

Article

Preoperative Left Ventricular Ejection Fraction and Adverse In-Hospital Outcomes in Geriatric Patients with Cardiovascular Disease Undergoing Non-Cardiac Surgery: A Secondary Cohort Analysis

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Abstract

Background: Older adults undergoing non-cardiac surgery are vulnerable to perioperative complications, but the prognostic value of routine echocardiographic markers in high-acuity cohorts remains incompletely defined. **Methods:** This secondary analysis of a prospective cohort included 503 consecutive adults with known cardiovascular disease undergoing non-cardiac surgery, characterized by a high proportion of urgent presentations. Patients were stratified by age (geriatric, ≥ 65 years; non-geriatric, < 65 years). The primary endpoint was major in-hospital adverse events (MIAEs), defined as a composite of in-hospital death, surgical reintervention, and postoperative acute kidney injury (AKI). Postoperative creatinine was not routinely measured in stable patients discharged early; therefore, renal outcomes were interpreted strictly as available-case analyses ($n = 364$). **Results:** MIAEs occurred more frequently in geriatric than in younger patients (45.5% vs. 30.8%). Within the geriatric cohort, patients with reduced LVEF ($< 50\%$) had lower MAPSE values and higher crude rates of AKI, death, and MIAE than those with $\text{LVEF} \geq 50\%$. In multivariable analyses, reduced LVEF was associated with MIAE, although this small subgroup was susceptible to statistical overfitting. MAPSE reflected longitudinal systolic dysfunction but did not retain independent prognostic value after adjustment. **Conclusions:** In this pilot subgroup analysis of high-acuity patients, reduced preoperative LVEF ($< 50\%$) served as a clinical flag identifying a high-risk geriatric phenotype with increased cardiorenal vulnerability. Given the event-enriched available-case denominator, these findings should be considered hypothesis-generating observations intended to increase clinical awareness.



Academic Editor: Michael S. Firstenberg

Received: 27 April 2026

Revised: 21 June 2026

Accepted: 25 June 2026

Published: 29 June 2026

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Keywords: geriatrics; perioperative risk; echocardiography; left ventricular ejection fraction; LVEF; mitral annular plane systolic excursion; MAPSE; acute kidney injury; non-cardiac surgery

1. Introduction

Older adults undergoing non-cardiac surgery represent a heterogeneous high-risk population in whom chronological age frequently coexists with frailty, multimorbidity, reduced functional reserve, and diminished tolerance to perioperative physiological stress [1–9]. Together, these factors contribute to higher rates of cardiovascular, pulmonary, renal, and

functional complications, while conventional perioperative risk scores do not always capture the full vulnerability of geriatric patients [2–9].

Cardiovascular disease is particularly relevant in this context. Current perioperative guidelines do not recommend routine transthoracic echocardiography for all patients undergoing non-cardiac surgery, but they support targeted imaging when ventricular dysfunction, heart failure, or significant valvular disease is suspected and when imaging findings are likely to influence perioperative management [10–14]. Because perioperative risk in older adults often reflects the interplay between cardiovascular reserve, renal vulnerability, and surgical stress, simple preoperative echocardiographic markers may provide clinically useful information beyond conventional clinical scores [12–14].

Left ventricular ejection fraction remains the most widely used index of systolic function. Reduced LVEF, as well as symptomatic or asymptomatic heart failure, has been associated with worse postoperative outcomes after non-cardiac surgery, including increased mortality and major organ complications [15–18]. In parallel, postoperative acute kidney injury has emerged as a clinically important complication of major surgery, particularly in older patients and in those with baseline renal or cardiovascular vulnerability [19–21]. In addition, perioperative diastolic dysfunction has been linked to adverse cardiovascular events after non-cardiac surgery [22].

Mitral annular plane systolic excursion (MAPSE) is a simple and reproducible marker of longitudinal left ventricular systolic function that correlates with LVEF and may detect subtle impairment not fully reflected by global systolic indices alone [23,24]. Preoperative transthoracic echocardiography has also shown potential to improve risk assessment in selected elderly patients with coronary artery disease undergoing non-cardiac surgery [18]. However, in older adults undergoing non-cardiac surgery, it remains uncertain whether readily available echocardiographic markers of systolic function can identify a subgroup at particularly high risk for major postoperative complications, including acute kidney injury and in-hospital death.

The present secondary cohort analysis therefore had two objectives: first, to compare geriatric (≥ 65 years) and non-geriatric patients with respect to echocardiographic profile and in-hospital outcomes; and second, to determine whether reduced preoperative LVEF identifies a particularly high-risk geriatric subgroup. MAPSE was evaluated as a complementary marker of longitudinal systolic function rather than as an established standalone prognostic parameter.

2. Materials and Methods

2.1. Study Design and Population

This substudy was based on a de-identified dataset derived from a prospective multi-center cohort study with longitudinal perioperative follow-up based on clinical, laboratory, and echocardiographic data. The parent cohort included 503 consecutive adults admitted between October 2022 and July 2025 to two surgical centers in Galați, Romania: Second Surgery Clinic of the “Sf. Apostol Andrei” Emergency Clinical County Hospital and the Department of Surgery of the “Dr. Aristide Serfioti” Military Emergency Hospital.

All included patients underwent non-cardiac surgery and had documented cardiovascular disease, which represented an inclusion criterion of the parent cohort. Major cardiometabolic comorbidities frequently present in this population included arterial hypertension, chronic coronary syndrome, atherosclerosis, chronic heart failure, atrial fibrillation or atrial flutter, diabetes mellitus, and obesity, defined as a body mass index (BMI) $> 30 \text{ kg/m}^2$. The cohort was intended to reflect real-world non-cardiac surgical practice and included both elective and emergency admissions.

