# Risk of fluid accumulation after cardiac surgery



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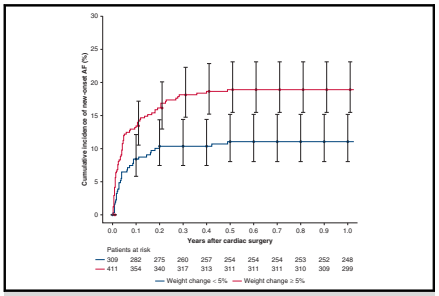
## ABSTRACT

**Objective:** Patients undergoing heart surgery are at high risk of postoperative fluid accumulation due to long procedures and cardiopulmonary bypass. In the present study, we sought to investigate the prevalence of postoperative fluid accumulation and its relation to adverse events in patients undergoing cardiac surgery.

**Methods:** CAREBANK is prospective, single-center cohort study focusing on the adverse events after cardiac surgery. The study population was divided into 2 groups based on 5% postoperative weight gain. All the in-hospital adverse events are registered on the database. The end points of the present study were length of hospital stay, length of intensive care unit stay, occurrence of new-onset atrial fibrillation after hospital major bleeding episodes major cardiac events, cerebrovascular events, and death. Three-month and 1-year follow-up data also include all major adverse events.

**Results:** Altogether 1001 adult cardiac surgery patients were enrolled. The most frequent operations were coronary artery bypass grafting (56.3%). Five hundred fifty-four out of 939 (59.0%) patients had ≥5% weight gain during index hospitalization. Patients with a weight gain ≥5% were more likely to be women, have lower body mass index, had heart failure, and more often had preoperative atrial fibrillation. In-hospital period fluid accumulation was associated with reoperation due bleeding and longer total hospital stay. At 3 months' follow-up, weight gain 5% or more was associated with increased occurrence of new-onset atrial fibrillation, this was not reflected in the occurrence of strokes, transient ischemic attacks, or myocardial infarctions.

**Conclusions:** Postoperative fluid excess is associated with adverse outcomes in cardiac surgery. Women, low-weight patients, and patients with cardiac failure or atrial fibrillation are prone to perioperative fluid accumulation. (JTCVS Open 2023;16:602-9)




**Cumulative incidence of new-onset AF during the first postoperative year.**

### CENTRAL MESSAGE

The results of our study suggest that fluid therapy for patients undergoing cardiac surgery should be more individualized, especially in certain subgroups such as patients with low BMI, women, and patients with heart failure or AF, as well as procedures with long cardiopulmonary bypass times.

### PERSPECTIVE

Patients undergoing heart surgery are at high risk of postoperative fluid accumulation due to long and complex procedures and the use of cardiopulmonary bypass. Our study indicates that weight gain early after cardiac surgery is associated with adverse postoperative events and supports that fluid therapy for patients undergoing cardiac surgery should be more individualized.

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**Abbreviations and Acronyms**

AF = atrial fibrillation
BARC = Bleeding Academic Research Consortium
BMI = body mass index
CABG = coronary artery bypass grafting
CPB = cardiopulmonary bypass
ECG = electrocardiogram
ICU = intensive care unit
TIA = transient ischemic attack

Patients undergoing heart surgery are at high risk of postoperative fluid accumulation due to cardiopulmonary bypass (CPB), cardioplegia administration, and treatment for surgical bleeding, as well as maintenance of adequate perfusion pressure to vital organs in the intensive care unit (ICU).[1] Several studies have shown an association between excessive fluid balance with length of hospital stay and morbidity and mortality in critically ill patients after surgery.[2,3]

In different types of surgical operations, restrictive fluid therapy has been associated with a reduction in postoperative complications.[4,5] Moreover, patients are often hospitalized for decompensated heart failure or ischemic heart disease before cardiac surgery, and therefore, may experience fluid overload before the operation.[1] The data on the effects and reasons of postoperative fluid overload in patients undergoing heart surgery are limited.[6]

In the present prospective study, we sought to investigate the prevalence of postoperative fluid accumulation in patients undergoing cardiac surgery. In particular, we study the association of postoperative weight gain with postoperative complications and, most importantly, try to identify patients at risk for fluid retention.

