Body Mass Index is an Independent Predictor of Acute Kidney Injury After Urgent Aortic Arch Surgery for Acute DeBakey Type I Aortic Dissection

Taoshuai Liu  
Beijing An Zhen Hospital: Capital Medical University Affiliated Anzhen Hospital

Yuwei Fu  
Peking University International Hospital  https://orcid.org/0000-0002-8310-5048

Jie Liu  
Chinese PLA General Hospital

Yongmin Liu  
Beijing An Zhen Hospital: Capital Medical University Affiliated Anzhen Hospital

Junming Zhu  
Beijing An Zhen Hospital: Capital Medical University Affiliated Anzhen Hospital

Lizhong Sun  
Beijing An Zhen Hospital: Capital Medical University Affiliated Anzhen Hospital

M.D. Ming Gong  
Beijing An Zhen Hospital: Capital Medical University Affiliated Anzhen Hospital

Ran Dong (✉ dongran1130@126.com)  
Beijing An Zhen Hospital: Capital Medical University Affiliated Anzhen Hospital

Hongjia Zhang  
Beijing An Zhen Hospital: Capital Medical University Affiliated Anzhen Hospital

Research article

**Keywords:** Acute kidney injury, Aortic total arch replacement surgery, Body mass index

**DOI:** https://doi.org/10.21203/rs.3.rs-127855/v1

**License:** This work is licensed under a Creative Commons Attribution 4.0 International License. 
Read Full License
Abstract

Background: Aortic arch surgery and obesity are both related to risk of acute kidney injury. Our hypothesis was the risk of postoperative acute kidney injury increases when the body mass index increases in patients underwent urgent aortic total arch replacement surgery for acute Debakey Type I aortic dissection.

Methods: We conducted a retrospective cohort study in Beijing Anzhen hospital from December 2015 to April 2017. All patients receiving urgent aortic total arch replacement surgery with a frozen elephant trunk implant for acute Debakey Type I aortic dissection were included. Body mass index was calculated based on height and weight. Acute kidney injury was diagnosed depended on the Kidney Disease Improving Global Outcomes standards.

Results: We included 115 consecutive patients in this timeframe. There were 53.0% (n=61) patients had acute kidney injury. Mean age was 47.8±10.7 years; 25.2% were women. Mean body mass index was 26.2±3.9 kg/m^2. In-hospital mortality was obvious increased in the acute kidney injury group (13.1% vs 1.9%; P=0.025). Multivariate logistic regression showed that body mass index was associated with postoperative acute kidney injury after adjust other confounding factors (odds ratio=1.18; 95% confidence interval: 1.04-1.34; P =0.012).

Conclusions: Body mass index was an independent predictor of acute kidney injury after urgent aortic total arch replacement surgery with a frozen elephant trunk implant.

Background

Acute kidney injury (AKI) was not an uncommon complication following cardiovascular surgery. The incidence was roughly 30%, and markedly increases their mortality and morbidity [1–4]. Occurrence of AKI following cardiac surgery is influenced by many factors, involving perioperative red blood cell transfusions, preoperative anemia, increased age, and intraoperative cardiopulmonary bypass (CPB) time [5–7]. However, AKI after aortic surgery has not been extensively studied. This kind of operation will increase the incidence of AKI, due to the complexity of this operation, including CPB time longer and circulatory arrest.

Currently, obesity is a worldwide public health issue. It is correlated with a broad range of cardiovascular disorders [8], including hypertension, insulin resistance, and diabetes mellitus [9]. Obese patients in general are prone to AKI owing to the higher burden of accompanying diseases and potential structural changes that appear in their kidneys, even the serum biochemistry was normal [10, 11]. There were limited studies to examine the effect of obesity on AKI in patients underwent urgent aortic total arch replacement (TAR) surgery with a frozen elephant trunk implant (FET) for acute Debakey Type I aortic dissection (ADTIAD).
Therefore, our objective was to investigate the effect of body mass index (BMI) on AKI in patients underwent urgent TAR + FET after adjust for all known confounding factors. Our hypothesis was that the risk of AKI would increase as BMI increased.

**Methods**

**Participants**

The retrospective cohort study was conducted at Beijing Anzhen hospital in China from December 2015 to April 2017. This study was allowed by the human research and development committees of this hospital and was adhered to the rules of the Declaration of Helsinki and principles of Good Clinical Practice. Individual consent was waived for the retrospective study. All patients with ADTIAD who underwent urgent TAR + FET surgery in this timeframe were included. All surgical treatments were operated by the same surgical team.

A total of 137 patients with ADTIAD undergoing urgent TAR + FET with CPB were admitted. A total of 18 patients were excluded because they underwent renal replacement therapy (RRT) before the operation. Three patients were excluded for they died intraoperatively or within 24 hours after surgery. One patient who lack of serum creatinine (sCr) was also excluded. Consequently, 115 consecutive patients were involved in the ultimate analysis. A flow chart of the screening and registration of study patients was shown in Fig. 1.