Patients were categorized as geriatric if aged ≥ 65 years. The present work was designed as a secondary cohort analysis focused on perioperative echocardiographic markers and in-hospital outcomes. Analyses involving renal outcomes were restricted to patients with both preoperative and postoperative serum creatinine values available. Postoperative creatinine was not routinely collected in all patients, particularly in those with favorable postoperative evolution who were discharged early. Therefore, renal analyses were interpreted as available-case analyses rather than full-cohort estimates.

2.2. Echocardiographic Variables

Preoperative echocardiographic assessment consisted of a focused bedside transthoracic echocardiographic evaluation consistent with a point-of-care ultrasound (POCUS) approach. All focused examinations were performed by a single operator in the perioperative setting. Echocardiographic measurements and qualitative assessments were obtained in accordance with current recommendations of the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) [25].

For the present analysis, left ventricular ejection fraction (LVEF, %) and mitral annular plane systolic excursion (MAPSE, mm) were extracted from the dataset. LVEF was measured using the Simpson biplane method and was considered the main index of global left ventricular systolic function. MAPSE was measured at the lateral mitral annulus in the apical four-chamber view and was used as a complementary marker of longitudinal left ventricular systolic performance. According to guideline-based reference ranges, normal LVEF ranges from 52% to 72% in men and from 54% to 74% in women, while lateral MAPSE values of approximately ≥ 12 mm are usually considered within the normal range [23,25]. LVEF and MAPSE were selected a priori as the echocardiographic variables of interest because they reflect global and longitudinal left ventricular systolic function, respectively.

For subgroup analyses within the geriatric cohort, patients were classified as having LVEF $< 50\%$ or LVEF $\geq 50\%$, using a clinically pragmatic threshold that retained all eligible patients. A secondary sensitivity analysis using strict strata ($< 50\%$ vs. $> 50\%$) excluded patients with LVEF exactly 50% in order to test the robustness of the findings around the threshold value.

2.3. Endpoints and Definitions

Postoperative acute kidney injury (AKI) was defined according to KDIGO serum creatinine criteria as an increase in serum creatinine of ≥ 0.3 mg/dL or ≥ 1.5 times baseline [19]. Baseline renal function was defined using the preoperative serum creatinine value. AKI stage 1 was defined as 1.5–1.9 times baseline or an absolute increase of ≥ 0.3 mg/dL; stage 2 as 2.0–2.9 times baseline; and stage 3 as ≥ 3.0 times baseline or a serum creatinine value ≥ 4.0 mg/dL [19]. Urine output criteria and renal replacement therapy data were unavailable and therefore could not be incorporated into AKI classification. Accordingly, renal outcomes were assessed only in patients with both preoperative and postoperative creatinine values available.

The primary endpoint was major in-hospital adverse events (MIAE), defined as the composite of in-hospital death, surgical reintervention, or postoperative AKI of any stage. Surgical reintervention was defined as any repeat surgical procedure performed during the index hospitalization. In-hospital death was defined as all-cause mortality occurring before discharge. Prolonged length of stay (LOS > 7 days) was assessed as a key secondary endpoint. An exploratory major composite replacing any-stage AKI with moderate-to-severe AKI (KDIGO stage 2–3) was also examined in order to provide a more conservative renal outcome definition.

All endpoints were assessed during the index hospitalization.

2.4. Statistical Analysis

Data were analyzed using IBM SPSS Statistics, version 26 (IBM Corporation, Armonk, NY, USA). Continuous variables are presented as mean $\pm$ standard deviation or median [interquartile range], as appropriate, and categorical variables as n (%). Group comparisons were performed using the Mann–Whitney U test for continuous variables and the chi-square test or Fisher's exact test for categorical variables, as appropriate. Odds ratios (ORs) with 95% confidence intervals (95% CIs) were calculated for key binary comparisons.

The main multivariable logistic regression model was fitted in the full available-case cohort to assess independent associations with major in-hospital adverse events (MIAE). The model included age group, LVEF, MAPSE, preoperative creatinine, urgent presentation, and sex. Because renal outcomes were only assessable in patients with both preoperative and postoperative creatinine values available, analyses involving AKI and MIAE were performed as available-case analyses. No imputation procedures were applied. Two-sided p values < 0.05 were considered statistically significant.

To explore whether operative case mix could account for the association between reduced LVEF and adverse outcome, grouped surgical intervention types based on postoperative diagnoses were additionally analyzed in the geriatric available-case cohort. For each grouped surgical category, 2×2 tables were constructed versus all remaining procedures, and univariable odds ratios for MIAE and in-hospital death were calculated with 95% confidence intervals; Fisher's exact test was used as appropriate. The surgical category showing significantly increased odds of in-hospital death was then entered into a geriatric sensitivity logistic regression model together with LVEF $< 50\%$, preoperative creatinine, urgent presentation, and sex.

Because the reduced-LVEF subgroup contained few non-events, a Firth's penalized logistic regression model was used in the geriatric sensitivity analysis to reduce sparse-data bias and quasi-separation.

2.5. Ethical Considerations

The study was conducted in accordance with the Declaration of Helsinki and the Code of Ethics of "Dunărea de Jos" University of Galați (UDJG). The protocol was approved by the Institutional Review Boards of both participating hospitals. Written informed consent was obtained from all participants or their legal representatives. Data confidentiality was ensured throughout the study.