## METHODS

### Patients and Source of Data

CAREBANK is an ongoing Finnish prospective cohort study on patients undergoing cardiac surgery. The CAREBANK study protocols were approved by the Medical Ethics Committee of the Hospital District of Southwest Finland (Nos. 8/1802/2014 and 65/1801/2015 from the Ethical Committee of the Hospital District of Southwest Finland) and the THL Ethics Committee of the Finnish Institute for Health and Welfare (Finland). Informed consent was obtained from the participants of the CAREBANK study. After giving written informed consent, the patient's medical records and laboratory results are comprehensively verified. Vital signs are measured, including preoperative weight and electrocardiogram (ECG). Operation date, urgency (ie, elective, emergency, or salvage), and operation type are marked. After the postoperative ICU period, weight is measured daily during the hospital stay. The highest postoperatively measured weight of daily measurements was included in the analyses. All the in-hospital adverse events are registered on the database. Three-month and 1-year follow-up data includes all major adverse events death, cerebrovascular events, myocardial infarction, repeat revascularization, and occurrence of atrial fibrillation (AF). Ischemic stroke was defined as a permanent focal neurological deficit adjudicated by a neurologist and confirmed via computed tomography or magnetic resonance imaging. Transient ischemic attack (TIA), defined by the treating neurologist. Myocardial infarction was confirmed by a 12-lead ECG and/or with coronary angiography. The diagnosis of AF was confirmed by a 12-lead ECG recording or telemonitoring indicating an AF episode of 10 minutes or longer. The research personnel collected the follow-up data with telephone calls and hospital and primary care records using a structured questionnaires and electronic case report forms. Follow-ups for this report were done at 3 and 12 months postoperatively.

The short-term end points of the present study were length of hospital stay, length of ICU stay, occurrence of new-onset AF in a 12-lead ECG, major bleeding episodes according to Bleeding Academic Research Consortium (BARC) criteria, major cardiac events, cerebrovascular events, and death as defined in 2017 Cardiovascular and Stroke Endpoint Definitions for Clinical Trials (https://doi.org/10.1161/CIRCULATIONAHA.117.033502). Three-month and 1-year outcomes were stroke, TIA, myocardial infarction, new-onset of AF, and occurrence of permanent AF.

The study population was divided into 2 groups based on 5% postoperative weight gain. Weight-based definition and the 5% limit are commonly used, especially in nephrology studies.[7,8]

### Statistical Methods

Data are presented as mean ± SD or counts and percentages where appropriate. The data were tested for normal distribution using the Shapiro-Wilk test. Outcomes of categorical variables were evaluated with the $\chi^2$ and Fisher exact tests. Continuous variables were evaluated using independent samples, the *t* test or Mann-Whitney *U* test. Multivariate analysis was used to evaluate possible predicting factors for 5% weight gain/increase. When testing statistically significant clinical outcomes in binary logistic regression, 5% weight gain was used as the dependent variable and sex, age, and body mass index (BMI) as covariates. Logistic regression models were adjusted for significant baseline and operative characteristics (Tables 1 and 2) and tested with the backward Wald method. Cause-specific competing risk hazard model accounting for death was used for new-onset AF after discharge analysis.

Linear regression models were used to evaluate effects of weight gain related to treatment times (ICU and hospital). Linear models were adjusted with weight, sex, and BMI. Statistical analyses were performed with SPSS statistics version 27.0 software for Mac (IBM-SPSS Inc) and R statistics software version 4.1.3 (R Foundation for Statistical Computing).

## RESULTS

Altogether, 1001 adult patients undergoing cardiac surgery were enrolled and 939 included (see Figure 1). The most common reason for exclusion was missing weight data. Hence, patients who died during surgery or in the ICU are not included in the study because they did not have weight measurements. During the first year, 2 (9%) patients died, 14 of them during hospitalization. Due to the low mortality, 1-year death has not been used as an end point in the study. The most frequent operations were coronary artery bypass grafting (CABG) (56.3%) and aortic valve replacement (30.9%), and 81.8% of them were elective. Mean weight gain at index hospitalization was 6.6% ± 4.9%. Overall, 554 out of 939 (59.0%) patients had ≥5% weight gain during index hospitalization. In kilograms, the mean amount of the fluid accumulation after cardiac surgery was 5.3 ± 3.7 kg in the whole study population.

