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Computed tomography-defined abdominal adiposity is associated with acute kidney injury in critically ill trauma patients

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Abstract

Objective—Higher body mass index (BMI) is associated with increased risk of acute kidney injury (AKI) after major trauma. Since BMI is non-specific, reflecting lean, fluid, and adipose mass, we evaluated the use of computed tomography (CT) to determine if abdominal adiposity underlies the BMI-AKI association.

Design—Prospective cohort study.

Setting—Level I Trauma Center of a university hospital.

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Patients—Patients older than 13 years with an Injury Severity Score ≥16 admitted to the trauma intensive care unit were followed for development of AKI over five days. Those with isolated severe head injury or on chronic dialysis were excluded.

Interventions—None

Measurements and Main Results—Clinical, anthropometric, and demographic variables were collected prospectively. CT images at the level of the L4-5 intervertebral disc space were extracted from the medical record and used by two operators to quantitate visceral and subcutaneous adipose tissue (VAT and SAT, respectively) areas. AKI was defined by Acute Kidney Injury Network (AKIN) creatinine and dialysis criteria. Of 400 subjects, 327 (81.8%) had CT scans suitable for analysis: 264/285 (92.6%) blunt trauma subjects, 63/115 (54.8%) penetrating trauma subjects. VAT and SAT areas were highly correlated between operators (ICC>0.999, $p<0.001$ for each) and within operator (ICC>0.999, $p<0.001$ for each). In multivariable analysis, the standardized risk of AKI was 15.1% (95% CI 10.6%,19.6%), 18.1% (14%,22.2%), and 23.1% (18.3%,27.9%) at the 25^{th}, 50^{th}, and 75^{th} percentiles of VAT area, respectively ($p=0.001$), with similar findings when using SAT area as the adiposity measure.

Conclusions—Quantitation of abdominal adiposity using CT scans obtained for clinical reasons is feasible and highly reliable in critically ill trauma patients. Abdominal adiposity is independently associated with AKI in this population, confirming that excess adipose tissue contributes to the BMI-AKI association. Further studies of the potential mechanisms linking adiposity with AKI are warranted.

Keywords

acute kidney injury; trauma; critical illness; obesity; adiposity; computed tomography

Introduction

Over 2 million people are hospitalized for injury each year in the United States. The impact of obesity on outcomes after major trauma, and critical illness in general, remains unclear, with conflicting reports regarding the association of obesity with organ dysfunction and mortality (1-4). Acute kidney injury (AKI) after major trauma is associated with a substantial increase in mortality, but its pathophysiology is incompletely understood and treatment options are limited (5). We recently reported an association of body mass index (BMI) with AKI following major trauma, an association also noted in general critical illness populations and patients with the acute respiratory distress syndrome (ARDS) (6-8). A pathophysiologic link between obesity and AKI is plausible: excess adipose tissue is associated with an inflammatory state, and circulating inflammatory mediators have been implicated in the pathogenesis of AKI (9, 10). Obesity may also predispose to AKI risk through abdominal adiposity-associated elevation in baseline intraabdominal pressure with potentiation of abdominal compartment syndrome or through subclinical obesity-related nephropathy (11).

The BMI measure is not specific for adiposity, however, as it also reflects lean and fluid mass. It is therefore not clear that adiposity underlies the association of BMI with AKI. This limitation of BMI is particularly pertinent to trauma patients—lean mass constitutes a

greater percentage of total mass in this population given its lower mean age than general intensive care unit (ICU) populations, and trauma patients are routinely given rapid large volume resuscitations on presentation prior to measurement of weight (12). Failure to capture variations in body composition has been suggested as a reason for the variable association of BMI with mortality in outpatient studies, and may explain some of the conflicting results in critically ill populations (13). Computed tomography (CT)-based quantitation of abdominal adipose tissue is a precise, specific technique that distinguishes visceral adipose tissue (VAT) from subcutaneous adipose tissue (SAT), measures which have shown strong associations with mortality in outpatient cohorts (14). Abdominal VAT and SAT have different associations with circulating inflammatory markers, making such a distinction potentially important for the study of AKI and other acute organ dysfunction syndromes in which inflammation plays a role (15-17). The use of CT-defined adiposity in studies of critically ill patients has, however, been quite limited (18, 19). Factors affecting feasibility such as availability of CTs and quality issues impacting adipose quantitation are not well described, nor are associations of VAT or SAT with clinical outcomes such as organ dysfunction.

