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Integrating Frailty into Perioperative Risk Assessment: Development of a Novel Score for Postoperative Complications After Major Uro-Oncologic Surgery

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Abstract

Background/Objectives: Frailty is an important predictor of adverse postoperative outcomes but is not routinely incorporated into perioperative risk assessment in uro-oncology. This study evaluated the association between frailty and postoperative complications and developed a novel composite risk score for predicting outcomes after major elective uro-oncologic surgery. **Methods:** In this prospective, single-center observational study, patients aged ≥50 years with urologic malignancies undergoing major elective surgery were enrolled. Frailty was assessed preoperatively using the Clinical Frailty Scale (CFS). Demographic, clinical, perioperative, and laboratory data were collected. The primary outcome was the occurrence of Clavien–Dindo grade ≥ II postoperative complications during hospitalization. Independent predictors were identified using multivariable logistic regression and incorporated into a composite risk score. **Results:** A total of 154 patients were included, and 48.1% developed Clavien–Dindo grade ≥ II postoperative complications. Frailty was identified in 26.6% of patients. Age > 65 years, frailty (CFS ≥ 4), and a SASA score ≤ 14 were independent predictors of postoperative complications and were incorporated into a novel composite risk score. The score effectively stratified patients into low-, intermediate-, and high-risk groups, with complication rates increasing from 18.8% to 83.6% across risk categories. Patients in the high-risk group had higher odds of clinically significant postoperative complications than those in the low-risk group (OR 22.15, 95% CI 8.56–57.32). **Conclusions:** A composite risk score integrating chronological age, frailty, and the SASA score provides a simple, clinically applicable approach to perioperative risk stratification in major uro-oncologic surgery. Following external validation, it may support individualized postoperative care and risk-adapted monitoring.

Keywords: frailty; cancer; postoperative complications; SASA; ageing; novel score

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1. Introduction

Major uro-oncologic surgery is associated with considerable postoperative morbidity and mortality, posing a significant challenge for perioperative care [1,2]. Procedures such

as radical cystectomy, radical and partial nephrectomy, radical prostatectomy, and radical nephroureterectomy are associated with substantial postoperative complications, including gastrointestinal and infectious events, postoperative delirium, and intensive care unit (ICU) admission, particularly among older patients [2–4]. These complications adversely affect patient outcomes and place a considerable burden on the healthcare system.

With global physiological ageing and increasing life expectancy, a growing number of older and frail patients are undergoing major surgery, with more than 60% of urologic procedures performed in patients older than 65 years [5,6]. In this context, frailty has emerged as a critical determinant of surgical outcomes. Defined as a state of increased vulnerability and reduced physiological reserve, resulting in a diminished ability to respond to stressors such as surgery, frailty independently predicts adverse postoperative outcomes. Importantly, it is distinct from chronological age and represents a more reliable indicator of a patient's biological health status [7]. Given that cancer and its treatment may accelerate physiological ageing, the risk of frailty is particularly high among older adults with cancer, with an estimated prevalence of 40–50% [8,9]. However, its prognostic significance is not limited to elderly populations; it extends to younger cohorts as well, specifically those aged 50 to 64 years, demonstrating association with increased mortality and poorer survival outcomes in critically ill and cancer patients younger than 65 years [9,10]. Therefore, accurate perioperative risk assessment has become increasingly important for supporting informed clinical decision-making, optimizing perioperative care, and facilitating the efficient allocation of healthcare resources, particularly in frail patients with multiple comorbidities.

Several risk assessment tools have been developed to predict postoperative outcomes. Although the American Society of Anesthesiologists (ASA) physical status classification remains the most widely used method for preoperative risk stratification, it has limited predictive accuracy and does not account for intraoperative factors that substantially influence postoperative outcomes [11–13]. To address these limitations, several composite risk prediction models have been developed, including the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) Surgical Risk Calculator, the Estimation of Physiological Ability and Surgical Stress (E-PASS), and the Physiological and Operative Severity Score for the Enumeration of Mortality and Morbidity (POSSUM) [14–17]. The Surgical Apgar Score (SAS) is a simple and validated intraoperative scoring system that predicts postoperative complications and mortality. Furthermore, combining the SAS with the ASA classification (forming the SASA score) has been shown to further improve risk prediction. This combined score provides an objective, practical, and easily calculated measure of perioperative risk [18–20].

In parallel, frailty assessment has gained recognition as a powerful tool for perioperative risk stratification and has been proposed as a "surgical vital sign" [21]. Growing evidence indicates that frailty is a stronger predictor of postoperative complications than traditional risk assessment measures, including chronological age, ASA physical status classification, and comorbidity burden [22,23]. Compared with non-frail patients, frail surgical patients experience higher rates of postoperative complications, ICU admission, prolonged hospital stay, discharge to institutional care, and increased healthcare costs [24–26]. Furthermore, recent studies suggest that integrating frailty assessment, particularly the Clinical Frailty Scale (CFS), with established surgical risk tools such as the ASA and the combined Surgical Apgar Score and ASA (SASA), POSSUM and E-PASS further improves the prediction of postoperative complications [27–29].

However, evidence regarding a simple point-based scoring system specifically developed for patients undergoing uro-oncological surgery remains limited. Therefore, this study aimed to develop a novel composite risk score for predicting postoperative outcomes following major elective uro-oncologic surgery.

