Risk factors analysis of acute kidney injury following open thoracic aortic surgery in the patients with or without acute aortic syndrome: a retrospective study

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Abstract

Background: The acute kidney injury (AKI) remains a frequent complication following open thoracic aortic surgery (OTAS) and worsens the postoperative prognosis. It remains unclear whether the predictors of AKI following OTAS are different in the patients with or without acute aortic syndrome (AAS).

Methods: Preoperative and intraoperative variables were compared between the patients with or without AKI, and were further analyzed for identifying the potential predictors of postoperative AKI. Subgroup analysis was conducted in the patients with or without AAS, respectively.

Results: AKI after OTAS occurred in 57.6% of the overall cohort, 70.1% of the patients with AAS and 46.7% of the patients without AAS. In the multivariate analysis, history of hypertension (OR 1.011, 95% CI: [1.001–1.022], p = 0.04), preoperative platelet (OR 0.995, 95% CI: [0.991–0.999], p = 0.006) and operation time (OR 1.572, 95% CI: [1.355–1.823], p < 0.001) were identified as independent predictors of postoperative AKI for the overall cohort; CPB time (OR 1.020, 95% CI: [1.009–1.031], p < 0.001) and preoperative LMR (OR 0.823, 95% CI: [0.701–0.966], p = 0.02) as independent predictors for the patients with AAS; age (OR 1.045, 95% CI: [1.015–1.076], p = 0.003), preoperative platelet (OR 0.993, 95% CI: [0.988–0.998], p = 0.04) and operation time (OR 1.496, 95% CI: [1.166–1.918], p = 0.002) as independent predictors for the patients without AAS.

Conclusions: The patients with AAS carry a higher risk for postoperative AKI compared with those without AAS. The predictive factors for postoperative AKI after OTAS are different for AAS- and non-AAS subgroups and operation time, CPB time and preoperative platelet are modifiable predictors of AKI.

Keywords: Acute aortic syndrome, Acute kidney injury, Independent predictor, Open thoracic aortic surgery
Introduction
The AKI complicates 10–70% patients undergoing OTAS, depending on the distinct definitions of AKI [1–7]. This complication predicts a dismal prognosis and increases the postoperative mortality and morbidity. Despite the recent advancements in cardiopulmonary bypass (CPB), anesthesia and intensive care, the incidence of AKI following OTAS remains high [8]. The AKI contemporarily represents a huge challenge for cardiovascular surgeons as no definite therapy has thus been developed. Though renal replacement therapy (RRT) is a feasible therapeutic option, modifying those potential risk factors could fundamentally prevent the occurrence of AKI and improves the short- and long-term outcomes [2, 9–12].

The primary objective of this retrospective cohort study was to clarify that whether different risk factors predict AKI after OTAS in the patients with or without AAS.

Materials and methods
Study design and participants
This single-center retrospective cohort study was approved by the Ethics Committee of Shandong Provincial Hospital and the written informed consent was waived due to the retrospective design. 399 consecutive patients were eventually recruited who underwent the elective or emergent OTAS between January 1, 2015 to December 31, 2018. The patients were excluded from the cohort who died within 72 h after operations or whose preoperative and intraoperative data were insufficient or who had preoperative renal insufficiency or previous renal transplantation (Fig. 1). The study was conducted following the Good Clinical Practice (GCP) as well as principles of the Declaration of Helsinki. The clinical data of those patients were carefully collected from admission to discharge. All the operations were completed by an identical surgical team. In this study, AAS represents a series of acute and catastrophic aortic lesions including acute aortic dissection, intramural hematoma, penetrating aortic ulcer, and rupture of aorta due to aortic aneurysm or trauma. Non-AAS represents the non-acute and non-catastrophic thoracic aortic lesions that require elective surgical treatment. The included 399 patients were divided into the AAS subgroup and non-AAS subgroup for further analysis. Potential demographic or perioperative variables considered associated with postoperative AKI were included on the basis of clinical experiences and literature review.

Definition of AKI following OTAS and postoperative outcomes
The primary outcome of this cohort study was AKI after OTAS. The diagnosis of AKI was established according to the modified Kidney Disease: Improving Global Outcomes guidelines (KDIGO) [13]. The postoperative AKI was defined as an increase of >50% of the baseline within the first 7 days or >0.3 mg/dL (26.5 umol/L) within the first 48 h in the postoperative serum creatinine (Scr). The baseline Scr was ascertained based on the latest preoperative tests. And the AKI was further graded as stage I, II and III according to the KDIGO classification and the patients were categorized in line with their highest levels of postoperative Scr. Besides, the postoperative outcomes attributable to AKI included RRT, length of ICU stay and ICU stay >7 days, intubation time and time >5 days, stroke, redo surgery and in-hospital mortality.

Surgical details
The Surgical details were summarized in the supplementary material.

Statistical analysis
Statistical analysis was performed using SPSS Statistics 25.0. Categorical variables were expressed as frequencies (n) with percentages (%). Continuous variables were expressed as mean ± standard deviation (SD) or median (quartile), depending on the data dispersion. The t-test was used if a continuous variable conformed normal distribution. And non-parametric Mann-Whitney U test was applied if a continuous variable was consistent with skewed distribution. A chi-squared or a Fisher’s exact test was used for categorical variables when necessary. The univariate and multivariate analyses were performed using binary logistic regression analysis. The candidate univariates (with a p valve less than 0.1) as well as those possible predictive variables were included in the multivariate predictive model. And the predictive model was further evaluated using the receiver operating curve (ROC) and the Hosmer-Lemeshow test. Except that the overall cohort were analyzed as above-mentioned, the subgroup analyses were additionally conducted for the patients with or without AAS. All the statistical tests were two-sided and a p valve less than 0.05 was considered statistically significant.