The objectives of this study were to determine the feasibility of using CT scans obtained for clinical purposes in major trauma patients to estimate abdominal VAT and SAT, and to determine the association of these adiposity measures with AKI. We quantified VAT and SAT areas at the level of the L4-5 intervertebral disc space in a well-characterized prospective trauma cohort, determined inter- and intra-operator correlation of this quantification method, identified potential pitfalls specific to application of this method to a critical illness population, and determined the association of abdominal adiposity with AKI.

Materials and Methods

Study population

Study subjects were enrolled prospectively from 2005 through 2010 from patients admitted to the Level I Trauma Center ICU at the Hospital of the University of Pennsylvania and followed for five days for the development of AKI. Full details on inclusion and exclusion have been previously reported (6). Patients ≥14 years of age with an Injury Severity Score (ISS) ≥16 were included (20). Key exclusion criteria were isolated severe head injury, death or discharge from the ICU within 24 hours of presentation, and chronic dialysis. Baseline data including demographics, medical history, trauma mechanism and severity, and transfusions were collected prospectively on each patient by review of the medical record. The Institutional Review Board of the University of Pennsylvania approved this study with a waiver of informed consent.

Adipose tissue area quantitation

For subjects with an abdominal CT available during the first 14 days of admission, axial slices at the level of the L4-5 intervertebral disc space were imported into the software system 3DVIEWNIX (21). The time window was limited to 14 days in order to reflect, as accurately as possible, VAT and SAT areas at the time of admission, prior to adipose tissue loss that might result from a prolonged hospitalization. The L4-5 level was chosen based on

the observed strong correlation of L4-5 VAT area with total abdominal VAT volume as well as demonstrated associations of L4-5 VAT and SAT areas with clinical outcomes in outpatients (14, 22). If a CT image within two 5mm cuts of the L4-5 level was of clearly superior quality for adipose measurement, it was chosen in place of the L4-5 image. The only reason defined *a priori* for exclusion from adipose quantitation once images were viewed was the presence, at the time of imaging, of a laparotomy fascial incision left open after surgery, typically used as a "damage control" technique for trauma patients (23). Resultant alterations in adipose mass-area relationship from the exposure of abdominal contents to atmospheric pressure makes adipose quantitation in this situation difficult to compare with that performed on a CT of a closed abdomen. Adipose quantitation was performed on all other CTs, though image quality issues potentially affecting accuracy were recorded.

To determine VAT and SAT areas, the 3DVIEWNIX software employs a user-guided LiveWire tracing tool that automatically delineates the myo-subcutaneous interface to draw the boundary between subcutaneous and visceral compartments (Figure 1A) (21). Tissue area (cm^2) in the adipose-attenuation range (−200 to −40 Hounsfield Units) both within (VAT) and outside of (SAT) the boundary was calculated after correcting for partial volume effects near the outer skin boundary. Two investigators (MGSS, EK) independently performed quantitation on all subjects. These investigators repeated tracings on all subjects on a subsequent occasion to evaluate intra-operator reliability. For each subject, final VAT and SAT areas were calculated as the mean of these four measurements (two from each investigator). Three investigators (MGSS, EK, JKU) reviewed all CTs with image quality issues (e.g., streak artifact). Any issues that appeared on visual inspection to have prevented accurate adipose capture were considered as additional exclusion criteria for the main analysis. The remaining CTs were considered usable. Investigators were blinded to subjects' AKI status during adipose quantitation and image quality review.

Patient weight was measured on ICU admission using a calibrated electronic hospital bed scale, and height was obtained from patient or family report or was estimated by nursing staff. Body mass index was calculated using the standard World Health Organization definition (24).

Outcome definition

AKI was defined and staged according to Acute Kidney Injury Network (AKIN) creatinine and renal replacement therapy (RRT) consensus criteria (25). These criteria define AKI as a serum creatinine increase of ≥0.3 mg/dL or ≥50% from baseline over a 48-hour period or the need for acute RRT. For AKI by serum creatinine, successive 2-day time windows from day 0, the calendar day of emergency department presentation, through day 5 were tracked (e.g., days 0-2, days 1-3), using the first measured creatinine of each window as the baseline value. Data for staging were collected through day 5 or ICU discharge, whichever came first. AKIN urine output criteria, which are normalized to weight (mL/kg/h), were not included in the AKI definition as such inclusion might cause a spurious association of adipose tissue with AKI given the inclusion of weight measures in both exposure and outcome.