**TABLE 1. Preoperative characteristics of the study population**

| Characteristic | All operations (n = 939) | Weight gain <5% (n = 385) | Weight gain ≥5% (n = 554) | *P* value |
|---|---|---|---|---|
| Age (y) | 65.7 ± 10.5 | 65.2 ± 9.6 | 66.1 ± 11.1 | .226 |
| Women | 218 (23.2) | 63 (16.4) | 155 (28.0) | **<.001** |
| Body mass index | 28.2 ± 5.0 | 29.8 ± 5.2 | 27.1 ± 4.5 | **<.001** |
| Previous endocarditis | 7 (0.7) | 1 (0.3) | 6 (1.1) | .251 |
| Treatment for dyslipidemia | 632 (67.3) | 277 (71.9) | 355 (64.1) | **.011** |
| Heart failure | 114 (12.1) | 36 (9.4) | 78 (14.1) | **.029** |
| Coronary artery disease | 500 (53.2) | 214 (55.6) | 286 (51.6) | .232 |
| Previous myocardial infarction | 129 (13.8) | 58 (15.1) | 71 (12.8) | .317 |
| Prior PCI | 121 (12.9) | 55 (14.3) | 66 (11.9) | .286 |
| Prior CABG | 8 (0.9) | 2 (0.5) | 6 (1.1) | .483 |
| Hypertension | 655 (69.8) | 285 (74.0) | 370 (66.8) | **.018** |
| Diabetes mellitus | 243 (25.9) | 121 (31.4) | 122 (22.0) | **.001** |
| Atrial fibrillation | 200 (21.4) | 66 (17.2) | 134 (24.2) | **.010** |
| PAD | 52 (5.6) | 24 (6.3) | 28 (5.1) | .430 |
| Chronic lung disease | 123 (13.1) | 50 (13.0) | 73 (13.2) | .932 |
| Active smoking | 129 (13.8) | 52 (13.5) | 77 (14.0) | .829 |
| Exsmoker | 284 (33.4) | 127 (36.3) | 157 (31.4) | .137 |
| Previous stroke | 75 (8.0) | 35 (9.1) | 40 (7.2) | .298 |

Continuous variables are presented as mean ± SD; categorical variables are presented as n (%). Statistically significant *P* values are shown with boldface type. *PCI*, Percutaneous coronary intervention; *CABG*, coronary artery bypass grafting; *PAD*, peripheral artery disease.

The maximum weight gain was measured in 2.5 ± 1.1 days after surgery.

Baseline and perioperative characteristics of the patients are shown in Tables 1 and 2. Patients with a weight gain of ≥5% were more likely to be women, have lower BMI, had heart failure and more often had preoperative AF. Also, patients with ≥5% weight gain more frequently underwent valve surgery, and they had longer aortic crossclamp time, and CPB time compared with those with <5% weight gain.

Preoperative and perioperative characteristics associated with ≥5% weight gain in multivariate regression models are presented in Tables 3 and 4. Characteristics associated with ≥5% weight gain were female sex (odds ratio [OR], 2.00; 95% CI, 1.42-2.82; $P < .001$), BMI (OR, 0.89; 95% CI, 0.87-0.92; $P < .001$), preoperative AF (OR, 1.72; 95% CI, 1.21-2.44; $P = .002$), preoperative heart failure (OR, 1.85; 95% CI, 1.18-2.90; $P = .008$), aortic valve replacement surgery (OR, 1.81; 95% CI, 1.33-2.47; $P < .001$), mitral

**TABLE 2. Operative characteristics of the study cohorts**

| Operation type | All (n = 939) | Weight gain <5% (n = 385) | Weight gain ≥5% (n = 554) | *P* value |
|---|---|---|---|---|
| Elective surgery | 768 (81.8) | 303 (78.7) | 465 (83.9) | **.041** |
| Urgent surgery | 168 (17.9) | 81 (21.0) | 87 (15.7) | **.038** |
| Any AVR | 290 (30.9) | 94 (24.4) | 196 (35.4) | **<.001** |
| Off-pump CABG | 159 (16.9) | 108 (28.1) | 51 (9.2) | **<.001** |
| CABG | 436 (46.4) | 228 (59.2) | 208 (37.5) | **<.001** |
| CABG + valve | 93 (9.9) | 13 (3.4) | 80 (14.4) | **<.001** |
| Any mitral valve | 157 (16.7) | 36 (9.4) | 121 (21.8) | **<.001** |
| Surgery of the ascending aorta | 96 (10.2) | 32 (8.3) | 64 (11.6) | .105 |
| LAA closure | 137 (14.6) | 36 (9.4) | 101 (18.2) | **<.001** |
| Aortic crossclamp time (min) | 96.2 ± 31.4 | 91.3 ± 27.8 | 97.4 ± 29.1 | **.004** |
| Cardiopulmonary bypass time (min) | 128.7 ± 55.8 | 120.3 ± 38.3 | 130.7 ± 59.3 | **.003** |

Continuous variables are presented as mean ± SD; categorical variables are presented as n (%). Statistically significant *P* values are shown with boldface type. *AVR*, Aortic valve replacement; *CABG*, coronary artery bypass grafting; *LAA*, left atrial appendage.