Results
Patient characteristics
A total of 399 patients were enrolled in this retrospective cohort study and the patient characteristics of overall cohort, AAS subgroup and non-AAS subgroup were shown respectively in the supplementary material. The patients were excluded who died within 72 h after operations (n = 4), whose preoperative and intraoperative data were insufficient (n = 3) as well as who had preoperative renal insufficiency and previous renal transplantation (n = 8). The causes of death of these 4 patients included
the refractory low cardiac output syndrome \((n = 2)\), life-threatening major bleeding \((n = 1)\) and malignant arrhythmia \((n = 1)\). The surgical options of overall cohort were presented in the supplementary Table 1. And the surgical options of AAS subgroup and non-AAS subgroup were showed in supplementary Table 2 and supplementary Table 3, respectively.

### Incidence of AKI after open thoracic aortic surgery

#### Postoperative AKI in the overall cohort

According to the modified KDIGO’s Criteria, the incidence of AKI after aortic operation was 57.6\% (230 in 399), among whom 153 patients (38.3\%) met the criteria of stage 1, 49 patients (12.3\%) satisfied the criteria for stage 2 AKI, and 28 patients (7.0\%) reached the stage 3 (Table 1).

#### Postoperative AKI in the patients with AAS

In the subgroup of patients with AAS, the incidence of postoperative AKI was evidently higher than that of the overall cohort \((p < 0.01)\). 131 in 187 (70.1\%) developed the postoperative AKI, among whom 71 patients (38.0\%) met the criteria of stage 1 AKI, and 24 patients (12.8\%) met reached the stage 3 (Table 3).

#### Postoperative AKI in the patients without AAS

Compared with the AAS subgroup, the incidence of postoperative AKI was markedly reduced in the non-AAS subgroup \((p < 0.001)\). Of 212 patients in the non-AAS subgroup, 82 patients (38.7\%) met the criteria of stage 1, 13 patients (6.1\%) reached the criteria for stage 2, 4 patients (1.9\%) were in stage 3 (Table 5).

### Risk factors of postoperative AKI after open thoracic aortic surgery

#### Risk factors of postoperative AKI for the overall cohort

Demographic and perioperative data of patients grouped by the severity of the KDIGO classification were present in Table 1. There were significant statistical differences in a series of variables including age, weight, BMI, history of hypertension, preoperative platelet, lymphocyte, monocyte, neutrophil and several other laboratory variables, Marfan syndrome, aortic dissection (as well as the Stanford type-A aortic dissection), intraoperative infusion of erythrocytes, fresh frozen plasma and platelets, combined valvular surgery and all the surgical data (Table 1).