2. Materials and Methods

2.1. Study Design and Patient Selection

Following approval by the Ethics Committee of the Faculty of Medicine, University of Belgrade (decision number 25/VII-1, dated 8 July 2024) and with subsequent endorsement of the Ethical Committte of the University Clinical Center of Serbia (No. 1600/54, dated 13 October 2025), a prospective, single-center, observational cohort study was conducted. This study included patients aged ≥50 years diagnosed with urological malignancy undergoing major open elective uro-oncologic surgery at the Clinic of Urology, University Clinical Center of Serbia, between 10 July 2024 and 31 January 2025. Written informed consent was obtained from all participants, and the study protocol complied with the Declaration of Helsinki. Patients were excluded if they had severe cognitive impairment (Mini-Mental State Examination [MMSE] score 0–17), aphasia, a history of neurological disease or injury preventing effective communication or accurate baseline functional assessment, as well as those with missing clinical data, lack of cooperation, inability to complete the frailty assessment, or who declined participation. Figure 1 presents the flowchart of the study participant selection process.

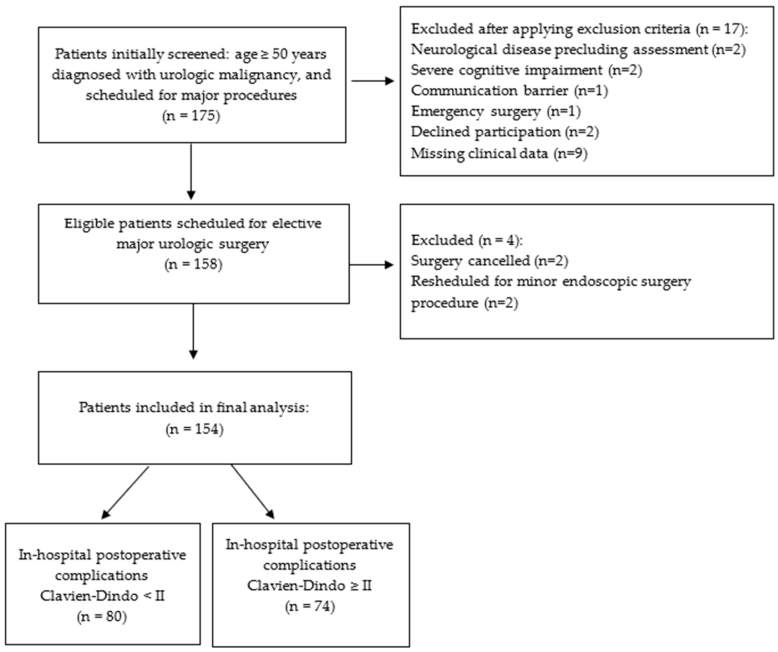


Figure 1. Flowchart of the study participant selection process.

2.2. Preoperative Frailty Assessment and Data Collection

Data of interest were obtained through patient interviews and review of medical records. Baseline demographic and clinical characteristics, including age, sex, height, weight, body mass index (BMI), place of residence, marital status, educational level, smoking and alcohol consumption status, comorbidities, and tumor-related characteristics (tumor location and presence of metastases), were collected. Smoking status was categorized into three groups: never smokers, former smokers (those who had previously smoked but had quit), and current smokers. The age-adjusted Charlson Comorbidity Index (aCCI) was calculated using the standardized scoring method, with a cut-off of 5 or greater being used to define the high-risk group [30,31]. Cognitive function was assessed using the Mini-Mental State Examination (MMSE).

Frailty was assessed preoperatively according to the baseline functional level using a validated Serbian version of the Clinical Frailty Scale (CFS 2.0) [32]. The CFS is a simple,

reliable tool for the identification of frailty, developed for the Canadian Study for Health and Ageing [33]. It classifies patients into nine categories by integrating clinical judgement with the assessment of comorbidity, cognitive impairment, and functional dependence. The first three categories of the scale (Very Fit, Fit, and Managing Well) describe non-frail individuals who remain active and experience few or no limiting symptoms. The intermediate categories (Very Mildly Frail, Mildly Frail and Moderately Frail) reflect progressively increasing levels of frailty and dependence. The final three categories (Severely Frail, Very Severely Frail, and Terminally Ill) identify patients with substantial care needs, marked functional impairment, and a limited life expectancy. All members of the research team involved in the CFS assessment completed standardized training before study initiation. Consistent with previous studies in the surgical population, a CFS score ≥ 4 was used to identify patients with increased frailty-related vulnerability [34]. This threshold includes patients living with very mild frailty, previously classified as "vulnerable" (CFS 4), in addition to those with established frailty (CFS ≥ 5), allowing the identification of patients with reduced physiological reserves who may be at increased risk of adverse postoperative outcomes. Although the CFS has primarily been validated in adults aged >65 years, perioperative guidelines recommend frailty assessment in younger high-risk patients, including those with malignancies [35]. This recommendation, together with evidence supporting the prognostic value of the CFS in the younger critically ill and oncology population, provided the rationale for its application in patients aged 50–65 years in the present study [9,10].

2.3. Perioperative Data

Perioperative variables included the American Society of Anaesthesiologists (ASA) physical status classification, surgical procedure, operative duration, estimated intraoperative blood loss, and intraoperative blood transfusion. Overall perioperative risk was assessed using the SASA score [19], which integrates the intraoperative Surgical Apgar Score (SAS) with the preoperative ASA physical status classification according to the following formula: $SASA = SAS + (6 - ASA) \times 2$. The total SASA score ranges from 0 to 20, with lower scores indicating a higher perioperative risk.

The SAS is a validated 10-point intraoperative scoring system based on estimated blood loss, the lowest mean arterial pressure, and the lowest heart rate recorded during surgery, with lower scores indicating a higher risk of postoperative complications [36]. The ASA physical status classification was obtained from the preoperative anaesthesiology assessment and reflects the patient's preoperative physical status, ranging from ASA I (a healthy patient) to ASA VI (a brain-dead patient whose organs are being removed for donor purposes) [12].