3. Results

3.1. Patient Flow and Completeness of Renal Data

A total of 503 consecutive adults undergoing non-cardiac surgery were included in the parent cohort. Of these, 385 patients (76.5%) were aged ≥ 65 years, and 118 patients (23.5%) were aged < 65 years. Complete preoperative and postoperative serum creatinine data were available in 364 patients (72.4% of the full cohort), including 286 geriatric patients and 78 younger patients. Thus, 139 patients were not eligible for renal endpoint analyses because postoperative creatinine values were unavailable. As shown in Figure 1, this was mainly related to the absence of routine postoperative creatinine testing in clinically stable patients with favorable postoperative evolution who were discharged early.

Within the geriatric available-case cohort, the primary subgroup analysis classified patients as having LVEF $< 50\%$ ($n = 21$) or LVEF $\geq 50\%$ ($n = 265$). A secondary strict-threshold sensitivity analysis excluded patients with LVEF = 50% ($n = 23$), leaving 21 patients with LVEF $< 50\%$ and 242 patients with LVEF $> 50\%$. Accordingly, all analyses involving postoperative AKI and MIAE were performed in the available-case cohort, whereas the strict $< 50\%$ versus $> 50\%$ comparison was reserved for sensitivity testing.

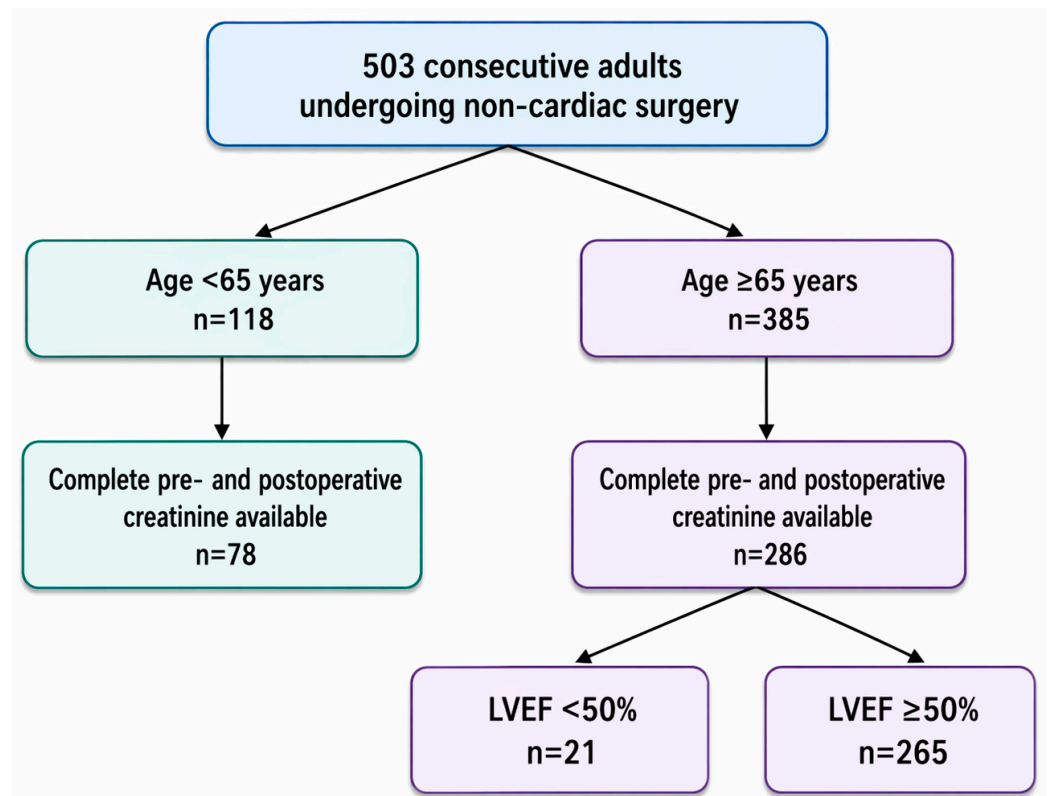


Figure 1. Flow of the analytic cohort and completeness of postoperative creatinine data.

3.2. Baseline Characteristics According to Age Group

Baseline characteristics according to age group are shown in Table 1. Female sex was similarly distributed between groups, and the proportion of urgent admissions was high in both younger and geriatric patients, without a statistically significant between-group difference.

Table 1. Baseline characteristics by age group.

Variable	<65 Years (n = 118)	≥65 Years (n = 385)	p-Value
Female, n (%)	46/118 (39.0%)	165/385 (42.9%)	0.456
Urgent presentation, n (%)	87/118 (73.7%)	259/385 (67.3%)	0.185
LVEF (%), mean ± SD	58.5 ± 5.3	57.3 ± 6.0	0.022
MAPSE (mm), mean ± SD	12.2 ± 1.6	12.0 ± 2.0	0.298
Preoperative creatinine (mg/dL), median [IQR]	0.93 [0.81–1.30]	1.05 [0.84–1.42]	0.096

Continuous variables were compared with the Mann–Whitney U test; categorical variables with the chi-square test.

Geriatric patients had a modestly lower mean LVEF than younger patients ($57.3 \pm 6.0\%$ vs. $58.5 \pm 5.3\%$, $p = 0.022$), whereas MAPSE values were similar between age groups (12.0 ± 2.0 mm vs. 12.2 ± 1.6 mm, $p = 0.298$). Median preoperative creatinine was numerically higher in older patients ($1.05 [0.84–1.42]$ mg/dL vs. $0.93 [0.81–1.30]$ mg/dL), but the difference was not statistically significant ($p = 0.096$).

3.3. In-Hospital Outcomes According to Age Group

In-hospital outcomes according to age group are summarized in Table 2. Rates of postoperative AKI, surgical reintervention, in-hospital death, and prolonged length of stay were numerically higher in geriatric patients than in younger patients, although none of these individual comparisons reached statistical significance.