**Data collection**

Trained staff collected detailed data of patients from electronic medical records of this hospital. Baseline characteristics involved age, gender, height, weight, BMI (calculated based on height and weight), drinking history, smoking history; Comorbidities: diabetes mellitus, hypertension, previous cerebrovascular disease, left ventricular ejection fraction (LVEF), coronary artery disease, hematocrit, preoperative blood urea nitrogen (BUN); sCr, preoperative hemoglobin, hemopericardium, eGFR (estimated glomerular filtration rate, calculated based on Epidemiology Collaboration equation), renal artery dissection, Penn class (Class Aa and Non class Aa), kidney malperfusion, acute myocardial infarction (AMI), preoperative shock; Intraoperative data: intraoperative packed red blood cells (PRBCs), intraoperative amount of plasma, intraoperative blood loss, CPB time, aortic occlusion clamp time, time of circulatory arrest, rectal temperature and nasopharyngeal temperature at circulatory arrest, the type of surgery (Bentall + TAR + FET or ascending aorta replacement + TAR + FET), combined with coronary artery bypass grafting (CABG) and combined with ascending aorta to femoral artery bypass surgery (aortic bypass surgery); Postoperative data: reoperation for bleeding, postoperative dialysis, intensive care unit (ICU) stays, hospital stays, in-hospital death. Primary indications for renal replacement therapy were uraemia, anuresis, volume overload and obviously biochemical abnormalities.

**Outcome variables**
The main endpoint event was the occurrence of AKI following urgent TAR + FET operation. Recently, KDIGO proposed a new range of guidelines for the characterization of AKI based on two previous classifications, RIFLE and AKIN [12, 13]. In this study, AKI was diagnosed based on KDIGO criteria: the postoperative sCr levels increased greater than 50% within 7 days or 0.3 mg/dL within two days by baseline after operation. Preoperative sCr values which recorded the last measurement before operation were regarded as baseline sCr.

**Assessment of covariates**

Our covariates were selected based on our prior work and studies and from others examining risk factors for postoperative AKI. Hypertension, DM, preoperative hemoglobin, hematocrit, preoperative baseline sCr, preoperative BUN, CPB time, intraoperative blood loss, and intraoperative amount of PRBCs were recorded in all participants. Preoperative hemoglobin, hematocrit, preoperative baseline creatinine, and preoperative BUN were recorded as the results of the laboratory test after hospital admission before surgery.

**Surgical technique**

All patients received TAR with FET. This method has been reported at great length by our research team [14]. Briefly, we used right axillary artery and atrium dextrum to perform CPB following heparinization [maintaining the activated clotting time exceed 480s]. The flow rates of CPB were 2.5 L/(min·m²). We kept the mean arterial pressure between 50 and 70 mmHg. Whether to perform an aortic valve replacement depended on the condition of the aortic valve. If the classification of aortic regurgitation was moderate or severe, we preferred to perform Bentall procedure (aortic valve replacement combined with ascending aorta replacement). If there was only mild regurgitation, we preferred to perform ascending aorta replacement only. A frozen elephant stent (MicroPort Medical Company Limited, Shanghai, China) and a four branched artificial vessel (Maquet Cardiovascular, Wayne, NJ) were employed in this implantation. We usually performed the surgery with moderate hypothermic circulatory arrest and antegrade cerebral perfusion.

**Data analysis**

Mean or median were used to express continuous variables according to data dispersion. Categorical variables were present with percentages (%). If continuous variables were normally distributed, t-tests were used to compare and if the data was skewed, non-parametric Mann–Whitney U tests were applied. The predictors of AKI were recognized by univariate regression analysis. Multiple regression models were used to evaluate the effect of BMI on postoperative AKI. Both non-adjusted and adjusted models (gender; age; previous cerebrovascular disease; smoking history; renal artery dissection; eGFR; AMI) were applied. Whether the concomitant variable was adjusted according to the following principle: if the matched odds ratio was changed at least 10% [15] by the variable when added to this model, then an adjustment was made. A generalized additive model (GAM) was also applied to discover linear relationships. BMI was analyzed as a continuous variant in multivariable logistic models. Further analysis was performed using 24 kg/m² as cut-off values based on the Chinese population BMI classification criteria [16]. Interaction
and stratified analysis were performed based on age (< 60 and ≥ 60 years), gender, hypertension, smoking history, drinking history, coronary artery disease, previous cerebrovascular disease, CPB time (< 204 or ≥ 204 min), aortic cross clamp time (< 115 or ≥ 115 min), circulation arrest time (< 27 or ≥ 27 min), operation time (< 8 or ≥ 8 h), Intraoperative blood loss (< 1500 or ≥ 1500 mL), Intraoperative amount of PRBCs (< 2 or ≥ 2 U), Intraoperative amount of plasma (< 400 or ≥ 400 mL) and hemoglobin (< 135 or ≥ 135 g/L). All of the analysis was conducted by the statistical software packages R and EmpowerStats.