Statistical analysis

The difference between CT availability in the final year versus prior years of the study was determined using the test for binomial proportions. For comparison of characteristics between subjects with and without usable CT scans, as well as subjects with and without AKI, differences were tested with the unpaired t-test, Wilcoxon rank-sum test, X^2 test, or Fisher's exact test as appropriate. Among subjects with usable CT scans, we calculated intraclass correlations (ICC) to test inter-operator and intra-operator reliability for VAT and SAT area measurements. We used Spearman's rho to test correlations between BMI and adipose area.

The associations with AKI of VAT and SAT areas as well as BMI were tested with the Wilcoxon rank-sum test. In order to avoid collinearity, a separate multivariable logistic regression model was constructed for each adipose measure (VAT, SAT, BMI) to adjust its association with AKI for potential confounders. We considered all baseline variables with an unadjusted association with AKI at $p<0.20$ as well as all hypothesized potential confounders for inclusion in the primary multivariable logistic regression models. We included confounders in the final models if they had a significant impact on the unadjusted association of adipose variables with AKI (as defined by a change in odds ratio ≥15%) or if they contributed significantly to model fit as determined by likelihood ratio tests (26). C-statistics were used to compare the fit of the three final models. Final multivariable models including all risk factors and confounders were used to compute standardized, adjusted AKI risks associated with each adiposity measure using post-estimation marginal analysis (27).

To determine any differences in the association of adiposity with AKI by trauma mechanism, we tested for interaction with adiposity measure (VAT, SAT, or BMI) using likelihood ratio tests to compare multivariable models with and without interaction terms. We also qualitatively examined the final models stratified by blunt versus penetrating trauma. In order to determine if the association of any single adiposity measure with AKI was independent of the effects of the others, we constructed alternative multivariable models each including two adipose measures (VAT+SAT, VAT+BMI, SAT+BMI) in addition to confounders. Finally, we performed a sensitivity analysis including in the multivariable models subjects excluded from the primary analysis due to CT image quality issues to determine whether their inclusion affected the adiposity-AKI association. All alternative multivariable models were constructed using the methods described for the primary models.

We constructed a multivariable logistic regression model to determine characteristics independently associated with the presence of a usable CT in the overall cohort. Baseline covariates with an unadjusted association with usable CT at $p<0.20$ were considered for the model, and were included if likelihood ratio tests showed significant contributions to model fit.

We calculated that 300 subjects would give the study power of 0.8 to detect differences in mean adipose areas of $11cm^2$ (VAT) and $27cm^2$ (SAT) between subjects with and without AKI, less than differences reported in adipose area between normal weight and overweight healthy subjects ($36cm^2$ (VAT), $129cm^2$ (SAT)) (28). All statistical analyses were done

using Stata/IC 11.1 (StataCorp LP, College Station, TX 77845). A two-sided $p<0.05$ was considered statistically significant.

Results

Association of adiposity with AKI

During the study period, 327 subjects had abdominal CT scans usable for adipose quantitation (Figure 2). The large majority of CTs (297, 90.8%) were performed on presentation or within the first day, with the remaining evenly distributed through days 2-13. VAT and SAT area measurements were highly correlated between operators (ICC>0.99, $p<0.001$ for each) and within operator (ICC>0.99, $p<0.001$ for each). Bland-Altman plots displaying these data are in Supplemental Digital Content, Figure 1. VAT and SAT areas were moderately correlated with BMI (Spearman's rho 0.56 and 0.70, respectively, $p<0.001$ for each).

AKI developed in 66/327 (20.2%) of subjects in the first 5 days, 32/66 (48.5%) on day 0 or 1. The majority (52/66, 78.8%) of subjects had stage 1 AKI, while 7 (10.6%) subjects each had stages 2 and 3. Subjects with AKI had significantly higher median VAT and SAT areas and BMI and were more likely to die than those who did not develop AKI (Table 1). A summary of adiposity averages by AKI stage is shown in Supplemental Digital Content, Figure 2. Separate multivariable models for VAT area, SAT area, and BMI showed that these adiposity measures were each associated with significantly increased odds of AKI after adjustment for confounders (Tables 2a-c). Comparison of C-statistics showed no significant differences in fit between the three models ($p=0.801$). The increases in standardized risk of AKI associated with increasing adiposity, estimated from these multivariable models, are shown in Figure 3. Intravenous contrast was received by most subjects but was less common in those with AKI (Table 1) (6). Inclusion of this covariate in multivariable models did not affect the associations of adiposity with AKI (data not shown). Only 8 subjects had underweight BMIs, and none developed AKI.