The incidences of CRRT, ICU stay > 7 days, intubation time > 5 days, stroke, redo surgery and in-hospital mortality were all significantly higher among the patients with AKI than those without AKI. The time of ICU stay
| Table 1 Characteristics of the Overall Cohort |
|----------------------------------------------|
|                                              |
| **Patient population (n)**                   |
| Stage 1 | Stage 2 | Stage 3 |
| **No AKI** | 169 | 153 | 49 | 28 |
| **AKI** | 171 | 156 | 50 | 29 |
| **P1 Value** | 0.05 | 0.02 | 0.002 | 0.0002 |
| **P2 Value** | 0.2 | 0.005 | 0.0001 | 0.0001 |
| **Demographic data**                          |
| Age (y) | 52.0 (18.0) | 54.0 (16.5) | 50.0 (13.0) | 41.5 (17.5) | 0.9 | 0.004 |
| **Sex, male (n)** | 112 (66.3%) | 116 (75.8%) | 34 (69.4%) | 21 (75.0%) | 0.08 | 0.3 |
| **Height (cm)** | 170.0 (13.0) | 170.0 (8.5) | 170.0 (14.0) | 169.0 (10.0) | 0.7 | 1.0 |
| **Weight (kg)** | 70.0 (16.0) | 72.0 (18.0) | 74.0 (24.0) | 75.0 (20.0) | 0.002 | 0.02 |
| **BMI (kg/m²)** | 24.6 (5.1) | 25.7 (5.8) | 25.2 (4.9) | 27.4 (5.8) | 0.003 | 0.009 |
| **Medical history**                           |
| **Diabetes (n)** | 4 (2.4%) | 4 (2.6%) | 3 (6.1%) | 1 (3.6%) | 0.5 | 0.6 |
| **Hypertension (n)** | 74 (43.8%) | 85 (55.6%) | 34 (69.4%) | 23 (82.1%) | < 0.001 | < 0.001 |
| **Chronic obstructive pulmonary disease (n)** | 4 (2.4%) | 6 (3.9%) | 1 (2.0%) | 0 (0.0%) | 0.7 | 0.6 |
| **Previous myocardial infarction (n)** | 1 (0.6%) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 0.7 | 0.7 |
| **Peripheral vascular disease (n)** | 13 (7.7%) | 11 (7.2%) | 5 (10.2%) | 1 (3.6%) | 0.9 | 0.8 |
| **Smoking (n)** | 57 (33.7%) | 59 (38.6%) | 19 (38.8%) | 12 (42.9%) | 0.3 | 0.7 |
| **Preoperative laboratory tests**              |
| **Platelet (10⁹/L)** | 197.0 (71.0) | 186.5 (71.8) | 199.0 (65.5) | 166.5 (68.3) | 0.006 | 0.01 |
| **Lymphocyte (10⁹/L)** | 1.63 (0.74) | 1.58 (0.90) | 1.18 (0.72) | 1.48 (0.90) | 0.004 | 0.001 |
| **Monocyte (10⁹/L)** | 0.44 (0.30) | 0.51 (0.40) | 0.79 (0.78) | 0.91 (0.70) | < 0.001 | < 0.001 |
| **Neutrophil (10⁹/L)** | 4.22 (2.95) | 4.86 (4.30) | 7.51 (5.64) | 10.1 (5.3) | < 0.001 | < 0.001 |
| **Hyperlipidemia (n)** | 55 (34.4%) | 44 (31.0%) | 7 (14.9%) | 10 (43.5%) | 0.2 | 0.04 |
| **Retinol binding protein (mg/L)** | 35.7 (16.2) | 37.8 (18.7) | 26.4 (24.7) | 37.3 (22.5) | 0.7 | 0.007 |
| **Urinary protein**                           |
| +−/−  | 17 (11.6%) | 25 (18.8%) | 10 (23.8%) | 4 (20.0%) | 0.05 | 0.2 |
| +     | 14 (9.5%) | 20 (15.0%) | 11 (26.2%) | 8 (40.0%) | 0.01 | 0.005 |
| ++    | 1 (0.7%) | 2 (1.5%) | 2 (4.8%) | 1 (5.0%) | 0.2 | 0.3 |
| INR   | 1.04 (0.12) | 1.04 (0.1) | 1.09 (0.15) | 1.10 (0.2) | 0.05 | 0.02 |
| **Preoperative renal function**               |
| **Preoperative SCR (µmol/L)** | 70.4 (21.79) | 73.6 (23.1) | 66.0 (26.3) | 76.0 (45.7) | 0.3 | 0.07 |
| > 106 (n) | 11 (6.5%) | 13 (8.5%) | 4 (8.2%) | 8 (28.6%) | 0.1 | 0.002 |
| **eGFR (mL/min/1.73 m²)** | 99.8 (22.0) | 97.2 (21.2) | 103.4 (18.2) | 94.4 (39.5) | 0.2 | 0.08 |
| **Preoperative cardiovascular status**         |
| **Marfan syndrome (n)** | 14 (8.3%) | 3 (2.0%) | 1 (2.0%) | 1 (3.6%) | 0.005 | 0.04 |
| **Aortic dissection (n)** | 56 (33.1%) | 71 (46.4%) | 36 (73.5%) | 24 (85.7%) | < 0.001 | < 0.001 |
| **Stanford type-A aortic dissection (n)** | 53 (31.4%) | 71 (46.4%) | 34 (69.4%) | 24 (85.7%) | < 0.001 | < 0.001 |
| **Intraoperative blood product use**           |
| **Erythrocytes (u)** | 2.0 (2.0) | 4.0 (3.9) | 4.0 (6.0) | 4.0 (4.5) | 0.001 | < 0.001 |
| **Fresh frozen plasma (mL)** | 400.0 (200.0) | 400.0 (150.0) | 400.0 (375.0) | 600.0 (500.0) | 0.06 | 0.002 |
| **Platelets (u)** | 1.0 (0.0) | 1.0 (1.0) | 1.0 (1.0) | 2.0 (1.0) | 0.002 | < 0.001 |
| **Surgical details**                          |
| **Involving the aortic arch (n)** | 79 (46.7%) | 97 (63.4%) | 38 (77.6%) | 26 (92.9%) | < 0.001 | < 0.001 |
| **Involving the descending aorta (n)** | 43 (25.4%) | 60 (39.2%) | 33 (67.3%) | 24 (85.7%) | < 0.001 | < 0.001 |
| **CPB duration(min)** | 133.0 (75.5) | 165.0 (79.0) | 201.0 (67.5) | 220.0 (52.0) | < 0.001 | < 0.001 |
| **DHCA or MHCA (n)** | 58 (34.3%) | 76 (49.7%) | 34 (69.4%) | 25 (89.9%) | < 0.001 | < 0.001 |
| **Aortic cross-clamp time (min)** | 86.0 (27.0) | 90.0 (31.0) | 96.0 (32.0) | 113.0 (32.0) | < 0.001 | < 0.001 |
| **Operation time (h)** | 6.0 (2.0) | 7.0 (2.0) | 8.5 (2.0) | 9.0 (2.5) | < 0.001 | < 0.001 |
| **Combined surgery**                          |
| **Valvular surgery (n)** | 94 (55.6%) | 67 (43.8%) | 10 (20.4%) | 3 (10.7%) | < 0.001 | < 0.001 |
and intubation also markedly increased in the patients with AKI compared those without AKI (Table 1).

In the univariate analysis of risk factors for the overall cohort, body weight, history of hypertension, Marfan syndrome, preoperative platelet, lymphocyte, monocyte and neutrophil, neutrophil to lymphocyte ratio (NLR), lymphocyte to monocyte ratio (LMR), preoperative urinary protein positive (+, ++), Marfan syndrome, aortic dissection (Stanford type-A aortic dissection), intraoperative fresh frozen plasma use, intraoperative involvement of aortic arch and descending aorta, CPB time, aortic cross-clamp time, operation time, DHCA or MHCA and concurrent valve surgery were candidate variables (Table 2).

**Risk factors of postoperative AKI for the patients with AAS**
For the subgroup of patients with AAS, there existed significant statistical differences in those variables including male gender, weight, history of hypertension, preoperative lymphocyte, monocyte and neutrophil and several other laboratory variables, CPB time, aortic cross-clamp time, operation time and combined CABG (Table 3).

