Surgical Stress and Physiological Reserve: A Novel Framework Predicts Complications and Optimizes Care Pathways in High-Energy Femur Fracture Surgery

Sumin Jeong BSN, Kole Joachim BA, Adrian Lin BS, Brandon Gettleman MD, Christopher Hamad MD, Amanda Perrotta BS, Ezekiel Dingle, BS, Alexandra Stavrakis MD, Alexander B. Christ MD
[1]David Geffen School of Medicine at UCLA, Department of Orthopaedic Surgery, Los Angeles, CA
suminjeong@mednet.ucla.edu

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INTRODUCTION: Postoperative outcomes following high-energy femur fracture surgery vary widely. Existing models often miss integrating surgical stress and physiologic reserve. We developed a data-driven framework to quantify both using registry data and evaluated their combined effect on short-term outcomes after fixation.

METHODS: We analyzed 6,118 femur fracture cases from NSQIP (2019–2023); 3,774 had complete data. Patient characteristics were summarized, including the sex distribution (31% male). Using principal component analysis, we derived two indices: a Hemodynamic Stress Index (operative time, RVUs, transfusions, bleeding, BMI, urgency) and a Physiologic Reserve Score (age, albumin, creatinine, dialysis, function, comorbidities). Patients were categorized into quadrants: High Stress/Low Reserve (HS/LR, n=1,021), High Stress/High Reserve (HS/HR, n=866), Low Stress/Low Reserve (LS/LR, n=866), and Low Stress/High Reserve (LS/HR, n=1,021). Multivariable regression assessed complications, referencing HS/HR.

RESULTS SECTION: Among 3,774 patients, LS/LR had the highest mean age (79.8±9.8 years), while HS/LR patients were older (76.7±11.1 years) than HS/HR (62.1±18.3 years), with higher BMI (32.5±8.7 vs. 31.9±8.2). Sex distributions differed across groups as well. Male patients were most frequently classified as LS/HR (35.8%) while female patients were most frequently grouped as HS/LR (74.4%). HS/LR experienced longer length of stay (6.45 vs. 4.91 days), higher readmissions (9.4% vs. 3.9%), and reoperations (3.5% vs. 1.5%) than LS/HR. Multivariable regression revealed HS/LR had higher odds of pneumonia (OR=3.31, 95% CI: 1.64-6.68), MI (OR=5.57, 95% CI: 1.25-24.76), sepsis (OR=3.16, 95% CI: 1.27-7.82), progressive renal insufficiency (OR=2.73, 95% CI: 1.50-4.96), acute renal failure (OR=5.14, 95% CI: 1.15-23.02), UTI (OR=2.17, 95% CI: 1.35-3.49), and postoperative bleeding (OR=2.42, 95% CI: 1.99-2.94) ($p<0.05$). LS/LR had increased risk for MI (OR=11.79, 95% CI: 2.77-50.15), pneumonia (OR=5.36, 95% CI: 2.70-10.62), and acute renal failure (OR=5.05, 95% CI: 1.10-23.10) ($p<0.05$). LS/HR had reduced odds for DVT (OR=0.42, 95% CI: 0.20-0.87), postoperative bleeding (OR=0.60, 95% CI: 0.48-0.75), and progressive renal insufficiency (OR=0.33, 95% CI: 0.13-0.85) ($p<0.05$).

DISCUSSION: This study introduces a novel framework that integrates measures of surgical stress and physiological reserve to stratify postoperative outcomes following high-energy femur fracture surgeries. By categorizing patients into four different quadrants, we were able to demonstrate that outcomes differ substantially depending on the integration between hemodynamic stress index and physiological reserve. Patients grouped in the high stress/low reserve category experienced the highest rate of complications, including higher risks of bleeding, pneumonia, and renal dysfunction. This reflects the compounded effect of physiological and operative stress. Patients in the low stress/low reserve group also demonstrated adverse outcomes, with elevated risks of myocardial infarction, pneumonia, and acute renal failure. In contrast, patients in the low stress/high reserve category showed protective associations, with reduced odds of bleeding and renal complications. These findings underscore the importance of evaluating both surgical stress and physiologic reserve as interactive risk profiles rather than as independent factors. Limitations include retrospective design and immeasurable surgical and patient confounders. However, this framework highlights a valuable way to guide management for patients in the setting of a complex femur fracture.

SIGNIFICANCE/CLINICAL RELEVANCE: Our framework offers a more comprehensive approach to perioperative risk stratification, by combining two factors that are often evaluated independently. This is a valuable tool that warrants further validation and may help tailor management in patients undergoing complex femur fracture fixations.

Variable	HS/HR (n=866)	LS/LR (n=866)	HS/LR (n=1,021)	LS/HR (n=1,021)
Age	62.1± 18.3	79.8± 9.8	76.7± 11.1	62.2± 20.5
Male	301 (34.8%)	242 (27.9%)	260 (25.5%)	366 (35.8%)
Female	564 (65.1%)	624 (72.1%)	760 (74.4%)	652 (63.9%)

Table 1. Baseline Characteristics of Patients Undergoing Femur Fracture Fixation, Stratified by Stress-Reserve Quadrant

Outcome	LS/HR OR (95% CI)	LS/LR OR (95% CI)	HS/LR OR (95% CI)
Pneumonia	1.02 (0.44-2.37)	5.36 (2.70-10.62)	3.31 (1.64-6.68)
Sepsis	0.85 (0.27-2.64)	2.70 (1.05-6.93)	3.16 (1.27-7.82)
Renal Insufficiency	0.33 (0.13-0.85)	2.42 (1.31-4.46)	2.73 (1.50-4.96)
UTI	0.81 (0.46-1.43)	1.89 (1.15-3.10)	2.17 (1.35-3.49)
Postoperative bleeding	0.60 (0.48-0.75)	1.30 (1.06-1.61)	2.42 (1.99-2.94)
MI	2.13 (0.41-10.99)	11.79 (2.77-50.15)	5.57 (1.25-24.76)
DVT	0.42 (0.20-0.87)	0.68 (0.35-1.31)	0.77 (0.42-1.41)

Table 2. Multivariable Logistic Regression of Complications by Quadrant.
Reference group: HS/HR (High Stress/High Reserve)