In alternative models that included two measures of adiposity, no adiposity measure had an association with AKI that was independent of the other (Supplemental Digital Content, Table 1a). Stratifying multivariable analyses by trauma mechanism (Supplemental Digital Content, Table 1b) demonstrated that VAT and SAT areas and BMI maintained significant associations with AKI among blunt trauma subjects (n=264). The adjusted associations of VAT and SAT areas and BMI with AKI were not statistically significant in the subgroup with penetrating trauma (n=63).

A sensitivity analysis including those subjects who had been excluded due to extensive edema on CT (n=11) resulted in a slight decrease in point estimates of the adjusted associations of adiposity measures with AKI, though all associations remained statistically significant (Supplemental Digital Content, Table 1c). Including all subjects with usable and unusable CTs, the adjusted association of BMI with AKI remained significant (OR 1.44 per standard deviation, 95% CI 1.12,1.86, $p=0.005$)

CT availability and quality

Subjects with usable CT scans constituted 81.8% (327/400) of all enrolled in the prospective trauma cohort during the study period. Those without usable CTs included 33 (8.3%) without an abdominal CT performed within 14 days of presentation or with images that could not be retrieved from the computerized radiology system, 29 (7.3%) with CTs available but with open laparotomy incisions at the time of imaging (Figure 1B), and 11 (2.8%) with extensive subcutaneous edema evident on CT limiting adipose measurement accuracy (Figure 1C). CT availability was more common in the final year than the first 3 years of the study (95/97, 97.9% v. 272/303, 89.8%, respectively, p=0.011). Minor quality issues (Supplemental Digital Content, Figure 3) which did not preclude adequate adipose quantitation were present in 121/327 (37%) subjects in the main analysis.

The baseline characteristics of subjects with and without usable CTs are compared in Table 3. Of note, there was no significant difference in BMI between these groups. A multivariable model including all baseline covariates associated with usable CTs showed that blunt trauma was the predominant distinguishing characteristic associated with having a usable CT (Supplemental Digital Content, Table 2). Usable CTs were available in 63/115 (54.8%) subjects with penetrating trauma compared with 264/285 (92.6%) with blunt trauma. This difference was largely due to decreased CT availability (94/115 (81.7%) v. 273/285 (95.8%), p<0.001) and more frequent open laparotomy incisions (24/115 (20.9%), v. 5/285 (1.8%), p<0.001) in penetrating versus blunt trauma subjects.

Discussion

Our primary objective in this study was to determine if CT-defined abdominal adipose tissue underlies the association of BMI with AKI in critically ill trauma patients. Abdominal VAT and SAT areas demonstrated significant associations with AKI after adjustment for previously identified risk factors such as fluid and blood product resuscitation, diabetes, and injury severity (6). Several recent studies have reported the association of obesity, determined by BMI, with AKI in trauma and other ICU populations (6-8). Our findings establish that adiposity, and not simply lean mass-associated differences in creatinine rise or excess positive fluid balance, contributes to the BMI-AKI association. This CT-based finding adds a level of specificity that strengthens the case for further investigation of adipose tissue as a risk factor in the causal pathway between traumatic insult and AKI.

Our demonstration that abdominal adipose tissue is an independent risk factor for AKI after trauma is a novel finding. Direct adipose quantitation has rarely been used in studies of obesity in critical illness. Collier et al determined the association of visceral-predominant adiposity with inflammatory markers in 281 obese trauma patients (18), while a study by Ferguson et al aimed to quantify obesity in 162 trauma patients based on adipose volume without the need to obtain height and weight (19). In addition to demonstrating an association of adiposity with organ injury, our study adds to these prior investigations by characterizing the subset of trauma patients with usable CTs and detailing qualitative challenges to accurate adipose quantitation in this population. Over 90% of subjects in our cohort had an abdominal CT within 14 days of admission, similar to the 87% rate in a recent

study of nearly 2000 critically ill blunt trauma patients (29). VAT and SAT quantification was feasible in the large majority, particularly in those with blunt trauma.