Table 2. In-hospital outcomes by age group.

Outcome	<65 Years	≥65 Years	p-Value
Full Cohort Analysis	(N = 118)	(N = 385)	
Surgical reintervention, n/N (%)	9/118 (7.6%)	50/385 (13.0%)	0.113
In-hospital death, n/N (%)	16/118 (13.6%)	73/385 (19.0%)	0.179
Prolonged LOS > 7 days, n/N (%)	58/118 (49.2%)	204/385 (53.0%)	0.466
Available-Case Analysis	(N = 78)	(N = 286)	p-value
Postoperative AKI (KDIGO), n/N (%)	11/78 (14.1%)	58/286 (20.3%)	0.217
MIAE (death/reintervention/AKI), n/N (%)	24/78 (30.8%)	130/286 (45.5%)	0.020

Death, reintervention, and length of stay (LOS) were assessed in the full cohort. Postoperative AKI and MIAE were assessed only among patients with both preoperative and postoperative creatinine measurements available (available-case analysis).

Postoperative AKI occurred in 58/286 geriatric patients (20.3%) and 11/78 younger patients (14.1%) ($p = 0.217$). Surgical reintervention was recorded in 50/385 older patients (13.0%) and 9/118 younger patients (7.6%) ($p = 0.113$), while in-hospital death occurred in 73/385 (19.0%) and 16/118 (13.6%), respectively ($p = 0.179$). Prolonged length of stay (LOS > 7 days) was observed in 204/385 geriatric patients (53.0%) and 58/118 younger patients (49.2%) ($p = 0.466$).

By contrast, the composite endpoint of major in-hospital adverse events (MIAE) occurred significantly more often in geriatric than in younger patients (130/286 [45.5%] vs. 24/78 [30.8%], $p = 0.020$).

3.4. Geriatric Subgroup Stratified by LVEF

Selected clinical, echocardiographic, and laboratory characteristics of geriatric patients with complete renal data stratified by preoperative LVEF are presented in Table 3, and in-hospital outcomes are shown in Table 4. Among the 286 geriatric patients with complete renal data, 21 had LVEF < 50% and 265 had LVEF ≥ 50%.

Table 3. Clinical, echocardiographic, and laboratory characteristics of geriatric patients with complete renal data stratified by LVEF (<50% vs. ≥50%).

Variable	LVEF < 50% (n = 21)	LVEF ≥ 50% (n = 265)	p-Value
Female, n (%)	5/21 (23.8%)	141/265 (53.2%)	0.009
Urgent presentation, n (%)	20/21 (95.2%)	203/265 (76.6%)	0.054
LVEF (%), mean ± SD	38.2 ± 6.1	58.5 ± 3.4	<0.001
MAPSE (mm), mean ± SD	9.0 ± 2.4	12.1 ± 1.8	<0.001
Preoperative creatinine (mg/dL), median [IQR]	1.43 [0.97–1.89]	1.06 [0.85–1.49]	0.070
Postoperative creatinine (mg/dL), median [IQR]	1.76 [1.05–2.36]	1.12 [0.89–1.68]	0.089

Compared with patients with LVEF ≥ 50%, those with LVEF < 50% were less frequently female (23.8% vs. 53.2%, $p = 0.009$) and more often presented urgently (95.2% vs. 76.6%, $p = 0.054$). As expected, they had lower mean LVEF (38.2 ± 6.1% vs. 58.5 ± 3.4%, $p < 0.001$) and lower MAPSE (9.0 ± 2.4 mm vs. 12.1 ± 1.8 mm, $p < 0.001$). Preoperative and postoperative creatinine values were numerically higher in the reduced-LVEF subgroup, although these differences did not reach statistical significance.

Table 4. In-hospital outcomes of geriatric patients with complete renal data stratified by LVEF (<50% vs. ≥50%).

Outcome	LVEF < 50%	LVEF ≥ 50%	p-Value
Postoperative AKI (KDIGO), n/N (%)	12/21 (57.1%)	46/265 (17.4%)	<0.001
Moderate-to-severe AKI (KDIGO stage 2–3), n/N (%)	4/21 (19.0%)	21/265 (7.9%)	0.098
Surgical reintervention, n/N (%)	4/21 (19.0%)	43/265 (16.2%)	0.759
In-hospital death, n/N (%)	14/21 (66.7%)	59/265 (22.3%)	<0.001
Prolonged LOS > 7 days, n/N (%)	12/21 (57.1%)	174/265 (65.7%)	0.431
MIAE (death/reintervention/AKI), n/N (%)	19/21 (90.5%)	111/265 (41.9%)	<0.001
Major composite (death/reintervention/AKI stage 2–3), n/N (%)	17/21 (81.0%)	98/265 (37.0%)	<0.001

In-hospital outcomes differed substantially between the two LVEF strata. Postoperative AKI occurred in 12/21 patients (57.1%) with LVEF < 50% compared with 46/265 patients (17.4%) with LVEF ≥ 50% ($p < 0.001$). Moderate-to-severe AKI (KDIGO stage 2–3) was observed in 19.0% and 7.9%, respectively ($p = 0.098$). Surgical reintervention rates were similar between groups (19.0% vs. 16.2%, $p = 0.759$). In-hospital death occurred in 14/21 patients (66.7%) with reduced LVEF and 59/265 patients (22.3%) with LVEF ≥ 50% ($p < 0.001$). Prolonged LOS > 7 days was observed in 57.1% and 65.7%, respectively ($p = 0.431$).