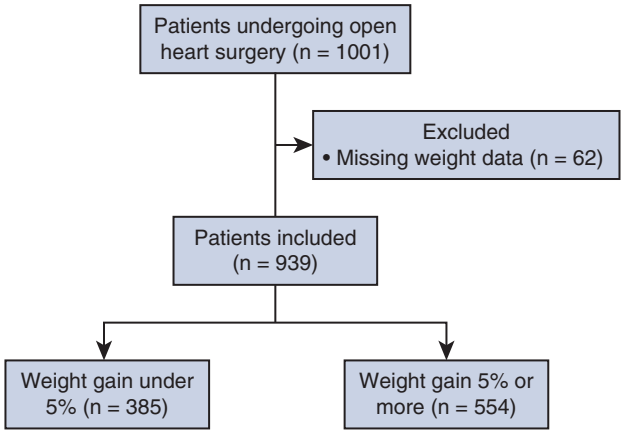


**FIGURE 1.** Flow chart of the study.

valve surgery (OR, 2.11; 95% CI, 1.39-3.20; $P < .001$), and CPB time (OR, 1.01; 95% CI, 1.01-1.01; $P < .001$).

Association of weight gain with postoperative short-term, 3-month and 1-year events are presented in Table 5. In-hospital period fluid accumulation was associated with reoperation due bleeding and longer total hospital stay. At 3 months, weight gain was associated with increased occurrence of new-onset AF.

## DISCUSSION

Our study indicates that weight gain early after cardiac surgery is associated with adverse postoperative events such as longer in-hospital treatment times. Especially low-weight patients, women, those with AF, and/or heart failure are at high risk of postoperative fluid accumulation. In addition, long cardiopulmonary bypass time and different operation types were remarkable risk factors for excessive fluid accumulation.

Several studies have demonstrated that excessive fluid accumulation postoperatively is associated with adverse clinical outcomes, suggesting the importance of fluid management control in ICU and postoperative wards.[9] Although there is evidence that perioperative goal-directed hemodynamic therapy may reduce mortality and morbidity in patients not undergoing cardiac surgery, the evidence is less clear after cardiac surgery.[2,4,5] Our study demonstrates clearly that fluid accumulation is common after cardiac surgery and it has several adverse effects. In the present study, in addition of adverse outcomes, we focused on finding the factors that may predict the fluid accumulation after cardiac surgery, to promote individual fluid therapy planning.

It is important to identify patients who are at risk to excessive fluid accumulation. Our results suggest that low-weight patients, women, and those with AF and heart failure are at higher risk for postoperative fluid overload. One explanation may be that fluid administration protocols do not take into enough account the baseline weight and BMI. In addition to female sex and low body weight, existing AF was also a preoperative predictor for weight gain. Prior studies have shown that fluid volume administered on second postoperative day was greater in patients who had AF,[10] suggesting that hemodynamics in patients with AF are more unstable. These patient-related factors should be considered when planning cardiac anesthesia.

In terms of operative factors, patients undergoing valve surgery appear to be at highest risk of fluid overload, whereas patients undergoing CABG, especially off-pump, are at lower risk. Valve surgery is often more complex than common CABG, which partly explains the result, because lengths of CPB and aortic crossclamping were also strongly associated with fluid accumulation. Left atrial appendage closure was also related to ≥5% weight gain, but this obviously has strong correlations with preoperative

**TABLE 3. Association of preoperative characteristics with ≥5% weight gain**

| Preoperative characteristic | Odds ratio | 95% CI | *P* value |
|---|---|---|---|
| Age (y) | 1.002 | 0.99-1.015 | .788 |
| Women | 2.003 | 1.42-2.82 | **<.001** |
| BMI | 0.891 | 0.87-0.92 | **<.001** |
| Treatment for dyslipidemia | 0.862 | 0.64-1.16 | .331 |
| Heart failure | 1.848 | 1.18-2.90 | **.008** |
| Previous myocardial infarction | 0.957 | 0.65-1.42 | .829 |
| Hypertension | 0.875 | 0.64-1.19 | .392 |
| Diabetes mellitus | 0.806 | 0.59-1.11 | .183 |
| Preoperative AF | 1.718 | 1.21-2.44 | **.002** |
| PAD | 0.601 | 0.33-1.10 | .099 |
| Chronic lung disease | 1.004 | 0.67-1.51 | .985 |

Logistic regression analyses (Backward Wald). Age, sex, and BMI as covariates. Statistically significant *P* values are shown with boldface type. *CI*, Confidence interval; *BMI*, body mass index; *AF*, atrial fibrillation; *PAD*, peripheral artery disease.