Several mechanisms could link abdominal adiposity with AKI, including potentiation by adipose tissue of the inflammatory response to acute insults. Evidence from animal models of AKI and some human studies has suggested a role for systemic inflammatory mediators in the pathogenesis of AKI (10, 16, 30, 31). It has been estimated that adipose tissue may produce approximately 20-30% of baseline circulating interleukin-6 (IL-6), and studies of humans given endotoxin challenge have shown dramatic increases in adipose expression of IL-6, tumor necrosis factor-α (TNF-α), and monocyte chemoattractant protein-1 (MCP-1) (32, 33). Global gene expression responses to major trauma are remarkably similar to those after endotoxin challenge (34). A study of ICU patients enrolled in Acute Respiratory Distress Syndrome Network trials found conflicting evidence, however, regarding the association of BMI with plasma levels of inflammatory mediators: IL-8 levels were inversely related to BMI, whereas von Willebrand's Factor, a marker of endothelial injury, increased proportionally with BMI (35). Immune-modulating adipokines such as leptin and resistin, which have shown associations with organ dysfunction in critically ill patients, may also play a role in the obesity-AKI association (36, 37). Further study would be needed to determine if adipose-sourced inflammation represents a mechanistic link between obesity and AKI risk after trauma.

Obesity is also a risk factor for chronic kidney disease (CKD), independent of associated hypertension and diabetes (38). Morbidly obese patients with normal glomerular filtration rates have been found to have a higher prevalence of abnormal glomerular architecture than non-obese controls (39). This raises the possibility that sub-clinical CKD could contribute to the association of abdominal adiposity with AKI.

Higher BMI is correlated with intraabdominal hypertension (IAH), which can predispose patients to AKI via renal venous congestion and an effective hypovolemic state from decreased venous return (40, 41, 41-43, 43). There was no standardized clinical protocol in our ICU for regularly measuring intraabdominal pressures during the study period, so we were unable to determine the degree to which IAH may have contributed to the adiposity-AKI association.

While two recent studies raised the question of whether obese trauma patients may be under-resuscitated relative to normal weight patients, adjustment for measures of resuscitation (systolic blood pressure, crystalloid, or blood product volume) did not alter the association of adiposity with AKI in our study (44, 45). In addition, unlike studies of obese outpatients implicating visceral-predominant adiposity in metabolic disease risk, the obesity-associated AKI risk in our study was not clearly dependent on a specific adipose compartment (14, 15, 46).

Two barriers to accurate adipose tissue quantitation may have implications for future studies. Open laparotomy incisions at the time of CT may alter the adipose mass-area relationship. Extensive subcutaneous edema, a finding likely related both to fluid resuscitation and third-spacing, might be a significant limiting factor in studies of non-

trauma critical care populations in which CTs, if performed at all, are not done uniformly on admission. In our study, few subjects had extensive edema and including these in the analysis did not alter the association of adipose tissue area with AKI.

This study has several limitations. First, CT scans usable for quantifying adipose tissue were near-complete only in the blunt trauma sub-population. Had it been possible to get adipose measurement on those without usable CTs, inclusion of these subjects may have altered the adiposity-AKI association. However, the associations of VAT and SAT areas and BMI with AKI were similar, and the BMI-AKI association was persistent in the overall cohort. Second, abdominal adipose tissue was quantified by area on single CT slices rather than by estimating adipose volume three-dimensionally. VAT area at the L4-5 level, however, is known to be an excellent surrogate of abdominal VAT volume (22). Using single slices also enabled us to avoid image quality barriers (e.g., streak artifact from bullet fragments) that affected some but not all slices in a given patient. Third, the accuracy of weight and height measurements obtained from the medical record could not be verified. This limitation is common in studies of obesity in critical illness and highlights the potential use of CT as a more specific and reproducible way to measure adiposity (47). Fourth, we were unable to determine specific causes of AKI for each subject. The multiple and common renal insults experienced in the studied population (e.g., ischemia, intravenous contrast, rhabdomyolysis, blood product transfusion), however, preclude assignment of a primary etiology in most cases. Fifth, we did not have sufficient numbers of subjects with stages 2 and 3 AKI to meaningfully analyze a “dose-effect” relationship between adipose tissue and AKI severity. Despite the predominance of stage 1 AKI, mortality was still quite elevated in AKI subjects underscoring the potential clinical relevance of the association of adiposity with even mild AKI. Similarly, we did not have adequate numbers of underweight subjects (n=8) to determine whether AKI risk might rise in the setting of malnutrition. Finally, this study was not designed to determine the adjusted association of adipose tissue with mortality—with 27/327 subjects dead at hospital discharge, no meaningful multivariable analysis of risk factors for mortality was possible. Larger, multicenter studies may help to assess whether the increased risk of AKI associated with adiposity translates into increased mortality.