The primary composite endpoint, MIAE, occurred in 19/21 patients (90.5%) with LVEF < 50% and 111/265 patients (41.9%) with LVEF ≥ 50% ($p < 0.001$). Similarly, the exploratory major composite of death, reintervention, or KDIGO stage 2–3 AKI occurred in 81.0% versus 37.0% ($p < 0.001$). The secondary strict-threshold sensitivity analysis excluding patients with LVEF = 50% showed the same overall direction of association.

All denominators reflect the geriatric available-case cohort classified according to LVEF < 50% or ≥50%.

3.5. Surgical Procedure Type and In-Hospital Risk

Procedure-specific univariable odds ratios for MIAE and in-hospital death in the geriatric available-case cohort are presented in Table 5. Amputation for gangrene (OR 10.96, 95% CI 3.21–37.44; $p < 0.001$) and bowel resection/emergency gastrointestinal surgery (OR 2.83, 95% CI 1.63–4.92; $p < 0.001$) were associated with significantly higher odds of MIAE. By contrast, cholecystectomy (OR 0.26, 95% CI 0.13–0.52; $p < 0.001$) and urologic surgery (OR 0.15, 95% CI 0.03–0.65; $p = 0.005$) were associated with lower odds of MIAE.

For in-hospital death, only bowel resection/emergency gastrointestinal surgery showed significantly increased odds (OR 6.61, 95% CI 3.66–11.95; $p < 0.001$), whereas cholecystectomy (OR 0.18, 95% CI 0.06–0.52; $p < 0.001$) and tumor surgery (OR 0.46, 95% CI 0.23–0.94; $p = 0.040$) were associated with lower odds of death. The highest overall burden of complications was observed in patients undergoing amputation for gangrene, among whom MIAE occurred in 23/26 patients (88.5%). Patients with LVEF < 50% were not significantly more likely to undergo the procedure group associated with higher odds of death than those with LVEF ≥ 50% (9/21 [42.9%] vs. 64/265 [24.2%], Fisher $p = 0.070$).

Table 5. Procedure-specific univariable odds ratios for MIAE and in-hospital death in the geriatric available-case cohort.

Surgical Group	n/N (%)	OR (95% CI)	p-Value
Panel A. Major in-hospital adverse events (MIAE)			
Bowel resection/emergency GI surgery	47/73 (64.4%)	2.83 (1.63–4.92)	<0.001
Tumor surgery	27/70 (38.6%)	0.69 (0.40–1.19)	0.214
Urologic surgery	2/17 (11.8%)	0.15 (0.03–0.65)	0.005
Cholecystectomy	12/56 (21.4%)	0.26 (0.13–0.52)	<0.001
Other hernia repair	3/15 (20.0%)	0.28 (0.08–1.03)	0.060
Amputation for gangrene	23/26 (88.5%)	10.96 (3.21–37.44)	<0.001
Abscess drainage/soft-tissue debridement	7/13 (53.8%)	1.42 (0.47–4.34)	0.579
Incisional hernia repair	7/11 (63.6%)	2.16 (0.62–7.56)	0.235
Appendectomy	2/3 (66.7%)	2.42 (0.22–27.01)	0.593
Benign gynecologic surgery	0/2 (0.0%)	NE	0.502
Panel B. In-hospital death			
Bowel resection/emergency GI surgery	40/73 (54.8%)	6.61 (3.66–11.95)	<0.001
Tumor surgery	11/70 (15.7%)	0.46 (0.23–0.94)	0.040
Urologic surgery	1/17 (5.9%)	0.17 (0.02–1.31)	0.081
Cholecystectomy	4/56 (7.1%)	0.18 (0.06–0.52)	<0.001
Other hernia repair	2/15 (13.3%)	0.43 (0.10–1.97)	0.369
Amputation for gangrene	10/26 (38.5%)	1.95 (0.84–4.52)	0.154
Abscess drainage/soft-tissue debridement	3/13 (23.1%)	0.87 (0.23–3.25)	1.000
Incisional hernia repair	2/11 (18.2%)	0.64 (0.13–3.03)	0.735
Appendectomy	0/3 (0.0%)	NE	0.573
Benign gynecologic surgery	0/2 (0.0%)	NE	1.000

Odds ratios compare each grouped surgical category with all remaining procedures in the geriatric available-case cohort. *p* values are from Fisher's exact test. NE indicates that the odds ratio was not estimable because one cell contained zero events. The "other procedures" category was not represented in the geriatric available-case cohort and is therefore not shown.

3.6. Multivariable Models for MIAE

Results of the main multivariable logistic regression analysis for MIAE are presented in Table 6. In the available-case cohort ($n = 364$), age ≥ 65 years was independently associated with MIAE (OR 2.10, 95% CI 1.13–3.90; $p = 0.018$). Lower LVEF was also independently associated with the primary endpoint (OR per +1% increase 0.88, 95% CI 0.83–0.93; $p < 0.001$), as were higher preoperative creatinine (OR 1.82, 95% CI 1.35–2.45; $p < 0.001$) and urgent presentation (OR 3.69, 95% CI 1.89–7.20; $p < 0.001$).

By contrast, MAPSE was not independently associated with MIAE after adjustment (OR 1.04, 95% CI 0.90–1.19; $p = 0.604$), and sex was not a significant predictor (OR 1.17, 95% CI 0.72–1.90; $p = 0.528$). In a geriatric sensitivity analysis, a Firth's penalized logistic regression model was fitted to address sparse-data bias related to the small reduced-LVEF subgroup. After adjustment for bowel resection/emergency gastrointestinal surgery, preoperative creatinine, urgent presentation, and sex, reduced preoperative LVEF $< 50\%$ remained independently associated with MIAE (adjusted OR 7.91, 95% CI 1.94–32.31). Bowel resection/emergency gastrointestinal surgery also remained independently associated with MIAE (adjusted OR 2.33, 95% CI 1.24–4.41).