Results

Baseline characteristics

After the exclusion criteria were applied, 115 consecutive patients were admitted in this cohort, with a median age of 47.8 ± 10.7 years; 29 (25.2%) were female. There were 61 patients (53%) with AKI. The average BMI was 26.2 ± 3.9 kg/m². The average preoperative BUN was 7.2 ± 2.5 mmol/L and preoperative sCr was 86.2 ± 29.1 umol/L. Comorbidities included hypertension (80%), diabetes mellitus (6.1%), previous cerebrovascular disease (5.2%), and coronary artery disease (5.2%). In total, 20% of patients required RRT. The baseline characteristics of the 115 study patients between AKI and non-AKI were given in Table 1.
Table 1
Characteristics of the study patients between AKI and No-AKI

| Variable                                | No-AKI (n = 54) | AKI (n = 61) | P-value |
|-----------------------------------------|-----------------|-------------|---------|
| Age                                     | 46.8 ± 11.0     | 48.7 ± 10.4 | 0.342   |
| Gender                                  |                 |             | 0.486   |
| male                                    | 42 (77.8%)      | 44 (72.1%)  |         |
| female                                  | 12 (22.2%)      | 17 (27.9%)  |         |
| BMI (kg/m²)                              | 25.0 ± 3.8      | 27.2 ± 3.7  | 0.002   |
| Diabetes mellitus                       | 1 (1.9%)        | 6 (9.8%)    | 0.074   |
| Hypertension                            | 42 (77.8%)      | 50 (82.0%)  | 0.575   |
| Previous cerebrovascular disease        | 4 (7.4%)        | 2 (3.3%)    | 0.320   |
| Coronary artery disease                 | 3 (5.6%)        | 3 (4.9%)    | 0.878   |
| Smoking history                         | 22 (40.7%)      | 34 (55.7%)  | 0.108   |
| Drinking history                        | 11 (20.4%)      | 12 (19.7%)  | 0.926   |
| Renal artery dissection                 | 10 (18.5%)      | 7 (11.5%)   | 0.288   |
| Hemopericardium                         | 9 (16.7%)       | 10 (16.4%)  | 0.969   |
| Penn class                              |                 |             | 0.665   |
| Class Aa                                | 34 (63.0%)      | 36 (59.0%)  |         |
| Non class Aa                            | 20 (37.0%)      | 25 (41.0%)  |         |
| Kidney malperfusion                     | 3 (5.6%)        | 4 (6.6%)    | 0.823   |
| AMI                                     | 2 (3.7%)        | 7 (11.5%)   | 0.121   |
| Preoperative shock                      | 9 (16.7%)       | 10 (16.4%)  | 0.969   |
| Preoperative sCr (umol/L)               | 82.0 ± 30.0     | 90.0 ± 27.9 | 0.141   |
| BUN (mmol/L)                            | 7.1 ± 2.7       | 7.3 ± 2.4   | 0.724   |
| Hemoglobin (g/L)                        | 137.2 ± 18.6    | 135.9 ± 16.3| 0.689   |

Bold value indicates significance at p < 0.05. Results are expressed as n (%) or mean ± SD or median [IQR].

AKI Acute Kidney Injury, AMI Acute Myocardial Infarction, BMI Body Mass Index, BUN Blood Urea Nitrogen, CPB Cardiopulmonary Bypass, CABG Coronary Artery Bypass Grafting, eGFR estimated Glomerular Filtration Rate, FET Frozen Elephant Trunk, ICU Intensive Care Unit, PRBCs Packed Red Blood Cells, sCr serum Creatinine, SD Standard Deviation, TAR Total Arch Replacement, IQR Interquartile Range
| Variable                                                | No-AKI (n = 54)   | AKI (n = 61)    | p-value |
|---------------------------------------------------------|------------------|----------------|---------|
| Hematocrit (%)                                          | 39.7 ± 5.0       | 39.1 ± 4.2     | 0.443   |
| eGFR mL/(min·1.73l)                                     | 94.2 ± 21.2      | 83.5 ± 22.8    | 0.011   |
| CPB time (min)                                          | 199.1 ± 45.6     | 222.0 ± 62.0   | 0.027   |
| Aortic cross clamp time (min)                           | 120.2 ± 49.0     | 127.0 ± 36.1   | 0.400   |
| Circulatory arrest time (min)                           | 27.4 ± 9.6       | 27.5 ± 7.6     | 0.914   |
| Operation time (h)                                      | 23.1 ± 1.6       | 22.7 ± 1.5     | 0.142   |
| Nasopharyngeal temperature at circulatory arrest (℃)    | 25.5 ± 2.3       | 25.1 ± 2.0     | 0.358   |
| Rectal temperature at circulatory arrest (℃)            | 7.9 ± 1.6        | 8.8 ± 2.0      | 0.007   |
| Intraoperative amount of PRBCs (mL)                     | 300.0 (0.0-600.0)| 600.0 (0.0-600.0)| 0.043   |
| Intraoperative blood loss (mL)                          | 1300.0 (1000.0-1575.0)| 1500.0 (1200.0-2000.0)| 0.024   |
| Intraoperative amount of plasma (mL)                    | 400.0 (0.0-550.0)| 400.0 (0.0-800.0)| 0.102   |
| Combined with CABG                                      | 3 (5.6%)         | 5 (8.2%)       | 0.578   |
| Combined with aortic bypass surgery                     | 0 (0.0%)         | 1 (1.6%)       | 0.345   |
| Bentall + TAR + FET                                     | 22 (40.7%)       | 25 (41.0%)     | 0.979   |
| Length of ICU                                           | 1.9 (1.0–3.0)    | 4.0 (2.0–9.0)  | <0.001  |
| Length of in hospital                                   | 1 (1.9%)         | 8 (13.1%)      | 0.025   |
| Reoperation for bleeding                                | 1 (1.9%)         | 8 (13.1%)      | 0.025   |
| In-hospital mortality                                   | 1 (1.9%)         | 8 (13.1%)      | 0.025   |