Conclusions

This study demonstrates that abdominal CT scans obtained for clinical purposes can feasibly be used for studies of adiposity in critically ill trauma patients, particularly those with blunt trauma. Both visceral and subcutaneous abdominal adiposity were independently associated with AKI to a similar degree as BMI. No difference was evident in the association of visceral and subcutaneous adiposity with AKI. Further study of the mechanisms underlying the adiposity-AKI relationship in trauma is warranted. The methods described in this study may also aid in future investigation of obesity’s impact in critical illness populations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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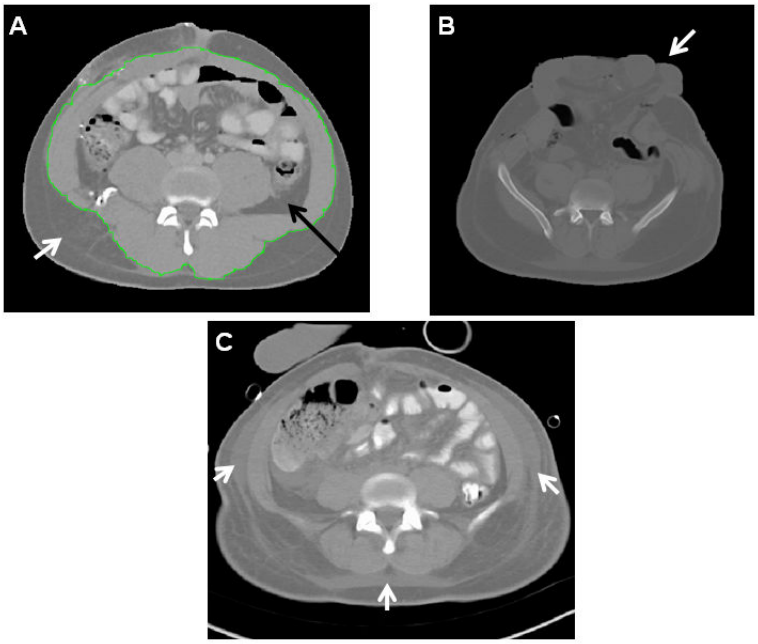

Figure 1. CT images of study subjects

Axial images at the L4-L5 level from abdominal computed tomographic (CT) scans of three study subjects. (A) Delineation of VAT (black arrow) and SAT (white arrow) compartments with tracing (green line) around abdominal wall musculature. (B) CT with open laparotomy incision and protruding viscera (white arrow). (C) CT with extensive edema (white arrows) in subcutaneous adipose tissue. Subjects with CT scans similar to those seen in images B or C were excluded from the primary analysis due to potential inaccuracies in adipose quantitation.

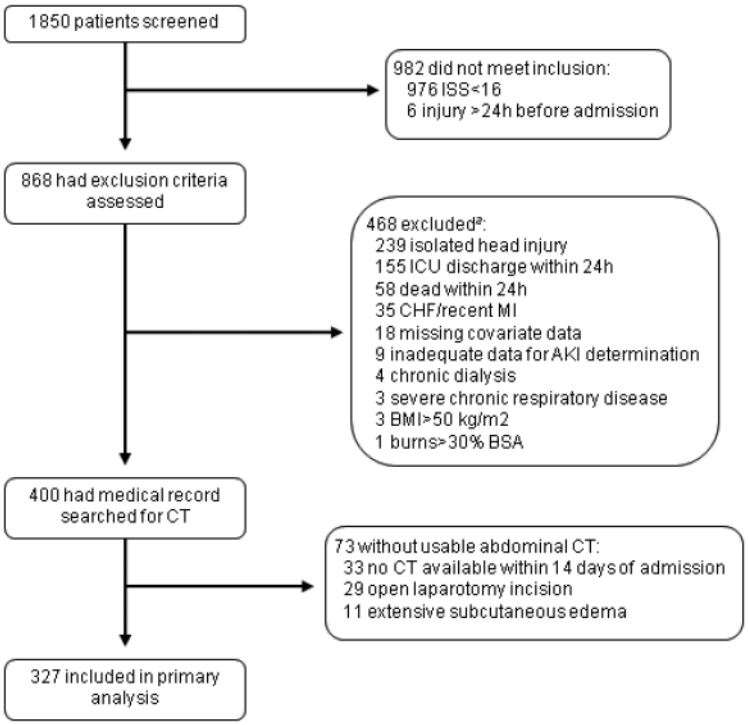

Figure 2. Screening and enrollment

[a]Some subjects excluded for more than one reason.