Similarly as above, the proportions of CRRT, ICU stay > 7 days, intubation time > 5 days, stroke, redo surgery and in-hospital mortality were all higher in the AKI group. Consistently, the durations of ICU stay and intubation were evidently increased in the patients with AKI in comparison with those without AKI (Table 3).

When it comes to the univariate analysis of risk factors for the AAS cohort, male gender, weight, preoperative lymphocyte, monocyte, neutrophil, NLR, LMR, CPB time, aortic cross-clamp time and operation time were included in the list of plausible variables (Table 4).

**Risk factors of postoperative AKI for the patients without AAS**
For the non-AAS subgroup, those variables reached statistical significance that include age, history of hypertension, preoperative platelet and eGFR, previous cardiovascular surgery, Marfan syndrome, intraoperative perfusion of fresh frozen plasma and platelets, operation involving the descending aorta, CPB time, aortic cross-clamp time, DHCA or MHCA and operation time (Table 5).

For the patients in the non-AAS subgroup, the rates of CRRT, ICU stay > 7 days, intubation time > 5 days and in-hospital mortality were evidently enhanced when compared to those without AKI. And the ICU length of stay also elevated in the patients with AKI (Table 5).

As for the univariate analysis of risk factors for the non-AAS cohort, several potential risk factors have been identified that consist of age, preoperative platelet and platelet to lymphocyte ratio (PLR), CPB time and operation time (Table 6).

**The establishment of predictive model for postoperative AKI**

**Predictive model for postoperative AKI in the overall cohort**
Those independent predictors of postoperative AKI after OTAS included history of hypertension (OR 1.011, 95% CI: [1.001–1.022], p = 0.04), preoperative platelet (OR 0.995, 95% CI: [0.991–0.999], p = 0.006) and operation time (OR 1.572, 95% CI: [1.355–1.823], p < 0.001). The equation obtained by binary Logistic regression analysis was as follows: \[ Y = 0.011 \times \text{history of hypertension} - 0.005 \times \text{preoperative platelet} + 0.452 \times \text{operation time} - 4.814. \] The predictive model was evaluated by the ROC curve. The area under a curve (AUC) of the ROC curve would be...
was 0.750 ($p < 0.001, 95\%CI: 0.702–0.798$) (Fig. 2). When the maximum value of the Youden index was 0.409, at this time $Y = 0.031$, the sensitivity of the model was 76.0% and the specificity was 64.9%.

**Predictive model for postoperative AKI in the patients with AAS**

For the patients with AAS, CPB time (OR 1.020, 95\% CI: [1.009–1.031], $p < 0.001$) and preoperative LMR (OR 0.823, 95\% CI: [0.701–0.966], $p = 0.02$) independently predicted the incidence of postoperative AKI. The equation obtained by binary Logistic regression analysis was: $Y = 0.020 \times \text{CPB time} - 0.195 \times \text{LMR} - 5.601$. The AUC of ROC curve (see Fig. 3) was 0.784 ($p < 0.001, 95\%CI: 0.714–0.855$) (Fig. 3). When the maximum value of the Youden index reached 0.467, at this time $Y = 1.056$, the sensitivity of the model was 66.7% and the specificity was 80.0%.

**Predictive model for postoperative AKI in the patients without acute aortic syndrome**

For the patients without AAS, age (OR 1.045, 95\% CI: [1.015–1.076], $p = 0.003$), preoperative platelet (OR 0.993, 95\% CI: [0.988–0.998], $p = 0.04$) and operation time (OR 1.496, 95\% CI: [1.166–1.918], $p = 0.002$) independently predicted the incidence of postoperative AKI. The equation obtained by binary Logistic regression analysis was: $Y = 0.044 \times \text{age} - 0.006 \times \text{preoperative platelet} + 0.403 \times \text{operation time} - 3.751$. The AUC of ROC curve (see Fig. 4) was 0.719 ($p < 0.001, 95\%CI: 0.651–0.787$). When the maximum value of the Youden index reached 0.467, at this time $Y = 1.0564$, the sensitivity of the model was 81.4% and the specificity was 52.2%.

**Discussion**

Prospective or retrospective studies have previously found that the incidence of AKI after thoracic aortic surgery is approximately 18–67%, depending on the definition of AKI [1–7]. Some of these prior papers recruited a highly heterogeneous group of patients, regardless of disease types and surgical options. And the other papers were designed to study on a specific group of patients, such as the patients undergoing elective or emergent OTAS, overweight patients who underwent total aorta replacement (TAR) combined with frozen

| Table 2 | Univariate Analysis of Risk Factors for the Overall Cohort |
|----------------|----------------|----------------|----------------|
| Variable        | Odds Ratio | 95\% Confidence Interval | $P$ Value |
| Age (y)         | 1.01       | 0.99–1.02          | 0.6         |
| Sex, male       | 1.48       | 0.95–2.28          | 0.08        |
| Weight          | 1.02       | 1.01–1.04          | 0.006       |
| Hypertension    | 2.07       | 1.38–3.10          | < 0.001     |
| Preoperative platelet | 1.00      | 0.99–1.00          | 0.006       |
| Preoperative lymphocyte | 0.64    | 0.46–0.88          | 0.007       |
| Preoperative monocyte | 3.76    | 2.02–7.00          | < 0.001     |
| Preoperative neutrophil | 1.16    | 1.08–1.23          | < 0.001     |
| NLR             | 1.17       | 1.10–1.25          | < 0.001     |
| LMR             | 0.88       | 0.81–0.96          | 0.003       |
| Preoperative urinary protein + or ++ | 2.43   | 1.30–4.53          | 0.005       |
| Marfan syndrome | 0.25       | 0.09–0.70          | 0.008       |
| Aortic dissection| 2.67       | 1.77–4.04          | < 0.001     |
| Stanford type-A aortic dissection | 2.80   | 1.84–4.24          | < 0.001     |
| Intraoperative fresh frozen plasma use | 1.00   | 1.00–1.00          | 0.01        |
| Involving the aortic arch | 2.66   | 1.76–4.02          | < 0.001     |
| Involving the descending aorta | 3.03   | 1.97–4.67          | < 0.001     |
| CPB duration    | 1.01       | 1.01–1.02          | < 0.001     |
| DHCA or MHCA    | 2.72       | 1.80–4.11          | < 0.001     |
| Aortic cross-clamp time | 1.02  | 1.01–1.02          | < 0.001     |
| Operation time  | 1.63       | 1.41–1.89          | < 0.001     |
| Combined valvular surgery | 0.43  | 0.28–0.64          | < 0.001     |