**TABLE 4. Association of operative characteristics with ≥5% weight gain**

| Operative characteristic | Odds ratio | 95% CI | *P* value |
|---|---|---|---|
| Elective surgery | 1.322 | 0.93-1.89 | .122 |
| AVR | 1.812 | 1.33-2.47 | **<.001** |
| Off-pump CABG | 0.252 | 0.17-0.37 | **<.001** |
| CABG | 0.457 | 0.35-0.60 | **<.001** |
| CABG + valve | 4.997 | 2.69-9.27 | **<.001** |
| Mitral valve | 2.109 | 1.39-3.20 | **<.001** |
| Surgery of the ascending aorta | 1.518 | 0.95-2.44 | .084 |
| LAA closure | 2.207 | 1.44-3.38 | **<.001** |
| Aortic crossclamp time (min) | 1.011 | 1.01-1.02 | **<.001** |
| Cardiopulmonary bypass time (min) | 1.009 | 1.01-1.01 | **<.001** |

Logistic regression analyses (Backward Wald) are adjusted with body mass index, age, and sex. Statistically significant *P* values are shown with boldface type. *CI*, Confidence interval; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting; *LAA*, left atrial appendage.

AF. The results suggest that together with patient characteristics (low-weight, AF, heart failure, and female sex), anesthesiologists should pay attention to fluid therapy in long cardiac surgery procedures.

It is widely known that fluid accumulation has adverse effects on patients' postoperative recovery.[5] In our study, postoperative weight gain was associated with reoperation due to bleeding. Reoperation has a significant effect on patient mortality, morbidity, and prolonged ICU stay.[11] The risk of reoperation is influenced by the quality of the surgery (surgical bleeding), but also by impaired hemostasis.[12] Because excessive fluid therapy can have major effects on hemostasis, this association between reoperation and fluid overload is complex. The association might be bidirectional so that fluid overload predisposes to reoperation and reoperation to repair impaired hemostasis. In addition, 1 reason for fluid accumulation may be the use of blood products.

**TABLE 5. Association of ≥5% weight gain with postoperative complications and events**

| Complications | All (n = 935) | Weight gain <5% (n = 383) | Weight gain ≥5% (n = 552) | *P* value |
|---|---|---|---|---|
| Postoperative complications | | | | |
| In-hospital death | 8 (0.9) | 5 (1.3) | 3 (0.5) | .284 |
| Reoperation due to bleeding | 50 (5.3) | 13 (3.4) | 37 (6.7) | **.027** |
| Pneumonia | 16 (1.7) | 9 (2.3) | 7 (1.3) | .208 |
| Stroke | 16 (1.7) | 9 (2.3) | 7 (1.3) | .210 |
| Acute dialysis | 2 (0.2) | 0 (0.0) | 2 (0.4) | .516 |
| Mediastinitis | 4 (0.4) | 1 (0.3) | 3 (0.5) | .648 |
| Length of ICU stay (h) | 44.7 ± 74.8 | 32.3 ± 35.1 | 32.4 ± 20.5 | .110 |
| Length of hospital stay (d) | 9.5 ± 6.0 | 8.6 ± 5.3 | 9.5 ± 5.1 | **.013** |
| In-hospital paroxysmal AF* | 276 (37.6) | 108 (34.1) | 168 (40.3) | .085 |
| 3-mo events | (n = 919) | (n = 374) | (n = 545) | |
| Stroke | 20 (2.2) | 14 (3.7) | 6 (1.1) | **.007** |
| TIA | 8 (0.9) | 0 (0.0) | 8 (1.5) | **.019** |
| MI | 2 (0.2%) | 1 (0.3%) | 1 (0.2) | 1.000 |
| New-onset AF in 3 mo† | 103 (15.0) | 32 (10.8) | 71 (18.1) | **.008** |
| 1-y events | (n = 847) | (n = 342) | (n = 505) | |
| Stroke | 25 (3.0) | 13 (3.8) | 12 (2.4) | .229 |
| TIA | 13 (1.5) | 2 (0.6) | 11 (2.2) | .064 |
| MI | 4 (0.5) | 1 (0.3) | 3 (0.6) | .652 |
| New-onset AF in 1 y‡ | 21 (3.3) | 5 (1.9) | 16 (4.3) | .097 |

Categorical variables are presented as n (%); continuous variables are presented as mean ± SD. Statistically significant *P* values are shown with boldface type. *ICU*, Intensive care unit; *AF*, atrial fibrillation; *TIA*, transient ischemic attack; *MI*, myocardial infarction. *Patients with preoperative AF excluded, n = 734 (317 out of 417). †Patients with preoperative AF and AF in previous study visit excluded (n = 688 [296 out of 392]). ‡Patients with preoperative AF and AF in 3-month period excluded (n = 629 [260 out of 369]).