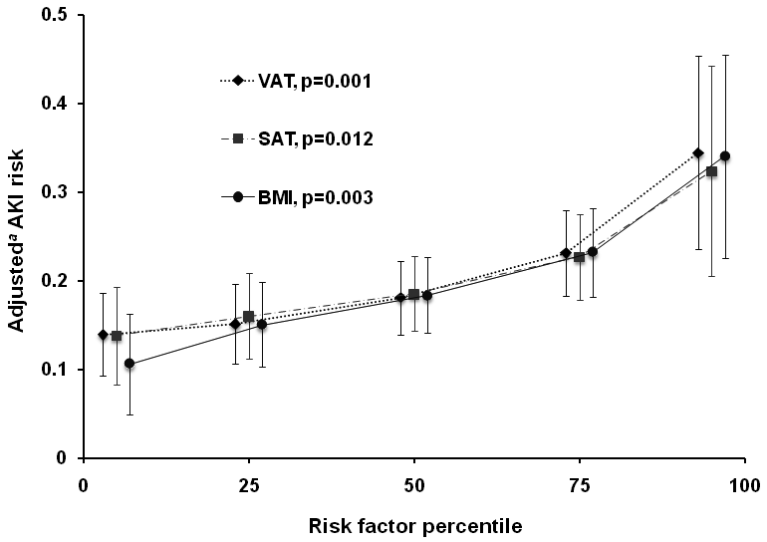

Figure 3. Adjusted risk of AKI increases with increasing adiposity

The adjusted risk of AKI associated with each adiposity measure is estimated at the 5th, 25th, 50th, 75th, and 95th percentiles of each measure. Points on the graph at each percentile have been spaced horizontally for purposes of visual clarity only. 95% confidence intervals for each risk estimate are shown with vertical error bars. P-values are for the adjusted association of each adiposity measure with AKI. Abbreviations—VAT: visceral adipose tissue area; SAT: subcutaneous adipose tissue area; BMI: body mass index. [a]Using post-estimation marginal analysis. See Table 2 for list of covariates included in the multivariable models.

Table 1

Among subjects with usable CT scans, comparison of characteristics of those with and without AKI.

	AKI (n=66)	No AKI (n=261)	*p*
Age, years	40 (26,59)	37 (24,50)	0.254
Male sex	48 (73)	187 (72)	0.862
Race[a]			0.423[d]
Caucasian	32 (48)	144 (55)	
African American	33 (50)	108 (41)	
Other	1(2)	9(3)	
Adiposity measures			
VAT area (cm^2)	**60 (23,111)**	**41 (17,88)**	**0.029**
SAT area (cm^2)	**225 (135,377)**	**171 (86,276)**	**0.006**
BMI (kg/m^2)	**28.5 (25.4,33.3)**	**25.6 (22.7,29.9)**	**<0.001**
Hypertension	15 (23)	46 (18)	0.342
Diabetes mellitus	9 (14)	11 (4)	0.004
Blunt trauma mechanism	49 (74)	215 (82)	0.134
ISS	26 (20,29)	22 (19,29)	0.037
AIS score abdomen	2 (0,3)	2 (0,3)	0.252
AIS score extremities	2 (1,3)	2 (0,3)	0.127
Low SBP in ED (mmHg)	99.5 ± 26.1	101.8 ± 23.5	0.491
APACHE III (non-renal)	53 (44,64)	51 (41.5,61.5)	0.222
First serum Cr (mg/dL)	1.1 (0.9,1.3)	1.0 (0.9,1.3)	0.080
OR prior to ICU admission	41 (62)	121 (46)	0.022
IV contrast[b]	49 (85)	221 (92)	0.101
Crystalloid, liters[c]	3.5 (1.7,6.5)	2.9 (1.3,7.5.0)	0.047
Blood products (units)[c]			
PRBC	0 (0.5,5.3)	0 (0,3)	0.086
FFP	0 (0,4)	0(0,1.5)	0.004
Platelets	0 (0,0)	0 (0,0)	0.036
Hospital mortality	15 (23)	12 (5)	<0.001

Data are shown as n (%) for categorical variables, mean ± standard deviation for normal continuous variables, and median (interquartile range) for non-normal continuous variables. Definition of abbreviations: CT=computed tomography; AKI=acute kidney injury; VAT=visceral adipose tissue; SAT=subcutaneous adipose tissue; BMI= body-mass index; ISS= Injury Severity Score; AIS= Abbreviated Injury Scale; APACHE III= Acute Physiology And Chronic Health Evaluation III; Cr=creatinine; OR=operating room; IV=intravenous; PRBC= packed red blood cells; AKI=acute kidney injury.

[a] Investigator-identified; “Other” are Asian (n=9) and American Indian (n=1).