Our findings regarding the reduced-LVEF subgroup ($< 50\%$) should be considered exploratory because of the small sample size ($n = 21$), which included 19 events and only 2 non-events. While the crude event rates (66.7% mortality and 90.5% MIAE) underscore the marked clinical vulnerability of these patients, the small subgroup size limits the precision of effect estimates. To mitigate sparse-data bias and quasi-separation, a Firth's penalized logistic regression model was applied and yielded a similar effect estimate; however, the wide confidence intervals indicate substantial uncertainty regarding the true magnitude of the association.

Table 6. Multivariable logistic regression models for MIAE.

Predictor	OR (95% CI)	p-Value
Main Model (Full Available-Case Cohort)		
Age $\geq$ 65 years	2.10 (1.13–3.90)	0.018
LVEF (per +1%)	0.88 (0.83–0.93)	<0.001
MAPSE (per +1 mm)	1.04 (0.90–1.19)	0.604
Preoperative creatinine (per +1 mg/dL)	1.82 (1.35–2.45)	<0.001
Urgent presentation	3.69 (1.89–7.20)	<0.001
Male sex	1.17 (0.72–1.90)	0.528
Geriatric Subgroup Sensitivity Model (Firth’s Penalized Regression)		
Reduced LVEF	7.91 (1.94–32.31)	
Preoperative creatinine (per +1 mg/dL)	1.81 (1.28–2.56)	
Urgent presentation	2.92 (1.42–6.00)	
Male sex	1.37 (0.80–2.36)	

The Main Model simultaneously adjusted for all listed baseline variables in the entire cohort with available postoperative data (N = 364). The Geriatric Subgroup Model limits the analysis to patients aged ≥ 65 years (N = 286) and applies Firth’s penalized likelihood estimation to obtain stable, defensible estimates for the reduced-LVEF predictor, which exhibited quasi-separation due to sparse data (only 2 non-events out of N = 21 patients with LVEF < 50% within this subgroup). For the penalized model, statistical significance is determined via the 95% CI.

4. Discussion

This study provides two clinically relevant observations. First, in available-case analyses, older adults in this non-cardiac surgical cohort experienced a higher burden of major in-hospital adverse events than younger patients. Second, within the geriatric subgroup, reduced preoperative LVEF identified a small but clinically important high-risk phenotype characterized by frequent postoperative AKI, higher in-hospital mortality, and lower MAPSE values.

Our cohort represents a high-acuity, all-cardiovascular disease population, with approximately two-thirds of cases consisting of emergency surgeries. This specific case-mix accounts for the high overall in-hospital mortality (19%) and the exceptionally high mortality seen in the reduced LVEF subgroup, distinguishing this population from a general, elective non-cardiac surgical cohort.

An important consideration when interpreting the age-group comparison is that the primary composite endpoint was assessed only in patients with complete postoperative creatinine measurements. A core methodological aspect of our study involves the informative missingness of postoperative creatinine, which was unavailable for 27.6% of the cohort. Because postoperative creatinine measurements were not routinely performed in stable patients who experienced shorter hospital stays and zero in-hospital mortality, our available-case analysis was systematically restricted to a higher-risk denominator. Consequently, the statistically significant age-group difference observed in MIAE rates (45.5% in geriatric vs. 30.8% in non-geriatric patients) must be interpreted cautiously. This finding is largely driven by an event-enriched denominator in the geriatric stratum rather than a pure biological age effect, representing a structural selection artifact that limits direct causal interpretation.

These findings are consistent with the broader geriatric perioperative literature showing that older surgical patients are more vulnerable to postoperative complications because age is closely intertwined with multimorbidity, frailty, functional decline, and reduced physiological reserve, rather than acting as an isolated biological risk factor [1–9]. Although the present dataset did not include formal frailty assessment or comprehensive geriatric evaluation, the age signal observed in the adjusted model likely reflects this broader vulnerability construct.

The renal component of the composite outcome is clinically meaningful. Postoperative AKI after non-cardiac surgery is associated with prolonged hospitalization, downstream cardiovascular and renal morbidity, and increased mortality, particularly in patients with advanced age, baseline kidney dysfunction, and coexisting cardiovascular disease [19–21]. Perioperative myocardial injury is also increasingly recognized as a clinically important determinant of short-term mortality after non-cardiac surgery [26]. In our cohort, higher preoperative creatinine and urgent presentation were strong multivariable correlates of MIAE, which is biologically plausible and further supports the cardiorenal nature of perioperative risk in older adults undergoing surgery.

The prognostic signal of reduced preoperative LVEF is also concordant with prior evidence showing that heart failure and lower ejection fraction are associated with worse postoperative outcomes after non-cardiac surgery [15–17]. In the present study, geriatric patients with LVEF < 50% had markedly higher odds of major in-hospital adverse events, postoperative AKI, and in-hospital death than those with LVEF $\geq$ 50%. However, these findings remain exploratory because the reduced-LVEF subgroup was small ($n = 21$). To address sparse-data bias and quasi-separation, a Firth's penalized logistic regression model was performed and yielded a similar effect estimate, supporting the robustness of the observed association. Nevertheless, the wide confidence intervals indicate substantial uncertainty regarding the true magnitude of the effect.

Future perioperative studies should investigate whether supranormal LVEF also carries prognostic implications in geriatric surgical patients, particularly in frail individuals with complex cardiometabolic and inflammatory profiles [27,28].