Bold value indicates significance at p < 0.05. Results are expressed as n (%) or mean ± SD or median [IQR].

AKI Acute Kidney Injury, AMI Acute Myocardial Infarction, BMI Body Mass Index, BUN Blood Urea Nitrogen, CPB Cardiopulmonary Bypass, CABG Coronary Artery Bypass Grafting, eGFR estimated Glomerular Filtration Rate, FET Frozen Elephant Trunk, ICU Intensive Care Unit, PRBCs Packed Red Blood Cells, sCr serum Creatinine, SD Standard Deviation, TAR Total Arch Replacement, IQR Interquartile Range

**Univariate analysis of predictors for AKI**

The consequences of a univariate analysis showed that BMI, eGFR, CPB time, operative time, intraoperative blood loss and intraoperative amount of PRBCs were significantly correlated with AKI. Smoking, hemoglobin levels, hypertension, hematocrit, preoperative sCr, BUN, aortic cross clamp time,
intraoperative amounts of plasma and circulatory arrest time were not significantly associated with AKI. The results were given in Table 2.
Table 2
Univariate analysis of risk factors associated with postoperative AKI in patients with ADTIAD

| Variable                          | Statistics          | OR (95%CI)           | P-value |
|----------------------------------|---------------------|----------------------|---------|
| Age                              | 47.81 ± 10.70       | 1.02 (0.98, 1.05)    | 0.339   |
| Gender                           |                     |                      |         |
| male                             | 86 (74.78%)         | 1.0                  |         |
| female                           | 29 (25.22%)         | 1.35 (0.58, 3.17)    | 0.487   |
| BMI (kg/m²)                      | 26.2 ± 3.9          | 1.18 (1.06, 1.33)    | 0.003   |
| Diabetes mellitus                | 7 (6.09%)           | 5.78 (0.67, 49.62)   | 0.110   |
| Hypertension                     | 92 (80.00%)         | 1.30 (0.52, 3.24)    | 0.576   |
| Previous cerebrovascular disease | 6 (5.22%)           | 0.42 (0.07, 2.41)    | 0.333   |
| Coronary artery disease          | 6 (5.22%)           | 0.88 (0.17, 4.55)    | 0.878   |
| Smoking history                  | 56 (48.70%)         | 1.83 (0.87, 3.85)    | 0.110   |
| Drinking history                 | 23 (20.00%)         | 0.96 (0.38, 2.39)    | 0.926   |
| Renal artery dissection          | 17 (14.78%)         | 0.57 (0.20, 1.62)    | 0.292   |
| Hemopericardium                  | 19 (16.52%)         | 0.98 (0.37, 2.63)    | 0.969   |
| Penn class                       |                     |                      |         |
| Class Aa                         | 70 (60.87%)         | 1.0                  |         |
| Non class Aa                     | 45 (39.13%)         | 1.18 (0.56, 2.50)    | 0.665   |
| Kidney malperfusion              | 7 (6.09%)           | 1.19 (0.25, 5.59)    | 0.823   |
| AMI                              | 9 (7.83%)           | 3.37 (0.67, 16.98)   | 0.141   |
| Preoperative shock               | 19 (16.52%)         | 0.98 (0.37, 2.63)    | 0.969   |
| Preoperative sCr (umol/L)        | 86.22 ± 29.07       | 1.01 (1.00, 1.02)    | 0.147   |

Bold value indicates significance at p < 0.05. §=The result failed because of the small sample size.

Results are expressed as n (%) or mean ± SD or median [IQR].