[b] Administered prior to meeting AKI criteria.

[c] Administered during resuscitation prior to ICU admission.

[d] Fisher’s exact test comparing 3 categories.

Table 2

Multivariable models of the association of adiposity measures with AKI, primary analysis (n=327).

2a. VAT area (C-statistic 0.730, 95% CI 0.661,0.799)

Characteristic	Odds ratio (95% CI)	*p*
VAT area, per SD	1.60 (1.20,2.14)	0.001
African American race	1.68 (0.84,3.36)	0.142
Diabetes	3.39 (1.23,9.31)	0.018
Blunt trauma mechanism	0.62 (0.26,1.48)	0.283
ISS, per SD	1.44 (1.07,1.93)	0.016
PRBC, per unit[b]	1.11 (1.04,1.19)	0.002
Crystalloid, per liter[b]	1.03 (0.92,1.15)	0.619

2b. SAT area (C-statistic 0.730, 95% CI 0.663,0.797)

Characteristic	Odds ratio (95% CI)	*p*
SAT area, per SD	1.45 (1.08,1.93)	0.012
Age, per 10 years	1.12 (0.94,1.34)	0.207
Diabetes	2.95 (1.07,8.11)	0.038
Blunt trauma mechanism	0.43 (0.19,0.99)	0.046
ISS, per SD	1.43 (1.07,1.92)	0.016
PRBC, per unit[b]	1.11 (1.04,1.19)	0.003
Crystalloid, per liter[b]	1.02 (0.92,1.15)	0.673

2c. BMI[a] (C-statistic 0.738, 95% CI 0.672,0.804)

Characteristic	Odds ratio (95% CI)	*p*
BMI, per SD	1.55 (1.17,2.07)	0.003
Age, per 10 years	1.11 (0.92,1.33)	0.266
Diabetes	3.24 (1.17,8.99)	0.024
Blunt trauma mechanism	0.52 (0.23,1.18)	0.119
ISS, per SD	1.40 (1.04,1.88)	0.025
PRBC, per unit[b]	1.10 (1.03,1.18)	0.004
Crystalloid, per liter[b]	1.02 (0.91,1.14)	0.751

Definition of abbreviations: AKI=acute kidney injury; CI= confidence interval; VAT=visceral adipose tissue; SD=standard deviation ; ISS= Injury Severity Score; PRBC= packed red blood cells; SAT=subcutaneous adipose tissue; BMI= body-mass index.

[a] BMI model n=326 due to unavailable height and weight for one subject.

[b] Administered during resuscitation prior to ICU admission.

Table 3

Comparison of characteristics of subjects with and without usable CT scans.

	Usable CT (n=327)	No usable CT (n=73)	*p*
Age, years	38 (24,52)	28 (22,44)	0.008
Male sex	235 (72)	62 (85)	0.021
Race[a]			<0.001[c]
Caucasian	176 (54)	12 (16)	
African American	141 (43)	60 (82)	
Other	10 (3)	1 (1)	
BMI (kg/m^2)	26.5 (23.1,30.8)	26.0 (23.5,29.2)	0.753
Hypertension	61 (19)	6 (8)	0.031
Diabetes mellitus	20 (6)	4 (5)	>0.999
Blunt trauma mechanism	264 (81)	21 (29)	<0.001
ISS	22 (19,29)	20 (18,25)	0.003
AIS score abdomen	2 (0,3)	3 (0,4)	<0.001
APACHE III	63 (52,76)	66 (55,83)	0.104
First serum Cr (mg/dL)	1.0 (0.9,1.3)	1.3 (1.1,1.4)	<0.001
Crystalloid, liters[b]	3.0 (1.4,5.5)	5.5 (3.0,7.8)	<0.001
PRBC, units[b]	0 (0,3)	4 (0,9)	<0.001
AKI	66 (20)	28 (38)	0.001
Hospital mortality	27 (8)	5 (7)	0.815

Data are shown as n (%) for categorical variables, mean ± standard deviation for normal continuous variables, and median (interquartile range) for non-normal continuous variables. Definition of abbreviations: CT=computed tomography; BMI= body-mass index; ISS= Injury Severity Score; AIS= Abbreviated Injury Scale; APACHE III= Acute Physiology And Chronic Health Evaluation III; PRBC= packed red blood cells; AKI=acute kidney injury.

[a] Investigator-identified; “Other” are Asian (n=10) and American Indian (n=1).

[b] Total amount during resuscitation prior to ICU admission.

[c] Fisher’s exact test comparing 3 categories.