Abbreviations: NLR Neutrophil to Lymphocyte Ratio, LMR Lymphocyte to Monocyte Ratio, SCr Serum Creatinine, CPB Cardiopulmonary Bypass, DHCA Deep Hypothermia and Circulatory Arrest, MHCA Median Hypothermia and Circulatory Arrest.
# Table 3 Characteristics of the patients with acute aortic syndrome

|                  | No AKI | AKI Stage | P1 Value | P2 Value |
|------------------|--------|-----------|----------|----------|
|                  |        | 1         | 2         | 3         |
| Patient population (n) | 56     | 71        | 36        | 24       |
| **Demographic data** |        |           |          |          |
| Age (y)          | 48.0 (16.5) | 48.0 (15.0) | 48.0 (13.5) | 41.0 (8.3) | 0.2 | 0.07 |
| Sex, male (n)    | 31 (55.4%) | 52 (73.2%) | 24 (66.7%) | 18 (75.0%) | 0.03 | 0.1 |
| Height (cm)      | 170.0 (12.8) | 171.0 (7.0) | 172.0 (10.5) | 170.0 (13.0) | 0.4 | 0.5 |
| Weight (kg)      | 71.9 ± 10.2 | 78.0 ± 12.6 | 77.1 ± 14.4 | 77.8 ± 13.4 | 0.003 | 0.07 |
| BMI (kg/m²)      | 25.5 ± 2.8 | 25.7 ± 5.6 | 26.4 ± 3.9 | 28.2 ± 3.7 | 0.3 | 0.2 |
| **Medical history** |        |           |          |          |
| Diabetes (n)     | 2 (3.6%) | 1 (1.4%) | 2 (5.6%) | 1 (4.2%) | 0.9 | 0.7 |
| Hypertension (n) | 38 (67.9%) | 46 (64.8%) | 30 (83.3%) | 23 (95.8%) | 0.3 | 0.009 |
| Chronic obstructive pulmonary disease (n) | 1 (1.8%) | 1 (1.4%) | 0 (0.0%) | 0 (0.0%) | 0.5 | 0.8 |
| Peripheral vascular disease (n) | 4 (7.1%) | 5 (7.0%) | 4 (11.1%) | 1 (4.2%) | 0.9 | 0.8 |
| Smoking (n)      | 17 (30.4%) | 21 (29.6%) | 13 (36.1%) | 9 (37.5%) | 0.7 | 0.8 |
| **Preoperative laboratory tests** |        |           |          |          |
| Platelet (10⁹/L) | 195.5 (106.0) | 191.0 (82.0) | 191.0 (83.3) | 177.0 (65.5) | 0.1 | 0.2 |
| Lymphocyte (10⁹/L) | 1.39 (0.75) | 1.24 (0.81) | 1.13 (0.59) | 1.41 (0.99) | 0.01 | 0.03 |
| Monocyte (10⁹/L) | 0.70 (0.56) | 0.67 (0.60) | 0.89 (0.63) | 0.92 (0.82) | 0.03 | 0.03 |
| Neutrophil (10⁹/L) | 7.39 ± 3.60 | 7.76 ± 3.41 | 8.97 ± 3.33 | 10.52 ± 3.76 | 0.04 | 0.001 |
| Hyperlipidemia (n) | 14 (25.0%) | 16 (22.5%) | 3 (8.3%) | 9 (37.5%) | 0.6 | 0.02 |
| Retinol binding protein (mg/L) | 276.0 (24.1) | 279.0 (17.1) | 212.0 (16.4) | 373.0 (25.2) | 0.7 | 0.02 |
| **Preoperative renal function** |        |           |          |          |
| Dissection involving renal artery (n) | 4 (7.1%) | 6 (8.5%) | 4 (11.1%) | 5 (20.8%) | 0.4 | 0.3 |
| Preoperative SCr (μmol/L) | 65.5 (31.0) | 75.0 (24.4) | 68.5 (36.2) | 81.1 (47.9) | 0.2 | 0.2 |
| > 106 (n)       | 6 (10.7%) | 10 (14.1%) | 4 (11.1%) | 7 (29.2%) | 0.3 | 0.2 |
| **Surgical details** |        |           |          |          |
| Involving the aortic arch (n) | 50 (89.3%) | 66 (93.0%) | 35 (97.2%) | 24 (100.0%) | 0.1 | 0.2 |
| Involving the descending aorta (n) | 43 (76.8%) | 59 (83.1%) | 33 (91.7%) | 23 (95.8%) | 0.06 | 0.1 |
| CPB duration (min) | 188.0 (38.8) | 201.0 (44.0) | 222.0 (51.8) | 235.0 (60.0) | < 0.001 | < 0.001 |
| DHCA or MHCA (n) | 48 (85.7%) | 65 (91.5%) | 34 (94.4%) | 23 (95.8%) | 0.1 | 0.4 |
| Aortic cross-clamp time (min) | 94.5 (21.8) | 99.0 (31.0) | 96.0 (32.5) | 110.0 (29.0) | 0.02 | 0.02 |
| Operation time (h) | 7.0 (1.5) | 8.0 (1.5) | 8.5 (1.9) | 9.0 (2.5) | < 0.001 | < 0.001 |
| **Combined surgery** |        |           |          |          |
| CABG (n)         | 1 (1.8%) | 2 (2.8%) | 0 (0.0%) | 3 (12.5%) | 0.5 | 0.04 |
| Valvular surgery (n) | 8 (14.3%) | 7 (9.9%) | 1 (2.8%) | 0 (0.0%) | 0.07 | 0.1 |
| **Outcomes** |        |           |          |          |
| Renal replacement therapy (n) | 0 (0.0%) | 0 (0.0%) | 0 (0.0%) | 11 (45.8%) | 0.03 | < 0.001 |
| Length of ICU stay (day) | 5.0 (3.8) | 5.0 (2.0) | 5.0 (4.0) | 12.0 (11.5) | 0.02 | < 0.001 |
| > 7 d (n)       | 17 (30.4%) | 16 (22.5%) | 13 (36.1%) | 22 (91.7%) | 0.3 | < 0.001 |
| Intubation time (h) | 190.0 (20.0) | 240.0 (32.0) | 405.0 (75.8) | 1475.0 (81.0) | < 0.001 | < 0.001 |
| > 5 d (n)       | 4 (7.1%) | 4 (5.6%) | 5 (13.9%) | 17 (70.8%) | 0.03 | < 0.001 |
| Redo surgery (n) | 2 (3.6%) | 2 (2.8%) | 5 (13.9%) | 6 (25.0%) | 0.1 | 0.002 |
| In-hospital mortality (n) | 1 (1.8%) | 1 (1.4%) | 0 (0.0%) | 7 (29.2%) | 0.2 | < 0.001 |