2.4. Follow-Up and Outcome Measures

The primary outcome was the occurrence of any postoperative complication of Clavien–Dindo grade II or higher occurring after the completion of surgery during the index hospitalization, classified according to the Clavien–Dindo classification system [37]. The Clavien–Dindo classification is a standardized five-grade system that categorizes postoperative complications according to their severity and the interventions required for their management. In patients who experienced multiple complications, only the highest Clavien–Dindo grade was considered for analysis. Postoperative complications were identified and recorded by a clinician who was blinded to the patients' frailty status and intraoperative data.

2.5. Statistical Analysis

Descriptive statistics included measures of central tendency (mean and median), measures of variability (standard deviation, 25th and 75th percentiles), and absolute and relative

frequencies. Normality of distribution was assessed using both graphical and analytical methods. Comparisons between groups were performed using the T test for independent samples or Mann–Whitney U test for numerical data, and the Chi-square test for categorical variables. Receiver operating characteristic (ROC) curve analysis was performed to assess the predictive performance of postoperative complications of Clavien–Dindo grade II or higher. The area under the curve (AUC), optimal cut-off values, sensitivity and specificity were calculated. Predictors of the outcome of interest were determined using univariate and multivariate logistic regression analysis. Variables associated with the primary outcome in univariable analyses were considered for multivariable logistic regression. To limit model overfitting, the number of candidate parameters was restricted in accordance with the number of observed outcome events. Variables with direct mathematical overlap were not entered simultaneously; therefore, age was preferred over age-adjusted CCI, SASA over ASA, and SASA was not modeled together with its constituent intraoperative components. Clinically relevant, non-redundant variables were entered into the multivariable model. Variables retaining statistical significance in the adjusted model were considered independent predictors of Clavien–Dindo grade ≥ II postoperative complications. Internal robustness of the final multivariable logistic regression model was assessed using 1000 bootstrap resamples. Bias-corrected and accelerated (BCa) 95% confidence intervals were obtained for the regression coefficients, and corresponding odds ratios and their 95% confidence intervals were derived by exponentiation of the coefficients and confidence limits. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using IBM SPSS Statistics, version 26.0.

3. Results

3.1. Baseline Characteristics

A total of 175 consecutive patients aged ≥50 years with urologic malignancy scheduled for major surgery were assessed for eligibility. After applying the exclusion criteria, 154 patients were included in the final analysis (Figure 1). Of the these, 121 (78.6%) were also included in our previously published study validating the Serbian version of the Clinical Frailty Scale [32]. The mean age of the study cohort was 66.3 ± 7.5 years, with 84 patients (54.5%) aged >65 years. Overall, 77% of the participants were male.

3.2. Postoperative Complications

One hundred twenty-three patients (79.8%) developed a total of 324 postoperative complications. The most common complications encountered during the postoperative period were renal (68/324; 20.99%), followed by infections (59/324; 18.21%), pulmonary (32/324; 9.88%), cardiovascular (31/324; 9.57%) and gastrointestinal (26/324; 8.02%) complications. (Supplemental Table S1). Overall, 74 patients (48.1%) experienced postoperative complications of Clavien–Dindo grade II or higher. Grade II complications were the most common, occurring in 57 patients (37.0%), whereas grade IIIa, IIIb, and IVa complications occurred in 4 (2.6%), 7 (4.5%), and 5 patients (3.2%), respectively (Supplemental Table S2). One patient (0.6%) died during hospitalization (Clavien–Dindo grade V).

Patients who developed clinically significant postoperative complications (Clavien–Dindo ≥ II) were significantly older than those with complications graded as Clavien–Dindo I or no complications (68.76 ± 7.09 vs. 64.06 ± 7.19 years, $p < 0.001$). Furthermore, age >65 years was significantly more frequent among patients with Clavien–Dindo grade ≥ II complications compared with those with Clavien–Dindo grade < II (73.0% vs. 37.5%, $p < 0.001$). No significant differences were observed between the two groups regarding sex distribution ($p = 0.789$), place of residence ($p = 0.053$), educational level ($p = 0.089$), smoking status ($p = 0.220$) and alcohol consumption ($p = 0.359$). The sociodemographic

characteristics of the study population according to postoperative complication rate are presented in Table 1.

Table 1. Sociodemographic characteristics of the study population according to postoperative complication rate.

Demographics	Total (n = 154)	Postoperative Complication Rate		p
		Clavien–Dindo < II (n = 80)	Clavien–Dindo ≥ II (n = 74)	
Age (years), mean ± sd	66.32 ± 7.5	64.06 ± 7.19	68.76 ± 7.09	<0.001
≤65	70 (45.5)	50 (62.5)	20 (27.0)	<0.001
>65	84 (54.5)	30 (37.5)	54 (73.0)	
Sex, n (%)				
Male	118 (76.6)	62 (77.5)	56 (75.7)	0.789
Female	36 (23.4)	18 (22.5)	18 (24.3)	
Place of residence, n (%)				
Urban	113 (73.4)	64 (80.0)	49 (66.2)	0.053
Rural	41 (26.6)	16 (20.0)	25 (33.8)	
Education, n (%)				
Elementary school	22 (14.3)	6 (7.5)	16 (21.6)	0.089
High school	84 (54.5)	46 (57.5)	38 (51.4)	
College/Higher School	30 19.5)	18 (22.5)	12 (16.2)	
University degree	18 (11.7)	10 (12.5)	8 (10.8)	
Smoking status, n (%)				
Never-smoker	68 (44.2)	31 (38.8)	37 (50.0)	0.220
Current smoker	63 (40.9)	38 (47.5)	25 (33.8)	
Former smoker	23 (14.9)	11 (13.8)	12 (16.2)	
Alcohol consumption, n (%)	19 (12.3)	8 (10.0)	11 (14.9)	0.359