Because all patients in the cohort had documented pre-existing cardiovascular disease, the observed association between reduced LVEF and adverse postoperative outcome is particularly relevant to a perioperative population in whom limited cardiovascular reserve is already likely to influence organ vulnerability and hemodynamic tolerance. In this context, the use of a pragmatic threshold of LVEF < 50% was intended to identify clinically relevant systolic dysfunction in a way that is operationally applicable in perioperative practice, rather than to replace sex-specific ASE/EACVI reference ranges for normal LVEF.

The interpretation of reduced LVEF in elderly patients should also consider contemporary heart failure management strategies. Cardiac implantable electronic devices, including cardiac resynchronization therapy (CRT), represent an important component of contemporary heart failure management in selected patients with reduced ejection fraction, including older adults [29]. However, information regarding CRT and other cardiac implantable electronic devices was not systematically collected in the present study. Therefore, the potential influence of ventricular resynchronization therapy on the observed association between reduced LVEF and perioperative outcomes could not be evaluated and warrants investigation in future studies.

Medical therapy for heart failure was used across the spectrum of left ventricular systolic function according to clinical indication. Most patients with markedly reduced systolic function were receiving comprehensive guideline-directed medical therapy, including the four foundational pillars of contemporary heart failure management. In geriatric populations, optimization of pharmacological treatment is frequently complicated by multimorbidity, polypharmacy, frailty, and age-related physiological changes, all of which may influence treatment tolerance and adherence [30]. Therefore, the adverse outcomes observed among patients with reduced LVEF occurred despite evidence-based medical management, suggesting that impaired systolic function may remain an important marker of perioperative vulnerability even in medically treated patients.

Emerging AI-based perioperative risk models may eventually integrate echocardiographic, clinical, and frailty-related variables. However, AI methodologies were not evaluated in the present study and are mentioned only as a future research direction [31].

Nevertheless, our study has important limitations. Several clinically relevant variables, including detailed characterization of valvular disease, pulmonary artery systolic pressure, right ventricular function, and previous coronary revascularization, were unavailable and therefore could not be incorporated into the analyses [10,13,32,33]. Furthermore, treatment intensity, adherence, and longitudinal therapeutic response for heart failure were not evaluated. Beyond chronological age and isolated cardiovascular diagnoses, general multimorbidity represents a major determinant of perioperative risk in older adults, and future studies should incorporate multimorbidity-based classifications alongside echocardiographic markers to achieve more comprehensive perioperative risk stratification [34].

Operative case mix also warrants consideration. In procedure-specific univariable analyses, amputation for gangrene and bowel resection/emergency gastrointestinal surgery were associated with significantly higher odds of MIAE, whereas only bowel resection/emergency gastrointestinal surgery was associated with significantly higher odds of in-hospital death. Importantly, patients with LVEF < 50% were not significantly overrepresented in this high-death-risk surgical subgroup, and reduced LVEF remained independently associated with MIAE after adjustment for bowel resection/emergency gastrointestinal surgery, preoperative creatinine, urgent presentation, and sex. These findings suggest that the reduced-LVEF signal was not explained solely by operative case mix.

Although the present analysis used a pragmatic threshold of LVEF < 50% to identify patients with impaired systolic function, only 9 of the 21 patients in this subgroup had an LVEF < 40%, consistent with the conventional echocardiographic threshold used to define HFrEF, whereas the remaining 12 patients had mildly reduced ejection fraction (LVEF 40–49%). The limited number of patients with LVEF < 40% precluded a separate multivariable analysis of this subgroup.

The high absolute event rates observed in the present study should also be interpreted in the context of the underlying cohort characteristics. All participants had established cardiovascular disease, approximately two-thirds underwent urgent surgical admission, and a substantial proportion underwent high-risk abdominal or vascular procedures. Therefore, the study population represents a particularly high-acuity surgical cohort rather than an unselected non-cardiac surgical population.

MAPSE deserves a more nuanced interpretation. It was clearly lower in geriatric patients with reduced LVEF, supporting its role as a simple marker of impaired longitudinal systolic function [23,24]. However, lateral MAPSE did not demonstrate independent prognostic value after multivariable adjustment. This finding requires cautious interpretation; due to the limited sample size and the high physiological and statistical collinearity between LVEF and MAPSE as markers of systolic performance, our study may have been underpowered to detect the incremental prognostic utility of longitudinal function. Consequently, our results should not be viewed as minimizing the clinical utility of MAPSE in perioperative risk stratification, but rather as indicating that independent prognostic value could not be demonstrated within the constraints of the current dataset. Future studies incorporating more comprehensive echocardiographic phenotyping, including diastolic function, loading conditions, right ventricular performance, and myocardial reserve, are needed to better define its independent role [22].

From a practical perspective, these findings suggest that older surgical patients with reduced preoperative LVEF may warrant closer perioperative surveillance, particularly when urgent presentation or baseline renal vulnerability is also present. This may be especially relevant for perioperative hemodynamic management, postoperative renal monitoring,

and early recognition of clinical deterioration. At the same time, these results should not be interpreted as support for routine echocardiography in all older adults scheduled for non-cardiac surgery. Contemporary guidelines advise against indiscriminate preoperative transthoracic echocardiography but support targeted testing when results are likely to influence management [10–14]. Our findings are therefore better interpreted as supporting a selective, echocardiography-informed approach in older adults with suspected ventricular dysfunction, renal vulnerability, or urgent surgical presentation.