**Abbreviations:** BMI body mass index, SCr Serum Creatinine, CPB Cardiopulmonary Bypass, DHCA Deep Hypothermia and Circulatory Arrest, MHCA Median Hypothermia and Circulatory Arrest, CABG Coronary Artery Bypass Graft

**NOTE.** The categorical variables in the table are presented by the number of cases (with percentage) and the continuous variables are expressed by the median (with interquartile range) or mean (with standard deviation).

* P1 Value: Compare the patients without AKI and all patients with AKI. P1 values* were the results of unpaired t-test or Mann-Whitney U test for continuous variables, and χ² test or Fisher’s exact test for categorical variables.

* P2 Value: Compare patients within four groups (without AKI and patients with stage 1, 2 and 3 AKI). P2 values* were the results of one-way analysis of variance or Kruskal-Wallis test for continuous variables, and χ² test or Fisher’s exact test for categorical variables.
elephant trunk (FET) implantation, patients receiving surgical treatment for type A aortic dissection and so on. We believe that the deviation of AKI incidence and predictive factors from various studies on OTAS was to a large extent attributable to the heterogeneity of recruited subjects including ethnicity, disease types and surgical procedures and etc. 

According to our search result, the incidence of postoperative AKI following OTAS has been rarely studied in the patients with AAS and our work was among the first to focus on this special subgroup. The definition of AAS comprises of a series of acute and catastrophic aortic lesions including acute aortic dissection, intramural hematoma, penetrating aortic ulcer, and rupture of aorta due to aortic aneurysm or trauma [14]. For most heart centers across the globe including ours, emergency aortic surgery is indicated for the patients with AAS. Even for the patients at advanced age and with co-morbidities, urgent surgery is highly recommended, and for the most circumstances is not surgically contraindicated. As expected, the predictive models for AKI were different between the AAS and non-AAS subgroups. Our results were consistent with several previous studies that CPB time instead of DHCA time were statistically linked with postoperative AKI [7, 15]. It is hypothesized by Sun and this team that DHCA

| Variable                        | Odds Ratio | 95% Confidence Interval | P Value |
|---------------------------------|------------|-------------------------|---------|
| Age (y)                         | 0.98       | 0.95–1.01               | 0.2     |
| Sex, male                       | 2.05       | 1.07–3.92               | 0.03    |
| Weight                          | 1.04       | 1.01–1.07               | 0.009   |
| Preoperative platelet           | 1.00       | 0.99–1.00               | 0.06    |
| Preoperative lymphocyte         | 0.61       | 0.37–1.01               | 0.05    |
| Preoperative monocyte           | 2.42       | 1.10–5.36               | 0.03    |
| Preoperative neutrophil         | 1.10       | 1.01–1.21               | 0.04    |
| NLR                             | 1.16       | 1.06–1.28               | 0.002   |
| LMR                             | 0.77       | 0.64–0.93               | 0.007   |
| Preoperative NYHA class III or IV | 0.39   | 0.14–1.03               | 0.06    |
| Involving the descending aorta  | 2.17       | 0.97–4.89               | 0.06    |
| CPB duration                    | 1.02       | 1.01–1.03               | < 0.001 |
| DHCA or MHCA                    | 2.26       | 0.82–6.20               | 0.1     |
| Aortic crossclamp time          | 1.02       | 1.00–1.04               | 0.01    |
| Operation time                  | 1.63       | 1.26–2.10               | < 0.001 |
| Combined valvular surgery       | 0.39       | 0.14–1.1               | 0.08    |