The comparison of preoperative characteristics between patients with Clavien–Dindo < II and Clavien–Dindo ≥ II complications is presented in Table 2. No significant differences were observed in mean BMI between the groups ($p = 0.409$), nor in BMI categories ($p = 0.591$). Cardiomyopathy was more prevalent in the Clavien–Dindo ≥ II group than in the Clavien–Dindo < II group (24.3% vs. 8.8%, $p = 0.009$), as was peripheral vascular disease (36.5% vs. 17.5%, $p = 0.008$). Assessment using the age-adjusted Charlson Comorbidity Index (aCCI) demonstrated a significantly greater proportion of patients with high aCCI score (≥5) in the Clavien–Dindo ≥ II group compared with the Clavien–Dindo < II group (82.4% vs. 60.0%, $p = 0.002$). Regarding ASA status, patients classified as ASA grade III were significantly more common among patients with clinically significant postoperative complications (55.4% vs. 32.5%, $p = 0.004$).

Patients with Clavien–Dindo grade ≥ II complications were also more likely to have undergone previous surgery (89.2% vs. 75.0%, $p = 0.023$). However, no significant difference was observed in the history of previous intra-abdominal surgery ($p = 0.228$). The distribution of urological malignancy localization differed significantly between the groups ($p = 0.002$). Bladder cancer was more frequent among patients with Clavien–Dindo grade ≥ II complications (39.2% vs. 15.0%), whereas kidney cancer was more common among those with Clavien–Dindo grade < II complications (58.8% vs. 39.2%). Surgical approach differed significantly between the groups ($p = 0.003$), with cystectomy being more frequent among patients with Clavien–Dindo ≥ II complications (40.5% vs. 16.3%). Neoadjuvant chemotherapy was administered to 5 patients (3.2%).

Finally, frailty was strongly associated with the severity of postoperative complication. A frailty score ≥4 was observed in 41.9% of patients with Clavien–Dindo grade ≥ II compli-

cations compared with only 12.5% of those with Clavien–Dindo grade < II complications ($p < 0.001$).

Table 2. Preoperative characteristics of the study population according to postoperative complication rate.

Preoperative Characteristics	Total ($n = 154$)	Postoperative Complication Rate		p
		Clavien–Dindo < II ($n = 80$)	Clavien–Dindo ≥ II ($n = 74$)	
BMI (kg/m^2), mean ± sd	26.82 ± 4.53	26.53 ± 3.79	27.14 ± 5.24	0.409
BMI categories, *n* (%)				
Underweight/Normal weight	57 (37.0)	28 (35.0)	29 (39.2)	0.591
Overweight/Obesity	97 (63.0)	52 (65.0)	45 (60.8)	
Presence of comorbidities, *n* (%)	138 (89.6)	68 (85.0)	70 (94.6)	0.092
Diabetes mellitus	37 (24.0)	18 (22.5)	19 (25.7)	0.645
Hypertension	123 (79.9)	63 (78.8)	60 (81.1)	0.719
Cardiomyopathy	25 (16.2)	7 (8.8)	18 (24.3)	0.009
Peripheral vascular disease	41 (26.6)	14 (17.5)	27 (36.5)	0.008
aCCI interval, *n* (%)				
aCCI < 5	45 (29.2)	32 (40.0)	13 (17.6)	0.002
aCCI ≥ 5	109 (70.8)	48 (60.0)	61 (82.4)	
ASA status				
II	87 (56.5)	54 (67.5)	33 (44.6)	0.004
III	67 (43.5)	26 (32.5)	41 (55.4)	
History of previous surgery, *n* (%)	126 (81.8)	60 (75.0)	66 (89.2)	0.023
Previous intra-abdominal surgery, *n* (%)	57 (37.0)	26 (32.5)	31 (41.9)	0.228
Localization of urological malignancy, *n* (%)				
Prostate	24 (15.6)	16 (20.0)	8 (10.8)	0.002
Kidney	76 (49.4)	47 (58.8)	29 (39.2)	
Ureter	13 (8.4)	5 (6.3)	8 (10.8)	
Bladder	41 (26.6)	12 (15.0)	29 (39.2)	
Surgical approach, *n* (%)				
Prostatectomy	24 (15.6)	16 (20.0)	8 (10.8)	0.003
Nephrectomy/nephroureterectomy	87 (56.5)	51 (63.8)	36 (48.6)	
Cystectomy and other *	43 (27.9)	13 (16.3)	30 (40.5)	
Metastases, *n* (%)	7 (4.5)	2 (2.5)	5 (6.8)	0.262
Frailty CFS ≥ 4, *n* (%)	41 (26.6)	10 (12.5)	31 (41.9)	<0.001

Abbreviations: BMI, body mass index; aCCI, age-adjusted Charlson Comorbidity Index; ASA, American Society of Anesthesiologists; and CFS, Clinical Frailty Scale. * Cystectomy and nephroureterectomy/partial cystectomy and ureterectomy.