AKI Acute Kidney Injury, AMI Acute Myocardial Infarction, BMI Body Mass Index, BUN Blood Urea Nitrogen, CPB Cardiopulmonary Bypass, CABG Coronary Artery Bypass Grafting, eGFR estimated Glomerular Filtration Rate, FET Frozen Elephant Trunk, ICU Intensive Care Unit, PRBCs Packed Red Blood Cells, sCr serum Creatinine, SD Standard Deviation, TAR Total Arch Replacement, IQR Interquartile Range
| Variable                                      | Statistics       | OR (95%CI)     | P-value |
|-----------------------------------------------|------------------|----------------|---------|
| BUN (mmol/L)                                 | 7.21 ± 2.51      | 1.03 (0.89, 1.19) | 0.722   |
| Hemoglobin (g/L)                             | 136.53 ± 17.32   | 1.00 (0.97, 1.02) | 0.686   |
| Hematocrit (%)                               | 39.38 ± 4.61     | 0.97 (0.89, 1.05) | 0.440   |
| eGFR mL/(min·1.73 m²)                        | 88.55 ± 22.64    | 0.98 (0.96, 1.00) | 0.013   |
| CPB time (min)                               | 211.25 ± 55.90   | 1.01 (1.00, 1.02) | 0.032   |
| Aortic cross clamp time (min)                | 123.81 ± 42.57   | 1.00 (0.99, 1.01) | 0.401   |
| Circulatory arrest time (min)                | 27.44 ± 8.54     | 1.00 (0.96, 1.05) | 0.913   |
| Operation time (h)                           | 8.36 ± 1.89      | 1.33 (1.07, 1.65) | 0.009   |
| Nasopharyngeal temperature at circulatory arrest (°C) | 22.86 ± 1.55 | 0.83 (0.65, 1.06) | 0.143   |
| Rectal temperature at circulatory arrest (°C) | 25.29 ± 2.13    | 0.92 (0.77, 1.10) | 0.356   |
| Combined with CABG                           | 8 (6.96%)        | 1.52 (0.35, 6.67) | 0.581   |
| Combined with aortic bypass surgery          | 1 (0.87%)        | §              | 0.992   |
| Bentall + TAR + FET                          | 47 (40.87%)      | 1.01 (0.48, 2.13) | 0.979   |
| Intraoperative amount of PRBCs (mL)          | 393.91 ± 413.17  | 1.00 (1.00, 1.00) | 0.048   |
| Intraoperative blood loss (mL)               | 1487.8 ± 710.5   | 1.00 (1.00, 1.00) | 0.032   |
| Intraoperative amount of plasma (mL)         | 400 (0-600)      | 1.00 (1.00, 1.00) | 0.104   |
| Reoperation for bleeding                     | 9 (7.83%)        | 8.00 (0.97, 66.21) | 0.054   |

Bold value indicates significance at p < 0.05. §=The result failed because of the small sample size.

Results are expressed as n (%) or mean ± SD or median [IQR].

AKI Acute Kidney Injury, AMI Acute Myocardial Infarction, BMI Body Mass Index, BUN Blood Urea Nitrogen, CPB Cardiopulmonary Bypass, CABG Coronary Artery Bypass Grafting, eGFR estimated Glomerular Filtration Rate, FET Frozen Elephant Trunk, ICU Intensive Care Unit, PRBCs Packed Red Blood Cells, sCr serum Creatinine, SD Standard Deviation, TAR Total Arch Replacement, IQR Interquartile Range

**The linear relationship between BMI and AKI after adjusting for covariates**

Spline smoothing was implemented using GAM to identify the linear relationship between BMI and AKI after adjusting for age; gender; previous cerebrovascular disease; smoking history; renal artery dissection;
eGFR; AMI. The red line represents the fitting spline. The blue points represent the 95% confidence intervals. The result was shown in Fig. 2.

**Multivariate analysis: independent predictor of AKI**

Table 3 revealed the consequences of multivariate regression analysis. We constructed three models: (I) unadjusted; (II) adjusted for demographics: age; gender; (III) adjusted for age; gender; previous cerebrovascular disease; smoking history; renal artery dissection; eGFR; AMI. The model I showed a significant association between BMI and AKI [odds ratio (OR) = 1.18; 95% confidence interval (CI): 1.06 – 1.33; p = 0.003]. In model II (adjusted for age and gender), the results were significant (OR = 1.21, 95% CI: 1.08–1.36; p = 0.002). Furthermore, in model III (adjusted for age; gender; previous cerebrovascular disease; smoking history; renal artery dissection; eGFR; AMI), the results still were significant (OR = 1.18, 95% CI: 1.04–1.34; p = 0.012).

| Variable          | Model I                         | Model II                        | Model III                        |
|-------------------|---------------------------------|---------------------------------|----------------------------------|
|                   | OR (95%CI)                      | P-value                         | OR (95%CI)                       | P-value |
| BMI (kg/m²)       | 1.18 (1.06, 1.33)               | 0.003                           | 1.21(1.08, 1.36)                 | 0.002   |
|                   |                                 |                                 | 1.18 (1.04, 1.34)                | 0.012   |
| BMI groups (kg/m²)|                                 |                                 |                                 |
| < 24              | 1.0                             | 1.0                             | 1.0                             |
| ≥ 24              | 3.27 (1.43, 7.48)               | 0.005                           | 4.02 (1.64, 9.89)               | 0.002   |
|                   |                                 |                                 | 3.45 (1.29, 9.23)               | 0.014   |

ADTIAD Acute DeBakey Type I Aortic Dissection, AKI Acute Kidney Injury, AMI Acute Myocardial Infarction, BMI Body Mass Index, eGFR estimated Glomerular Filtration Rate, OR Odd Ratio, 95% CI 95% Confidence Interval

Model I: adjust for none.