Besides reoperation, fluid overload was associated with longer hospital stay. It is clear that patients with longer hospital stays use a greater amount of resources with a markedly higher health care costs.[13]

Fluid accumulation also caused 3-month and 1-year complications because it was associated with the occurrence of new-onset paroxysmal AF. The effects of AF on a patient's quality of life are well known[14]; most importantly, the need for anticoagulation therapy due to an increased risk of stroke.[15] The mechanism of how postoperative fluid overload influences the onset of AF remains elusive, but possible explanations may be the mechanical stretching of the atria during fluid accumulation as well as electrolyte disturbances. Previous studies have shown that postoperative AF have several adverse effects, such as increased risk of short-term stroke and mortality.[16,17]

The major strength of this study is the prospective setting of the CAREBANK study, focusing on the adverse events after cardiac surgery. Furthermore, measured weight gain was used to evaluate the fluid balance instead of calculating the administered fluids, which is not reliable for predicting body weight change.[2] However, because we used percent weight gain, we might have missed some important fluid overload in obese patients. With the limited number of patients and because of the patients who died in the ICU were excluded because of the missing weight data, our data may be underpowered to show significant association with outcomes such as mortality and major adverse cardiac and

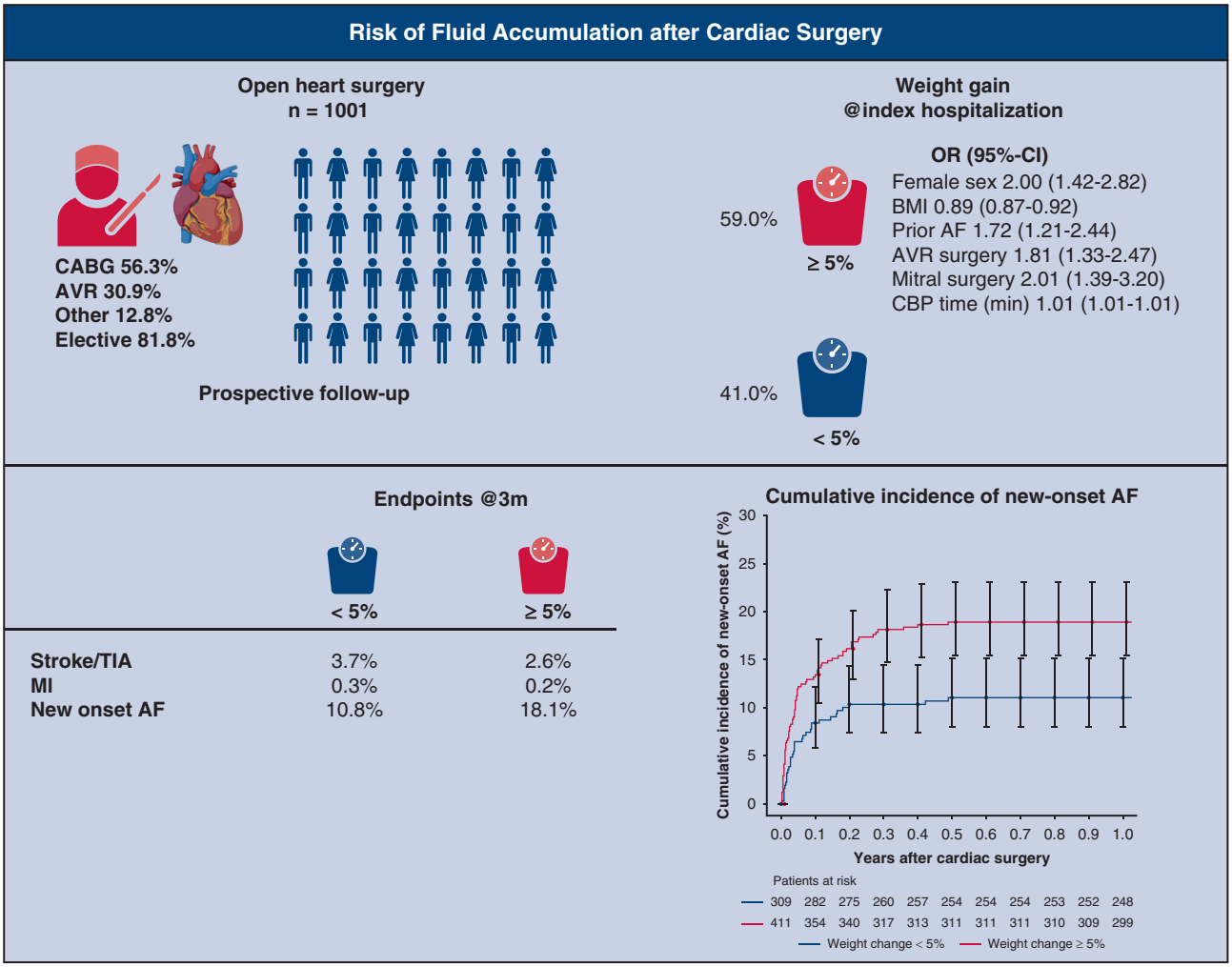




**FIGURE 2.** Risk of fluid accumulation after cardiac surgery. *OR*, Odds ratio; *CI*, confidence interval; *BMI*, body mass index; *AF*, atrial fibrillation; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting; *CBP*, cardiopulmonary bypass; *TIA*, transient ischemic attack; *MI*, myocardial infarction.

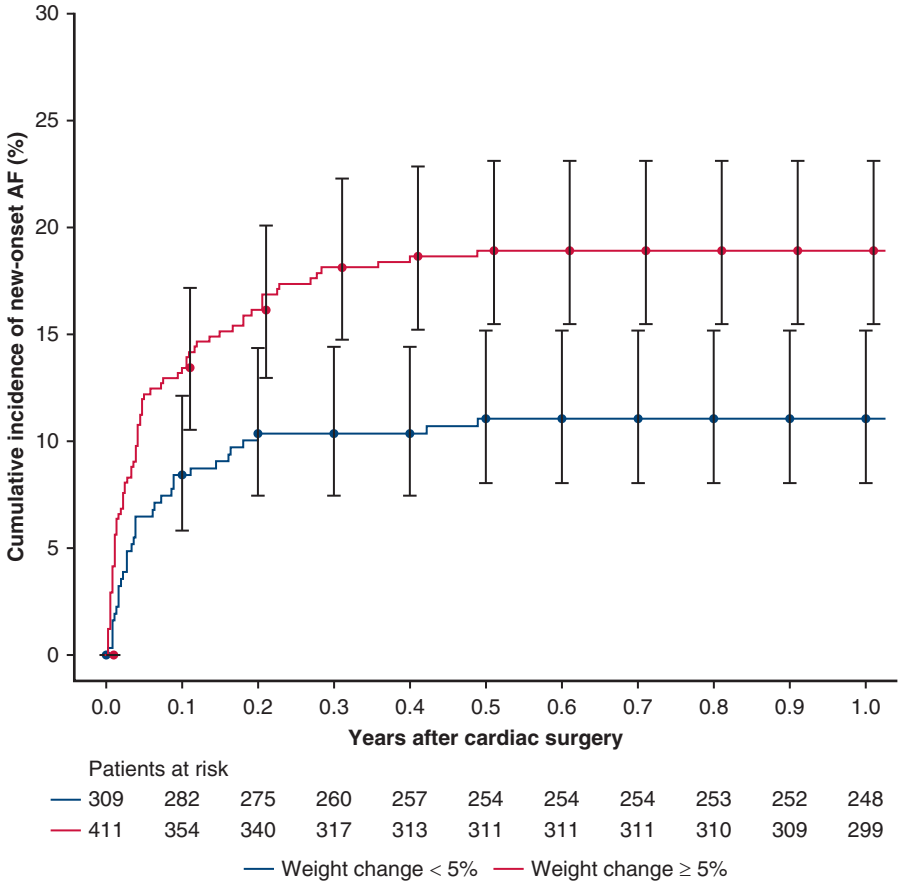


**FIGURE 3.** Cumulative incidence of atrial fibrillation during the first postoperative year. *AF*, Atrial fibrillation.

cerebrovascular events. Also, the inherent limitation of our study is that positive fluid balance may also be due to sicker patients with higher hospital mortality because they did not respond to treatment, such as fluid resuscitation. Finally, given the observational nature of our study, the causality of the associations cannot be assured and requires a randomized controlled study (Figure 2).