Intraoperative characteristics according to postoperative complication rate are presented in Table 3. Patients who developed Clavien–Dindo ≥ II complications underwent significantly longer surgical procedures than those with Clavien–Dindo < II complications, with a median operative time of 170 (125–210) minutes versus 123 (100–170) minutes, respectively ($p < 0.001$). Furthermore, procedures lasting more than 180 min were significantly more common in the Clavien–Dindo ≥ II group (39.2% vs. 15.0%, $p = 0.001$). Intraoperative blood loss was also significantly greater among patients with clinically significant postoperative complications ($p < 0.001$). Patients with blood loss exceeding 500 mL were markedly overrepresented in the Clavien–Dindo ≥ II group (39.2% vs. 10.0%, $p < 0.001$). Blood transfusions were administered to 45.9% of patients in the Clavien–Dindo ≥ II group compared with only 7.5% of patients in the Clavien–Dindo < II group ($p < 0.001$). Both the median Surgical Apgar Score (SAS) ($p < 0.001$), and the median SASA score were significantly lower among patients with Clavien–Dindo ≥ II complications ($p < 0.001$).

Table 3. Intraoperative characteristics according to postoperative complication rate.

Intraoperative Characteristics	Total (n = 154)	Postoperative Complication Rate		p
		Clavien–Dindo < II (n = 80)	Clavien–Dindo ≥ II (n = 74)	
Surgery duration (min) *	150 (115–186.2)	123 (100–170)	170 (125–210)	<0.001
Surgery duration, n (%)				
≤180 min	113 (73.4)	68 (85.0)	45 (60.8)	0.001
>180 min	41 (26.6)	12 (15.0)	29 (39.2)	
Blood loss (mL) *	300 (50–500)	200 (50–300)	500 (200–700)	<0.001
Blood loss (mL), n (%)				
<50 mL	40 (26.0)	31 (38.8)	9 (12.2)	
50–500 mL	77 (50.0)	41 (51.3)	36 (48.6)	<0.001
>500 mL	37 (24.0)	8 (10.0)	29 (39.2)	
Blood transfusion, n (%)	40 (26.0)	6 (7.5)	34 (45.9)	<0.001
SAS *	7 (6–8)	8 (7–9)	6 (5–7)	<0.001
SASA *	14 (13–16)	15 (14–16)	13 (12–14)	<0.001

Abbreviations: SAS, Surgical Apgar score; SASA, Surgical Apgar Score combined with American Society of Anesthesiologist status; and * median (25th–75th percentile).

The area under the curve (AUC) for SASA for differentiation of postoperative complication rate was 0.820 ($p < 0.001$). The diagnostic performance of SASA ≤ 14 for predicting postoperative complication rate in terms of sensitivity, specificity, PPV and NPV was 77.0%, 71.3%, 71.3% and 77.0%, respectively. The reported PPV and NPV correspond to the observed postoperative complication rate of 48.1% in this cohort and are therefore prevalence-dependent (Figure 2).

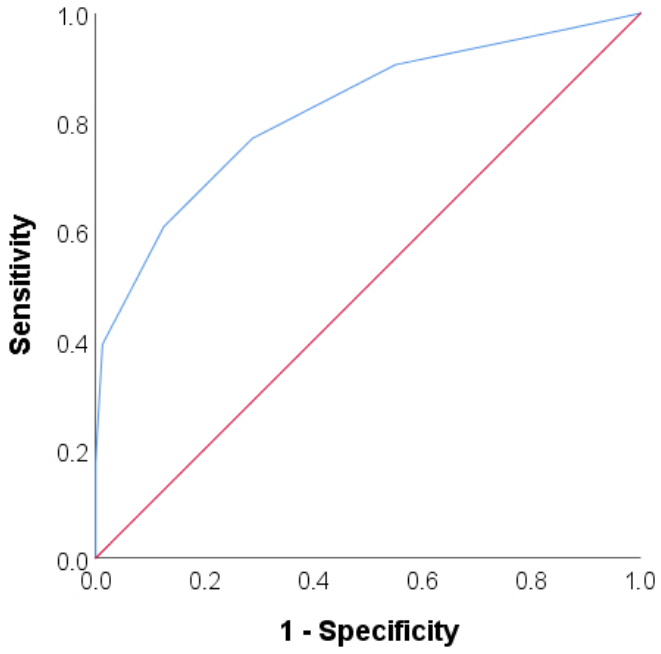


Figure 2. ROC curve of SASA for differentiation of postoperative complication rate. The blue line represents the ROC curve, while the red line represents the reference line.

3.3. Univariate and Multivariate Logistic Regression

Univariate and multivariate logistic regression analyses for predictors of clinically significant postoperative complication rate are presented in Table 4. In the univariate analysis, patients older than 65 years (OR 4.50, 95% CI 2.27–8.92, $p < 0.001$), a history of previous surgery (OR 2.75, 95% CI 1.13–6.71, $p = 0.026$), cardiomyopathy (OR 3.35, 95% CI 1.31–8.58,

$p = 0.012$) and peripheral vascular disease (OR 2.71, 95% CI 1.28–5.71, $p = 0.009$) were significant predictors of Clavien–Dindo ≥ II postoperative complications. Charlson Comorbidity Index was significantly associated with postoperative complications (OR 3.13, 95% CI 1.48–6.61, $p = 0.003$), as was higher ASA status (OR 2.58, 95% CI 1.34–4.97, $p = 0.005$). A frailty score ≥ 4 emerged as one of the strongest preoperative predictors, increasing the odds of clinically significant postoperative complications more than fivefold (OR 5.05, 95% CI 2.25–11.32, $p < 0.001$). Intraoperative factors were likewise strongly associated with adverse outcomes. Surgical duration greater than 180 min increased the risk by more than three times (OR 3.65, 95% CI 1.69–7.89, $p = 0.001$). Compared with patients without clinically significant blood loss (<50 mL), blood loss of 50–500 mL was associated with a threefold increase in odds (OR 3.02, 95% CI 1.27–7.89, $p = 0.012$), while blood loss >500 mL was associated with a more than twelvefold increase in odds of having clinically significant postoperative complications (OR 12.49, 95% CI 4.25–36.72, $p < 0.001$). The need for intraoperative blood transfusion was also a strong predictor of clinically significant complications (OR 10.48, 95% CI 4.06–36.72, $p < 0.001$). Among all evaluated variables, a SASA score ≤ 14 showed one of the strongest associations with postoperative complication rate, conferring an approximately eightfold increased risk of clinically significant complications (OR 8.31, 95% CI 4.02–17.18, $p < 0.001$). Surgical approach was also significantly associated with outcome ($p = 0.003$); compared with prostatectomy, cystectomy alone or in combination with ureterectomy/nephroureterectomy was associated with approximately 4.6-fold higher odds of complications (OR 4.62, 95% CI 1.58–13.45, $p = 0.005$), and with approximately 3.3-fold higher odds compared with nephrectomy/nephroureterectomy (OR 3.27, 95% CI 1.50–7.12, $p = 0.003$).