Model II: adjust for age; gender;

Model III: adjust for age; gender; previous cerebrovascular disease; smoking history; renal artery dissection; eGFR; AMI

Secondary analyses were performed using 24 kg/m² as cut-off values based on the Chinese BMI classification reference standard. In the non-adjusted model, BMI < 24 kg/m² was taken as a reference. The risk of postoperative AKI in the BMI ≥ 24 kg/m² groups increased by 2.27 times (OR = 3.27, 95% CI:
1.43–7.48; \( p = 0.005 \)). After adjusting for other confounding factors, the results were still statistically significant; the risk of AKI increased by 2.45 (OR = 3.45, 95% CI: 1.29–9.23; \( p = 0.014 \)).

**Stratified analysis**

Stratified analysis was performed in patients separated by age (age < 60 years and age \( \geq 60 \) years), diabetes mellitus, hypertension, previous cerebrovascular disease, coronary artery disease, smoking history, drinking history, coronary artery disease, previous cerebrovascular disease, CPB time (< 204 or \( \geq 204 \) min), aortic cross clamp time (< 115 or \( \geq 115 \) min), circulation arrest time (< 27 or \( \geq 27 \) min), operation time (< 8 or \( \geq 8 \) h), Intraoperative blood loss (< 1500 or \( \geq 1500 \) mL), Intraoperative amount of PRBCs (< 2 or \( \geq 2 \) U), Intraoperative amount of plasma (< 400 or \( \geq 400 \) mL) and hemoglobin (< 135 or \( \geq 135 \) g/L). BMI was still an independent predictor of AKI in these high-risk subgroups. The results of stratified analysis are given in Fig. 3.

**Discussion**

In this cohort study of 115 patients underwent urgent TAR + FET for ADTIAD, we found BMI was positively correlated with postoperative AKI. A 1-kg/m\(^2\) increase of BMI was correlated with a 18% higher risk of postoperative AKI. Taking BMI < 24 kg/m\(^2\) as reference, the risk of AKI in BMI \( \geq 24 \) kg/m\(^2\) group increased by 2.45 times. This confirms the relationship between BMI and postoperative AKI and verifies our hypothesis.

The finding was same with results of Kumar et al. [17], who identified a obviously increase in incidence of postoperative AKI in patients with a BMI greater than 40 kg/m\(^2\). Certainly, there were some obvious differences between their study and this study. First, lots of patients were obese (46% vs 13%) in their study cohort. Second, there were no patients in our study with BMI equal or exceed 40 kg/m\(^2\). Third, they didn't examine the impact of baseline hemoglobin and hematocrit on AKI, which was a risk factor associated with AKI [18]. O'Sullivan et al. [19] analyzed 432 consecutive patients received cardiovascular surgery with CPB and they found a BMI of 30 kg/m\(^2\) or greater was an independent predictor of AKI (OR = 2.12, 95% CI: 1.27–3.54; \( p = 0.004 \)). This finding was consistent with the results of our study. Moreover, several other studies [20–24] have found that BMI was an independent predictor of development of AKI in patients received cardiovascular surgery, which further confirmed our findings.

There were some studies showed various results. Roh et al. [25] analyzed 98 patients underwent thoracic aorta replacement due to AD and found that BMI was not correlated with AKI (OR = 1.04, 95% CI: 0.93–1.16; \( p = 0.54 \)). However, as the authors acknowledged, the smaller number of participants might have led to insufficient statistical validity. Vellinga et al. [26] analyzed 565 consecutive patients undergoing CABG with the employment of cardiopulmonary bypass and did not find that BMI was associated with postoperative AKI. This could be due to the fact that the study population was different.

The potential molecular mechanisms for the connection between BMI and AKI remain unclear. Billings et al. [27] explored the connection in 445 consecutive patients underwent cardiac surgery. The results
showed BMI was independently associated with AKI. Additionally, baseline F2-isoprostane, intraoperative F2-isoprostane, and intraoperative plasminogen activator inhibitor-1 concentrations were also independent predictors of AKI. But, after adjusting for these variables, BMI was no longer associated with AKI, indicating that the influence may be interrupted by oxidative stress.

This study has several strengths. First, the patients selected for this study comprised a homogeneous population of patients with ADTIAD, underwent urgent TAR + FET. Second, we adopted the KDIGO guidelines for AKI instead of the previous 2 classifications, as the KDIGO guidelines have been revised more recently and offer clarity and simplicity for clinical use. Third, although the study was an observational research and impressionable to possible confounder, we performed rigorous statistical methods to minimize remaining confounders. Finally, we handled target independent variable as both continuous variable and categorical variable. Such an approach can reduce the contingency in the data analysis and enhance the robustness of results.

It was very vital to explore the predictors related to AKI. Emphasis on obesity as a problem may be helpful for clinicians to deal with patients pre- and postoperatively. For elective surgical patients, weight-loss may be a useful method to reduce the risk of AKI preoperatively. However, it may not be effective for the emergent surgery on various occasions. Furthermore, we should pay more attention to patients with higher BMIs who are undergoing urgent TAR + FET in case the occurrence of postoperative AKI.

