02
Paraspinous muscle total volume, cm^3	0.97	0.95–0.99	0.01
Paraspinous muscle total attenuation, HU	0.95	0.93–0.97	< 0.001
Paraspinous muscle fat volume, cm^3	1.08	1.04–1.11	< 0.001
Paraspinous muscle lean volume, cm^3	0.95	0.93–0.97	< 0.001
Paraspinous muscle lean attenuation, HU	0.94	0.91–0.96	< 0.001
Psoas muscle total volume, cm^3	0.95	0.91–0.98	0.002
Psoas muscle total attenuation, HU	0.93	0.91–0.95	< 0.001
Psoas muscle fat volume, cm^3	1.38	1.14–1.68	0.001
Psoas muscle lean volume, cm^3	0.93	0.90–0.97	< 0.001
Psoas muscle lean attenuation, HU	0.92	0.89–0.95	< 0.001
Abdominal aortic calcification, Agatston units	1.00	1.00–1.00	0.08
Presence of abdominal aortic calcification	2.64	1.11–6.31	0.03

Table 4

Adjusted hazard ratio of kidney waitlist mortality.

	Model 1 – Traditional Factors			Model 2 – CT Measures			Model 3 – Traditional & CT		
	HR	95% CI	p	HR	95% CI	P	HR	95% CI	p
Age, per 1-year increase	1.05	1.02–1.09	0.001				1.04	1.00–1.08	0.03
Years on dialysis, per 1-year increase	1.14	1.03–1.26	0.01				1.12	0.99–1.25	0.06
Total fat attenuation, per 1 unit increase in HU				1.03	1.01–1.06	0.006	1.03	1.00–1.06	0.02
Paraspinous total volume, per 1-unit increase in cm^3				0.99	0.97–1.01	0.19	0.98	0.96–0.99	0.03
Psoas total attenuation, per 1-unit increase in HU				0.93	0.90–0.95	< 0.001	0.93	0.91–0.96	< 0.001

*
Net Reclassification Index=0.555 (95% CI: 0.31–0.75, p < 0.001); AIC=277.420, calibration p-value=0.33, Harrell's c statistic=0.795