## CONCLUSIONS

We found that women, low-weight patients, and patients with cardiac failure or AF are especially prone to perioperative fluid accumulation. Also, valve operations and operations with long CPB times predispose to fluid accumulation. Postoperative fluid excess is associated with adverse outcomes such as TIA and new-onset AF. The results suggest that fluid therapy for cardiac surgical patients should be more individualized, with particular attention to women, low-weight patients, and patients with heart failure or AF (Figure 3).

### Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* style requires editors and reviewers to disclose conflicts of interest and to decline handing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

### References

1. Bellomo R, Raman J, Ronco C. Intensive care unit management of the critically ill patient with fluid overload after open heart surgery. *Cardiology*. 2001;96:169-76.
2. You JW, Lee SJ, Kim YE, Cho YJ, Jeong YY, Kim HC, et al. Association between weight change and clinical outcomes in critically ill patients. *J Crit Care*. 2013;28:923-7.
3. Shum HP, Lee FMH, Chan KC, Yan WW. Interaction between fluid balance and disease severity on patient outcome in the critically ill. *J Crit Care*. 2011;26:613-9.
4. Haapio E, Kinnunen I, Airaksinen JKE, Irjala H, Kiviniemi T. Excessive intravenous fluid therapy in head and neck cancer surgery. *Head Neck*. 2017;39:37-41.
5. Brandstrup B, Tønnesen H, Beier-Holgersen R, Hjortsø E, Ørding H, Lindorff-Larsen K, et al. Effects of intravenous fluid restriction on postoperative complications: comparison of two perioperative fluid regimens—a randomized assessor-blinded multicenter trial. *Ann Surg*. 2003;238:641-8.
6. Xu J, Shen B, Fang Y, Liu Z, Zou J, Liu L, et al. Postoperative fluid overload is a useful predictor of the short-term outcome of renal replacement therapy for acute kidney injury after cardiac surgery. *Medicine (Baltimore)*. 2015;94:e1360.
7. Messmer AS, Zingg C, Müller M, Gerber JL, Schefold JC, Pfortmueller CA. Fluid overload and mortality in adult critical care patients—a systematic review and meta-analysis of observational studies. *Crit Care Med*. 2020;48:1862-70.

8. Selewski DT, Goldstein SL. The role of fluid overload in the prediction of outcome in acute kidney injury. *Pediatr Nephrol*. 2018;33:13-24.
9. Sim J, Young Kwak J, Tae Jung Y. Association between postoperative fluid balance and mortality and morbidity in critically ill patients with complicated intra-abdominal infections: a retrospective study. *Acute Crit Care*. 2020;35:189-96.
10. Kalus JS, Caron MF, White CM, Mather JF, Gallagher R, Boden WE, et al. Impact of fluid balance on incidence of atrial fibrillation after cardiothoracic surgery. *Am J Cardiol*. 2004;94:1423-5.
11. Jonathan Unsworth-White M, Herriot A, Valencia O, Poloniecki J, Smith EE, Murday AJ, et al. Resternotomy for bleeding after cardiac operation: a marker for increased morbidity and mortality. *Ann Thorac Surg*. 1995;59:664-7.
12. Brown JA, Kilic A, Aranda-Michel E, Navid F, Serna-Gallegos D, Bianco V, et al. Long-term outcomes of reoperation for bleeding after cardiac surgery. *Semin Thorac Cardiovasc Surg*. 2021;33:764-73.
13. Cooke CR. Economics of mechanical ventilation and respiratory failure. *Crit Care Clin*. 2012;28:39-55.
14. Thrall G, Lane D, Carroll D, Lip GYH. Quality of life in patients with atrial fibrillation: a systematic review. *Am J Med*. 2006;119:448. e1-19.
15. Hindricks G, Potpara T, Dagres N, Arbelo E, Bax JJ, Blomström-Lundqvist C, et al. 2020 ESC Guidelines for the diagnosis and management of atrial fibrillation developed in collaboration with the European Association for Cardio-Thoracic Surgery (EACTS). *Eur Heart J*. 2021;42:373-498.
16. Steinberg BA, Zhao Y, He X, Hernandez AF, Fullerton DA, Thomas KL, et al. Management of postoperative atrial fibrillation and subsequent outcomes in contemporary patients undergoing cardiac surgery: insights from the Society of Thoracic Surgeons CAPS-Care Atrial Fibrillation Registry. *Clin Cardiol*. 2014;37:7-13.
17. Batra G, Ahlsson A, Lindahl B, Lindhagen L, Wickbom A, Oldgren J. Atrial fibrillation in patients undergoing coronary artery surgery is associated with adverse outcome. *Ups J Med Sci*. 2019;124:70-7.

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