There were also some limitations in the present study: (1) in this study, our research subjects were patients who received aortic surgery for ADTIAD. Therefore, there was a certain deficiency in the universality and extrapolation of research. (2) because we exclude patients requiring RRT before surgery, therefore, the findings of this study cannot be used for these people. (3) it was a retrospective cohort study, which may have limited the observational study design.

**Conclusion**

BMI was an independent predictor of AKI in patients underwent urgent TAR + FET surgery for ADTIAD. It was crucial to explore the molecular mechanisms for perform preventative therapies.

**Abbreviations**

ADTIAD
- acute DeBakey Type I aortic dissection
AKI: acute kidney injury
AKIN: Acute Kidney Injury Network
AMI: acute myocardial infarction
BMI: body mass index
BUN: blood urea nitrogen
CABG: coronary artery bypass grafting
CI: confidence interval
CPB: cardiopulmonary bypass
GAM: generalized additive model
ICU: intensive care unit
KDIGO: Kidney Disease Improving Global Outcomes
LVEF: left ventricular ejection fraction
OR: odds ratio
PRBCs: packed red blood cells
RIFLE: Risk, Injury, Failure, Loss and End-stage
RRT: renal replacement therapy
SCP: selective cerebral perfusion
sCr: serum creatinine
Declarations

Acknowledgements

We would like to thank Xinglin Chen and Changzhong Chen for their generous support in data analysis.

Authors’ Contributions

Taoshuai Liu, Yuwei Fu Shijun Xu, Ming Gong, Hongjia Zhang designed the study; Taoshuai Liu, Yuwei Fu Xinliang Guan, Jiachen Li, Zining Wu, Lei Li collected the data; Shijun Xu, Jie Liu analysed the data; Taoshuai Liu, Yuwei Fu, Shijun Xu analysed and interpreted the results; Shijun Xu wrote this article. All authors read and approved the final manuscript.

Funding

This study was supported by National Key R&D Program of China (2017YFC1308000) and the Beijing Lab for Cardiovascular Precision Medicine, Beijing, China. PXM2017_014226_000037.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study protocol was approved by Ethics Committee of Beijing Anzhen Hospital (2014019).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

1 Department of Cardiac Surgery, Beijing Aortic Disease Center, Beijing Anzhen Hospital, Capital Medical University, Beijing Institute of Heart Lung and Blood Vessel Diseases and Beijing Engineering Research Center of Vascular Prostheses, No.2 Anzhen Street, Beijing, 100029, China. 2 Department of ultrasound, Peking University International Hospital, No. 1, shengmingyuan Road, Zhongguancun Life Science Park, Changping District, Beijing, 102206, China. 3 Department of Vascular and Endovascular Surgery, Chinese PLA General Hospital, Beijing, 100853, China.

References
1. Dardashti A, Ederoth P, Algotsson L, Brondén B, Bjursten H. Incidence, dynamics, and prognostic value of acute kidney injury for death after cardiac surgery. J Thorac Cardiovasc Surg. 2014;147(2):800–7.

2. Kandler K, Jensen ME, Nilsson JC, Møller CH, Steinbrüchel DA. Acute kidney injury is independently associated with higher mortality after cardiac surgery. J Cardiothorac Vasc Anesth. 2014;28(6):1448–52.

3. Karkouti K, Grocott HP, Hall R, Jessen ME, Kruger C, Lerner AB, et al. Interrelationship of preoperative anemia, intraoperative anemia, and red blood cell transfusion as potentially modifiable risk factors for acute kidney injury in cardiac surgery: a historical multicentre cohort study. Can J Anaesth. 2015;62(4):377–84.

4. Wang Y, Bellomo R. Cardiac surgery-associated acute kidney injury: risk factors, pathophysiology and treatment. Nature reviews Nephrology. 2017;13(11):697–711.

5. Karkouti K, Wijeysundera DN, Yau TM, Callum JL, Cheng DC, Crowther M, et al. Acute kidney injury after cardiac surgery: focus on modifiable risk factors. Circulation. 2009;119(4):495–502.

6. Neugarten J, Golestaneh L. Female sex reduces the risk of hospital-associated acute kidney injury: a meta-analysis. BMC Nephrol. 2018;19(1):314.

7. Shaw A. Update on acute kidney injury after cardiac surgery. J Thorac Cardiovasc Surg. 2012;143(3):676–81.

8. Alnasser SM, Huang W, Gore JM, Steg PG, Eagle KA, Anderson FA Jr, et al. Late Consequences of Acute Coronary Syndromes: Global Registry of Acute Coronary Events (GRACE) Follow-up. Am J Med. 2015;128(7):766–75.

9. Rice K, Te Hiwi B, Zwarenstein M, Lavallee B, Barre DE, Harris SB. Best Practices for the Prevention and Management of Diabetes and Obesity-Related Chronic Disease among Indigenous Peoples in Canada: A Review. Canadian journal of diabetes. 2016;40(3):216–25.