Abbreviations: NLR Neutrophil to Lymphocyte Ratio, LMR Lymphocyte to Monocyte Ratio, CPB Cardiopulmonary Bypass, DHCA Deep Hypothermia and Circulatory Arrest, MHCA Median Hypothermia and Circulatory Arrest
Table 5 Characteristics of the patients without acute aortic syndrome

| Patient population (n) | No AKI | AKI Stage | P1 Value* | P2 Value* |
|------------------------|--------|-----------|-----------|-----------|
| 113                    | 82     | 13        | 4         |           |

Demographic data

| Age (y) | Sex, male (n) | Height (cm) | Weight (kg) | BMI (kg/m²) |
|---------|---------------|-------------|-------------|-------------|
| 53.0 (17.5) | 81 (71.7%) | 170.0 (14.0) | 67.0 (16.0) | 24.2 (5.3) |
| 60.0 (11.0) | 64 (78.0%) | 168.0 (10.5) | 69.1 (15.6) | 25.0 (5.7) |
| 52.0 (14.0) | 10 (76.9%) | 165.0 (15.0) | 66.0 (15.0) | 22.9 (5.0) |
| 55.0 (19.5) | 3 (75.0%) | 166.5 (4.5) | 62.0 (17.0) | 22.8 (5.6) |

Medical history

| Diabetes (n) | Hypertension (n) | Chronic obstructive pulmonary disease (n) | Previous myocardial infarction (n) | Peripheral vascular disease (n) | Smoking (n) |
|--------------|------------------|----------------------------------------|----------------------------------|-------------------------------|-------------|
| 2 (1.8%)     | 36 (31.9%)       | 3 (2.7%)                               | 1 (0.9%)                         | 9 (8.0%)                      | 40 (35.4%)  |
| 3 (3.7%)     | 39 (47.6%)       | 5 (6.1%)                               | 0 (0.0%)                         | 6 (7.3%)                      | 38 (46.3%)  |
| 1 (7.7%)     | 4 (38.8%)        | 1 (7.7%)                               | 0 (0.0%)                         | 1 (7.7%)                      | 6 (46.2%)   |
| 0 (0.0%)     | 0 (0.0%)         | 0 (0.0%)                               | 0 (0.0%)                         | 0 (0.0%)                      | 3 (75.0%)   |

Preoperative laboratory tests

| Platelet (10⁹/L) | Preoperative renal function |
|------------------|-----------------------------|
| 197.0 (57.5)     | 99.8 (16.1)                 |
| 183.0 (58.0)     | 95.9 (18.1)                 |
| 203.0 (54.5)     | 101.7 (16.4)                |
| 137.5 (109.3)    | 97.2 (37.6)                 |

Preoperative cardiovascular status

| Previous cardiovascular surgery (n) | LVEF (%) | Marfan syndrome (n) |
|-----------------------------------|----------|---------------------|
| 2 (1.8%)                          | 58.0 (8.0) | 11 (9.7%)         |
| 1 (1.2%)                          | 60.0 (4.5) | 2 (2.4%)          |
| 0 (0.0%)                          | 52.5 (17.8) | 1 (7.7%)         |
| 1 (25.0%)                         | 59.0 (11.8) | 0 (0.0%)          |

Intraoperative blood product use

| Erythrocytes (u) | Fresh frozen plasma (ml) | Platelets (u) |
|------------------|--------------------------|---------------|
| 2.0 (3.0)        | 2.0 (4.0)                | 1.0 (1.0)     |
| 2.0 (4.0)        | 3.0 (3.0)                | 1.0 (1.0)     |
| 4.0 (6.0)        | 4.0 (6.0)                | 2.0 (1.0)     |

Surgical details

| Involving the aortic arch (n) | Involving the descending aorta (n) | CPB duration(min) | DHCA or MHCA (n) | Aortic cross-clamp time (min) | Operation time (h) | Combined surgery |
|-------------------------------|----------------------------------|-------------------|------------------|-------------------------------|-------------------|-----------------|
| 29 (25.7%)                    | 0 (0.0%)                         | 117.5 (41.0)      | 10 (8.8%)        | 81.0 (27.8)                  | 5.0 (1.0)         | CABG (n)         |
| 31 (27.8%)                    | 0 (0.0%)                         | 131.0 (50.5)      | 11 (13.4%)       | 83.0 (31.3)                  | 6.0 (1.5)         | 8 (7.1%)        |
| 31 (27.8%)                    | 0 (0.0%)                         | 131.0 (50.5)      | 11 (13.4%)       | 83.0 (31.3)                  | 7.0 (2.3)         | 11 (13.4%)      |
| 3 (23.1%)                     | 0 (0.0%)                         | 101.7 (16.4)      | 10 (8.8%)        | 81.0 (27.8)                  | 7.0 (2.3)         | 2 (15.4%)       |
| 2 (50.0%)                     | 1 (25.0%)                        | 97.2 (37.6)       | 10 (8.8%)        | 81.0 (27.8)                  | 8.5 (2.5)         | 1 (25.0%)       |
| 0.09                          | 0.1                              | 0.005             | 0.03             | 0.08                          | < 0.001           | 0.09            |
| 0.2                           | < 0.001                          | 0.003             | 0.03             | 0.04                          | < 0.001           | 0.3             |