5. Study Limitations

This study has several limitations. First, the geriatric subgroup with LVEF < 50% was small ($n = 21$), which resulted in wide confidence intervals and limited the precision of the estimated effect sizes. The reduced-LVEF subgroup also exhibited a very high event burden. Although a Firth's penalized logistic regression model was used to mitigate sparse-data bias and quasi-separation, the small number of patients resulted in wide confidence intervals and limited the precision of effect estimates. Consequently, effect estimates should be interpreted cautiously and viewed as hypothesis-generating rather than definitive. Second, although the primary threshold of LVEF < 50% versus $\geq 50\%$ is clinically pragmatic and avoids excluding patients at the cut point, dichotomization of a continuous variable inevitably reduces information. In addition, this threshold does not fully reflect sex-specific ASE/EACVI reference ranges for normal LVEF.

Third, postoperative creatinine measurements were unavailable in 27.6% of the overall cohort. Importantly, this missing-data pattern was likely not random because postoperative laboratory testing was less frequently performed in clinically stable patients discharged early. Consequently, patients with more favorable postoperative evolution were systematically underrepresented in renal analyses, creating a potential selection bias that may have inflated the observed incidence of AKI and the composite MIAE endpoint. Therefore, all renal outcome analyses should be interpreted as available-case analyses rather than estimates applicable to the entire cohort.

Fourth, echocardiographic assessment was performed as a focused bedside transthoracic examination by a single operator. Although this approach improved methodological consistency, it may limit external reproducibility and does not allow for a formal assessment of interobserver variability.

Fifth, the dataset did not include several clinically important variables, such as formal frailty assessment, detailed comorbidity burden, functional status, surgical complexity, anesthetic exposure, perioperative hemodynamic data, or a sufficiently granular classification of operative severity. Furthermore, the echocardiographic dataset was intentionally focused and did not include detailed characterization of valvular heart disease, pulmonary artery systolic pressure (sPAP), right ventricular function, or other structural cardiac abnormalities that may independently influence perioperative cardiovascular outcomes [32]. Likewise, detailed information regarding previous coronary revascularization, including prior or recent percutaneous coronary intervention (PCI), was unavailable [33]. Although heart failure therapies were routinely prescribed according to clinical indication, detailed information regarding treatment duration, dose optimization, adherence, and longitudinal therapeutic response was unavailable and could not be incorporated into the analyses. These factors may represent important modifiers of perioperative cardiovascular risk and should be incorporated into future studies using more comprehensive echocardiographic and clinical phenotyping.

Sixth, AKI was defined exclusively by serum creatinine criteria because urine output and renal replacement therapy data were unavailable, which may have underestimated the true incidence according to the full KDIGO criteria.

Seventh, the primary composite endpoint combined events of differing clinical weight, and the overall signal may have been influenced unequally by its individual components.

Eighth, natriuretic peptide measurements (BNP/NT-proBNP) were not systematically available, precluding formal guideline-based classification of heart failure phenotypes, particularly HFpEF.

Finally, all patients had pre-existing cardiovascular disease and were treated in two centers from the same regional setting, which may limit the generalizability of the findings to broader non-cardiac surgical populations. As a secondary observational analysis, the present study can identify clinical associations but cannot establish causality.

Despite these limitations, the study also has practical strengths. It focuses on a clinically relevant geriatric surgical population with documented cardiovascular disease, uses a hard in-hospital composite outcome, applies standardized KDIGO creatinine criteria, and demonstrates a coherent relationship between reduced LVEF, lower MAPSE, and adverse perioperative evolution.

6. Conclusions

In available-case analyses, geriatric patients demonstrated a higher burden of major in-hospital adverse events than younger patients. Given the non-random pattern of missing postoperative creatinine measurements, this observation should be interpreted cautiously. Within the available-case geriatric cohort, reduced preoperative LVEF identified a small but clinically important subgroup with higher rates of postoperative AKI and in-hospital death. Because of the small number of patients with reduced LVEF and the observational design of the study, these findings should be considered exploratory and require confirmation in larger prospective cohorts. Future studies incorporating comprehensive geriatric assessment, multimorbidity profiling, and broader echocardiographic phenotyping may help refine perioperative risk stratification in older adults undergoing non-cardiac surgery.

Author Contributions: Conceptualization, A.B. and D.F.; methodology, L.F.R.; software, C.G.; validation, A.B., D.F. and C.G.; formal analysis, A.B.; investigation, A.B.; resources, C.G.; data curation, D.F.; writing—original draft preparation, A.B.; writing—review and editing, L.F.R.; visualization, D.F.; supervision, L.F.R.; project administration, C.G.; funding acquisition, C.G. All authors have read and agreed to the published version of the manuscript.

Funding: The payment of APC was supported by “Dunarea de Jos” University of Galati.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the “Dr. Aristide Serfioti” Emergency Military Hospital, Galati, Romania, protocol code: 326/M1-544/27 December 2022, and by the Ethics Committee of the “Sf. Apostol Andrei”, County Emergency Clinical Hospital, Galati, Romania, protocol code: 25942/13 October 2022.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Acknowledgments: The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AI	artificial intelligence
ASE	American Society of Echocardiography
AKI	acute kidney injury
CI	confidence interval
CIED	cardiac implantable electronic
CRT	cardiac resynchronization therapy
EACVI	European Association of Cardiovascular Imaging
GI	gastrointestinal
KDIGO	Kidney Disease- Improving Global Outcomes
LOS	length of stay
LVEF	left ventricular ejection fraction
MAPSE	mitral annular plane systolic excursion
MIAE	major in-hospital adverse events
OR	odds ratio
PCI	percutaneous coronary intervention
sPAP	systolic pulmonary artery pressure

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