10. Kramer HJ, Saranathan A, Luke A, Durazo-Arvizu RA, Guichan C, Hou S, et al. Increasing body mass index and obesity in the incident ESRD population. Journal of the American Society of Nephrology: JASN. 2006;17(5):1453–9.

11. Veeneman JM, de Jong PE, Huisman RM, Reijngoud DJ. Re: Adey et al. Reduced synthesis of muscle proteins in chronic renal failure. Am J Physiol Endocrinol Metab 278: E219-E225, 2000. American journal of physiology Endocrinology and metabolism. 2001;280(1):E197-8.

12. Kellum JA, Lameire N. Diagnosis, evaluation, and management of acute kidney injury: a KDIGO summary (Part 1). Critical care (London, England). 2013;17(1):204.

13. Lameire N, Kellum JA. Contrast-induced acute kidney injury and renal support for acute kidney injury: a KDIGO summary (Part 2). Critical care (London, England). 2013;17(1):205.

14. Sun L, Qi R, Zhu J, Liu Y, Zheng J. Total arch replacement combined with stented elephant trunk implantation: a new "standard" therapy for type a dissection involving repair of the aortic arch? Circulation. 2011;123(9):971–8.
15. Kernan WN, Viscoli CM, Brass LM, Broderick JP, Brott T, Feldmann E, et al. Phenylpropanolamine and the risk of hemorrhagic stroke. N Engl J Med. 2000;343(25):1826–32.

16. Zhang J, Wang H, Wang Z, Du W, Su C, Zhang J, et al. Prevalence and stabilizing trends in overweight and obesity among children and adolescents in China, 2011–2015. BMC Public Health. 2018;18(1):571.

17. Kumar AB, Bridget Zimmerman M, Suneja M. Obesity and post-cardiopulmonary bypass-associated acute kidney injury: a single-center retrospective analysis. J Cardiothorac Vasc Anesth. 2014;28(3):551–6.

18. Xue FS, Li RP, Cui XL, Wang SY. Assessing effect of obesity on acute kidney injury following cardiac surgery with cardiopulmonary bypass. J Cardiothorac Vasc Anesth. 2015;29(2):e11.

19. O'Sullivan KE, Byrne JS, Hudson A, Murphy AM, Sadlier DM, Hurley JP. The effect of obesity on acute kidney injury after cardiac surgery. J Thorac Cardiovasc Surg. 2015;150(6):1622–8.

20. Berg KS, Stenseth R, Wahba A, Pleym H, Videm V. How can we best predict acute kidney injury following cardiac surgery?: a prospective observational study. Eur J Anaesthesiol. 2013;30(11):704–12.

21. Englberger L, Suri RM, Greason KL, Burkhart HM, Sundt TM 3rd, Daly RC, et al. Deep hypothermic circulatory arrest is not a risk factor for acute kidney injury in thoracic aortic surgery. J Thorac Cardiovasc Surg. 2011;141(2):552–8.

22. Kanji HD, Schulze CJ, Hervas-Malo M, Wang P, Ross DB, Zibdawi M, et al. Difference between pre-operative and cardiopulmonary bypass mean arterial pressure is independently associated with early cardiac surgery-associated acute kidney injury. J Cardiothorac Surg. 2010;5:71.

23. Ko B, Garcia S, Mithani S, Tholakanahalli V, Adabag S. Risk of acute kidney injury in patients who undergo coronary angiography and cardiac surgery in close succession. European heart journal. 2012;33(16):2065–70.

24. Ko T, Higashitani M, Sato A, Uemura Y, Norimatsu T, Mahara K, et al. Impact of Acute Kidney Injury on Early to Long-Term Outcomes in Patients Who Underwent Surgery for Type A Acute Aortic Dissection. Am J Cardiol. 2015;116(3):463–8.

25. Roh GU, Lee JW, Nam SB, Lee J, Choi JR, Shim YH. Incidence and risk factors of acute kidney injury after thoracic aortic surgery for acute dissection. Ann Thorac Surg. 2012;94(3):766–71.

26. Vellinga S, Verbrugghe W, De Paep R, Verpooten GA, Janssen van Doom K. Identification of modifiable risk factors for acute kidney injury after cardiac surgery. Neth J Med. 2012;70(10):450–4.

27. Billings FT, Pretorius M, Schildcrout JS, Mercaldo ND, Byrne JG, Ikizler TA, et al. Obesity and oxidative stress predict AKI after cardiac surgery. Journal of the American Society of Nephrology: JASN. 2012;23(7):1221–8.

Figures
Figure 3

Subgroup analysis of the association between BMI and AKI in patients with ADTIAD. Each stratification adjusted for all the factors: (age, diabetes mellitus, hypertension, previous cerebrovascular disease, coronary artery disease, smoking history, drinking history, coronary artery disease, previous cerebrovascular disease, CPB time, aortic cross clamp time, circulation arrest time, operation time,
Intraoperative blood loss, Intraoperative amount of PRBCs, Intraoperative amount of plasma and hemoglobin). except the stratification factor itself.