Outcomes

| Renal replacement therapy (n) | ICU length of stay (day) | > 7 d (n) | Intubation time (h) | > 5 d (n) | In-hospital mortality (n) |
|------------------------------|--------------------------|----------|--------------------|----------|--------------------------|
| 0 (0.0%)                    | 0 (0.0%)                 | 0 (0.0%) | 0 (0.0%)           | 0 (0.0%) | 0 (0.0%)                 |
| 0 (0.0%)                    | 0 (0.0%)                 | 0 (0.0%) | 0 (0.0%)           | 0 (0.0%) | 0 (0.0%)                 |
| 0 (0.0%)                    | 0 (0.0%)                 | 0 (0.0%) | 0 (0.0%)           | 0 (0.0%) | 0 (0.0%)                 |
| 0 (0.0%)                    | 0 (0.0%)                 | 0 (0.0%) | 0 (0.0%)           | 0 (0.0%) | 0 (0.0%)                 |
| 0.09                         | 0.3                      | 0.02     | 0.03               | 0.1      | 0.5                      |
| < 0.001                     | < 0.001                  | < 0.001  | 0.001              | 0.06     | < 0.001                  |

Abbreviations: BMI body mass index, INR International Normalized Ratio, eGFR Estimated Glomerular Filtration Rate, LVEF Left Ventricular Ejection Fraction, CPB Cardiopulmonary Bypass, DHCA Deep Hypothermia and Circulatory Arrest, MHCA Median Hypothermia and Circulatory Arrest, CABG Coronary Artery Bypass Graft

NOTE. The categorical variables in the table are presented by the number of cases (with percentage) and the continuous variables are expressed by the median (with interquartile range) or mean (with standard deviation)

* P1 Value: Compare the patients without AKI and all patients with AKI. P1 values* were the results of unpaired t-test or Mann-Whitney U test for continuous variables, and χ² test or Fisher’s exact test for categorical variables

* P2 Value: Compare patients within four groups (without AKI and patients with stage 1, 2 and 3 AKI). P2 values# were the results of one-way analysis of variance or KruskalWallis test for continuous variables, and χ² test or Fisher’s exact test for categorical variables
could significantly extend the CPB time, which is likely to be counterbalanced by the protective effects of DHCA on renal function. Additionally, the preoperative LMR might also function as a novel bio-marker for predicting postoperative AKI following OTAS, and such report has not been published so far and it awaits further investigation.

Our team also analyzed the data from the non-AAS subgroup in whom elective OTAS were performed. Englberger and his colleagues carried out a retrospective study with a larger sample size on elective OTAS [2]. However, our work was the first to investigate the AKI following elective OTAS in Chinese ethnicity though the sample size was relatively small. Besides, the results of diagnostic test suggested that our predictive model for AKI after OTAS has a good predictive ability, with its sensitivity and specificity to be further improved in the future.

Table 6 Univariate Analysis of Risk Factors for the patients without acute aortic syndrome

| Variable            | Odds Ratio | 95% Confidence Interval | P Value |
|---------------------|------------|-------------------------|---------|
| Age (y)             | 1.05       | 1.02–1.08               | < 0.001 |
| Sex, male           | 1.38       | 0.74–2.59               | 0.3     |
| Hypertension        | 1.64       | 0.94–2.88               | 0.08    |
| Smoking             | 1.65       | 0.95–2.86               | 0.08    |
| Preoperative platelet | 0.99     | 0.99–1.00               | 0.02    |
| PLR                 | 0.99       | 0.99–1.00               | 0.05    |
| Preoperative eGFR   | 0.98       | 0.97–1.00               | 0.06    |
| Marfan syndrome     | 0.29       | 0.08–1.07               | 0.06    |
| Involving the aortic arch | 1.66  | 0.92–2.98               | 0.09    |
| CPB duration        | 1.01       | 1.00–1.02               | 0.01    |
| Operation time      | 1.56       | 1.22–1.99               | < 0.001 |

Abbreviations: PLR Platelet to Lymphocyte Ratio, eGFR Estimated Glomerular Filtration Rate, CPB Cardiopulmonary Bypass
Conclusions
The patients with AAS have a higher risk of developing postoperative AKI after OTAS compared with those without AAS. The predictive factors for postoperative AKI following OTAS vary between AAS and non-AAS subgroups. Operation time, CPB time and preoperative platelet are modifiable predictors of AKI.

Supplementary information
Supplementary information accompanies this paper at https://doi.org/10.1186/s13019-020-01257-1.

Additional file 1.
Additional file 2. Supplementary Table 1 Surgical options of the overall cohort
Additional file 3. Supplementary Table 2 Surgical options of AAS patient
Additional file 4. Supplementary Table 3 Surgical options of non-AAS patients

Abbreviations
AKI: Acute kidney injury; OTAS: Open thoracic aortic surgery; AAS: Acute aortic syndrome; CPB: Cardiopulmonary bypass; RRT: Renal replacement therapy; GCP: Good Clinical Practice; KDIGO: Kidney Disease: Improving Global Outcomes guidelines; Scr: Serum creatinine; SD: Standard deviation; ROC: Receiver operating curve; NLR: Neutrophil to lymphocyte ratio; LMR: Lymphocyte to monocyte ratio; PLR: Platelet to lymphocyte ratio; TAR: Total aorta replacement; FET: Frozen elephant trunk; SIRS: Systemic inflammation response syndrome

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Authors' contributions
YC and XM designed the research. XM, JL, YY, DZ, SC and HM analyzed the data. ZW, HZ and CZ were responsible for data collection and analysis, decision to publish, or preparation of the manuscript.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate
This single-center retrospective cohort study was approved by the Ethics Committee of Shandong Provincial Hospital and the written informed consent was waived due to the retrospective design.

Consent for publication
Consents for publication were obtained from all individuals involved in our study.

Competing interests
The authors declare that they have no competing interests.

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