Table 4. Univariate and multivariate logistic regression analysis with Clavien–Dindo ≥ II as dependent variable.

Variable	*p*	OR	95% CI
Univariate			
Age > 65	<0.001	4.50	2.27–8.92
History of previous surgery	0.026	2.75	1.13–6.71
Cardiomyopathy	0.012	3.35	1.31–8.58
Peripheral vascular disease	0.009	2.71	1.28–5.71
aCCI interval	0.003	3.13	1.48–6.61
ASA status	0.005	2.58	1.34–4.97
Frailty, CFS ≥ 4	<0.001	5.05	2.25–11.32
Surgery duration, >180 min	0.001	3.65	1.69–7.90
Blood loss (mL)			
<50 mL	ref.	-	-
50–500 mL	0.012	3.02	1.27–7.20
>500 mL	<0.001	12.49	4.25–36.72
Blood transfusion	<0.001	10.48	4.06–36.72
SASA ≤ 14	<0.001	8.31	4.02–17.18
Surgical approach, *n* (%)			
Prostatectomy vs. Cystectomy and other *	0.005	4.62	1.58–13.45
Nephrectomy/Nephroureterectomy vs. Cystectomy and other *	0.003	3.27	1.50–7.12
Multivariate			
SASA ≤ 14	<0.001	7.97	3.59–17.66
Frailty, CFS ≥ 4	0.017	3.15	1.23–8.08
Age > 65	0.002	3.59	1.60–8.08

Abbreviations: CFS, Clinical Frailty Scale; SASA, Surgical Apgar Score combined with American Society of Anaesthesiologists score; aCCI, age-adjusted Charlson Comorbidity Index; ASA, American Society of Anesthesiologists; and * Cystectomy and nephroureterectomy/partial cystectomy and ureterectomy.

Based on the number of outcome events and after excluding overlapping predictors, clinically relevant variables from the univariate logistic regression analysis were entered into the multivariable logistic regression model. Patients with a SASA score ≤ 14 had nearly eight times greater odds of developing Clavien–Dindo ≥ II complications (OR 7.97, 95% CI 3.59–17.66, $p < 0.001$). A frailty score ≥ 4 independently increased the odds more than threefold (OR 3.15, 95% CI 1.23–8.08, $p = 0.017$), while age > 65 years remained a significant predictor, increasing the odds of clinically significant complications by approximately 3.6 times (OR 3.59, 95% CI 1.60–8.08, $p = 0.002$). Surgical approach was not independently associated with Clavien–Dindo ≥ II postoperative complications in the multivariable analysis ($p = 0.082$).

Bootstrap validation using 1000 resamples confirmed the robustness of the final multivariable model. Age > 65 years remained independently associated with postoperative complications (OR 3.59, BCa 95% CI 1.47–10.48, $p = 0.003$), as did SASA ≤ 14 (OR 7.97, BCa 95% CI 3.20–29.70, $p = 0.001$), and frailty defined as CFS ≥ 4 (OR 3.16, BCa 95% CI 1.41–8.76, $p = 0.004$).

3.4. Novel Score Development and Internal Validation

Based on the independent predictors identified in the multivariate logistic regression analysis, a novel composite risk score was developed incorporating age, frailty status, and SASA score (Table 5). Point allocation was determined according to the relative strength of association observed in the multivariate model. Age > 65 years and frailty score ≥ 4 were each assigned 1 point, whereas SASA score ≤ 14, which demonstrated the strongest association with clinically significant postoperative complications, was assigned 2 points. The total score ranged from 0 to 4 points.

Table 5. Novel composite risk score construction.

Variable	Category	Points
Age	≤65 years	0
Age	>65 years	1
Frailty score	<4	0
Frailty score	≥4	1
SASA score	>14	0
SASA score	≤14	2

Abbreviations: SASA, Surgical Apgar Score combined with American Society of Anaesthesiologists score.

Patients were subsequently stratified into three risk categories according to their total score: low risk (0–1 points), medium risk (2 points), and high risk (3–4 points) of postoperative complications. The incidence of clinically significant postoperative complications increased progressively across risk categories (Table 6 and Supplemental Table S3). In the low-risk group, only 12 of 64 patients (18.8%) developed Clavien–Dindo ≥ II complications, and in the medium-risk group, postoperative complications occurred in 16 of 35 patients (45.7%). The highest complication rate was observed in the high-risk group, where 46 of 55 patients (83.6%) developed Clavien–Dindo ≥ II complications.

Table 6. Predictive performance of the composite risk score for clinically significant postoperative complications.

Risk Category	Clavien–Dindo < II	Clavien–Dindo ≥ II	OR	95% CI
Low risk (0–1)	52/64 (81.3%)	12/64 (18.8%)	ref.	-
Medium risk (2)	19/35 (54.3%)	16/35 (45.7%)	3.65	1.46–9.11
High risk (3–4)	9/55 (16.4%)	46/55 (83.6%)	22.15	8.56–57.32

Compared with the low-risk category, patients in the medium-risk group had a 3.65-fold higher odds of developing postoperative complications (OR 3.65, 95% CI 1.46–9.11). The risk increased markedly in the high-risk category, where patients exhibited more than a 22-fold higher likelihood of postoperative complications (OR 22.15, 95% CI 8.56–57.32) relative to low-risk patients.

The discriminatory performance of SASA, dichotomized SASA, the Age + CFS model, and the composite 0–4 score is presented in Table 7. SASA evaluated on its original numerical scale demonstrated good discrimination for clinically significant postoperative complications, with an AUC of 0.820 (95% CI 0.754–0.887). When dichotomized at the cut-off of ≤14, the AUC decreased to 0.741 (95% CI 0.661–0.821). The Age + CFS model yielded an AUC of 0.725 (95% CI 0.645–0.806).

Table 7. The discriminatory performance of the individual predictors and the composite score.

Variable	AUC with 95% CI for AUC
SASA	0.820 (0.754–0.887)
SASA ≤ 14	0.741 (0.661–0.821)
Age + CFS	0.725 (0.645–0.806)
Score (0–4)	0.828 (0.763–0.894)

The composite 0–4 score showed the highest discriminatory performance among the evaluated approaches, with an AUC of 0.828 (95% CI 0.763–0.894), which was numerically higher than that of SASA assessed on its original numerical scale (0.828 vs. 0.820). The lower AUC observed for SASA ≤ 14 compared with continuous SASA indicates a loss of discriminatory information following dichotomization.

In paired sample difference ROC analysis, there was no statistically significant difference in discriminatory performance between dichotomized SASA (≤14) and the Age + CFS model (AUC 0.741 vs. 0.725, $p = 0.749$), while risk score AUC differed significantly from SASA ≤ 14 ($p < 0.001$) and Age + CFS model ($p = 0.002$).

In Table 8, length of postoperative stay according to the composite risk score for clinically significant postoperative complications is presented. The length of postoperative hospital stay increased across composite risk categories, with a median of 9 days (IQR 8–10.75) in the low-risk group, 10 days (IQR 8–13) in the medium-risk group, and 11 days (IQR 9–13) in the high-risk group. The overall difference between groups was statistically significant ($p = 0.002$), with a significant difference observed between the low- and high-risk groups ($p < 0.001$).

Table 8. Length of postoperative stay according to the composite risk score for clinically significant postoperative complications.

Composite Risk Score	Length of Postoperative Stay, Median (25th–75th Percentile)	*p*
Low risk (0–1)	9 (8–10.75)	0.002 * low vs. high ($p <$ 0.001)
Medium risk (2)	10 (8–13)	
High risk (3–4)	11 (9–13)	

* between-group significance.

4. Discussion

The main finding of this study is the development of a novel composite risk score that integrates age, frailty, and the SASA score to stratify patients undergoing major urologic oncologic surgery according to their risk of postoperative complications. The score effectively differentiated low-, intermediate-, and high-risk patients, with progressively

increasing rates of Clavien–Dindo grade ≥ II complications across the three risk categories. High-risk patients had higher odds of postoperative complications than those in the low-risk category, highlighting the potential clinical utility of this simple risk stratification tool. More than one-quarter of the cohort was classified as frail, underscoring the high prevalence of reduced physiological reserve in this patient population and the importance of incorporating frailty assessment into routine perioperative evaluation. Unlike existing surgical risk assessment tools that primarily rely on physiological or intraoperative variables, the proposed score combines frailty with established perioperative risk factors, providing a more comprehensive assessment of postoperative risk in patients undergoing major urologic oncologic surgery.

Our study findings, which reveal an independent association between frailty and Clavien–Dindo grade ≥ II postoperative complications, align with the growing body of evidence indicating that frailty provides prognostic insight that extends beyond conventional perioperative risk assessments. Frailty is identified as a reliable predictor of postoperative morbidity and mortality across a wide range of surgical specialties, including emergency laparotomy [38], general surgery [39], cardiac surgery [40], and hip surgery [41]. Similar findings have been reported in urologic surgery, where the adverse prognostic association of frailty extends across different procedures, including major oncologic operations, and is not restricted to the oldest patients [42,43]. A systematic review and meta-analysis by Aceto et al. has confirmed that frailty is strongly associated with prolonged hospital stay, increased postoperative complications, and higher mortality following urologic oncologic surgery [44]. Importantly, studies involving patients undergoing radical cystectomy have reported that frailty is an independent predictor of postoperative morbidity and mortality, with a stronger and comparable association with adverse perioperative outcomes relative to chronological age and comorbidity burden [45–47]. These findings support the concept that frailty should not be regarded merely as a surrogate marker of advanced age or comorbidity, but rather as a measure of diminished physiological reserve and increased vulnerability to surgical stress.

Although chronological age and frailty are closely related, patients of similar age may differ substantially in their physiological reserve and ability to withstand surgical stress. In our study, both chronological age and frailty remained independent predictors of postoperative complications, highlighting their complementary prognostic value. Therefore, incorporating frailty assessment alongside chronological age may provide a more comprehensive and individualized approach to perioperative risk stratification.

In our cohort, the SASA score emerged as a particularly strong perioperative predictor of postoperative complications. This aligns with the findings of Farina-Castro et al., who identified SASA and SAS as strong predictors of postoperative morbidity and mortality in nonagenarian surgical patients [48]. Similarly, a recent study demonstrated that SASA outperformed SAS in predicting early postoperative ICU admission, further supporting its value in perioperative risk stratification [49]. Together, these findings underscore the importance of integrating preoperative patient characteristics with intraoperative physiological parameters to refine perioperative risk assessment. Previous studies have highlighted the potential value of combining frailty with established perioperative risk measures. Amin et al. found that combining frailty with the ASA physical status classification modestly improved predictive performance compared with frailty indices alone [50]. Specifically, Yin et al. demonstrated that adding the Clinical Frailty Scale to the SASA significantly enhanced its ability to discriminate postoperative complications in older patients undergoing elective abdominal surgery [27]. Similarly, Mastalerz et al. identified SAS as an independent predictor of 30-day postoperative morbidity in older patients undergoing elective laparoscopic cholecystectomy, whereas frailty and advanced age were associated with

one-year mortality [51]. More recently, the FRAC cohort study developed a multivariable risk score for postoperative complications in older patients undergoing elective urological surgery, incorporating frailty assessed through physical performance (SPPB) alongside clinical parameters, whereas CFS-assessed frailty was not retained in the final model [52].

Building on this evidence, our study focused exclusively on patients undergoing major open uro-oncological surgery and proposed a simplified, clinically applicable, point-based composite score integrating chronological age, CFS, and SASA for stratification of in-hospital postoperative complication risk. However, further validation is required to establish the generalizability and clinical utility of the proposed new composite score.

The clinical implications of our findings extend beyond risk prediction, suggesting a two-phase approach to perioperative patient management. Preoperatively, the assessment of baseline functional status using CFS enables early detection of patients with reduced physiological reserve and increased vulnerability to adverse postoperative outcomes. This may facilitate individualized preoperative management, including comorbidity optimization and consideration of targeted prehabilitation strategies. Although the interval between cancer diagnosis and surgery may limit opportunities for extensive preoperative optimization, early identification of frailty remains clinically relevant. A recent systematic review and meta-analysis suggested that prehabilitation interventions may reduce overall postoperative complications in frail patients undergoing cancer surgery [53]. However, a recent multicenter randomized trial by McIsaac et al. found no significant reduction in postoperative complications or disability following home-based prehabilitation in older surgical patients with frailty [54]. These findings highlight the need for further research to determine the effectiveness of individualized preoperative interventions, particularly in patients undergoing major uro-oncologic surgery.

In contrast, the final clinical utility of our proposed composite score lies in its potential application at the end of anaesthesia, when both preoperative and intraoperative variables are available. By combining chronological age, frailty and the SASA score, it integrates baseline physiological vulnerability with the patient's intraoperative course. As its components can be obtained during standard perioperative care, the score can be calculated without additional specialized testing. Following external validation, it may support early postoperative risk stratification, facilitating individualized care planning, and guide decisions regarding the appropriate level of postoperative monitoring and care.

Although frailty is increasingly recognized as an important determinant of surgical outcomes, evidence regarding its integration with established intraoperative risk scores in major urologic oncologic surgery remains limited. Our findings suggest a complementary role for preoperative frailty assessment in identifying patients who may benefit from targeted optimization and for a composite score in supporting risk-adapted postoperative management. Further studies are needed to confirm its clinical utility and potential impact on postoperative outcomes.

Strengths and Limitations

This study has several strengths and limitations. Its main strengths include the prospective design, the assessment of frailty using a standardized and validated CFS, and the objective grading of postoperative outcomes using the established Clavien–Dindo classification system. An additional contribution of our study is the development of a simple, clinically applicable composite risk score integrating chronological age, preoperative frailty, and intraoperative physiological parameters. The proposed score relies on routinely available clinical data without requiring additional diagnostic testing.

However, several limitations should be acknowledged. First, this was a single-center study involving a relatively small sample of patients undergoing major urologic oncologic

surgery, which may limit the generalizability of these findings. Second, postoperative complications were assessed only during the hospitalization, potentially underestimating overall postoperative morbidity by excluding complications occurring after discharge. Furthermore, the proposed score was developed and evaluated within the same cohort, without independent validation. Future multicenter studies with a larger and more diverse patient population are needed to validate the proposed score and to assess its applicability across different surgical approaches and clinical settings.

5. Conclusions

Integrating frailty with chronological age and the SASA score provides a simple, clinically applicable approach to risk stratification at the end of major uro-oncologic surgery. This composite score captures complementary dimensions of surgical risk that are not reflected by conventional assessment tools alone and has the potential to support individualized postoperative care planning and monitoring. External validation is warranted before routine clinical implementation, but the proposed model represents a promising step towards more personalized perioperative care in urologic oncology.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jcm15228968/s1, Table S1: Type of postoperative complications; Table S2: Sugical complications according to Clavien-Dindo Classification; Table S3: The distribution of Clavien–Dindo ≥ II postoperative complications according to five possible score values.

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

Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to institutional and participant privacy restrictions.

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Abbreviations

The following abbreviations are used in this manuscript:

SASA	Surgical Apgar Score combined with the American Society of Anesthesiologists physical status classification
CFS	Clinical Frailty Scale

ICU	Intensive care unit
ASA	American Society of Anesthesiologists
SAS	Surgical Apgar Score
ACS NSQIP	American College of Surgeons National Surgical Quality Improvement Program
E-PASS	Estimation of Physiological Ability and Surgical Stress
POSSUM	Physiological and Operative Severity Score for the Enumeration of Mortality and Morbidity
MMSE	Mini-Mental State Examination
aCCI	Age-adjusted Charlson Comorbidity Index
BMI	Body mass index

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