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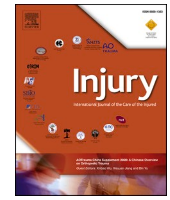

Two big bones, one big decision: When to fix bilateral femur fractures

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ABSTRACT

Purpose: For polytrauma patients with bilateral femoral shaft fractures (BFSF), there is currently no consensus on the optimal timing of surgery. This study assesses the impact of early ($\leq$ 24 h) versus delayed (>24 h) definitive fixation on clinical outcomes, especially focusing on concomitant versus staged repair. We hypothesized that early definitive fixation leads to lower mortality and morbidity rates.

Methods: The 2017–2020 Trauma Quality Improvement Program was used to identify patients aged $\geq$16 years with BFSF who underwent definitive fixation. Early definitive fixation (EDF) was defined as fixation of both femoral shaft fractures within 24 h, delayed definitive fixation (DDF) as fixation of both fractures after 24 h, and early staged fixation (ESF) as fixation of one femur within 24 h and the other femur after 24 h. Propensity score matching and multilevel mixed effects regression models were used to compare groups.

Results: 1,118 patients were included, of which 62.8% underwent EDF. Following propensity score matching, 279 balanced pairs were formed. EDF was associated with decreased overall morbidity (12.9% vs 22.6%, $p = 0.003$), lower rate of deep venous thrombosis (2.2% vs 6.5%, $p = 0.012$), a shorter ICU LOS (5 vs 7 days, $p < 0.001$) and a shorter hospital LOS (10 vs 15 days, $p < 0.001$). When compared to DDF, early staged fixation (ESF) was associated with lower rates of ventilator acquired pneumonia (0.0% vs 4.9%, $p = 0.007$), but a longer ICU LOS (8 vs 6 days, $p = 0.004$). Using regression analysis, every 24-hour delay to definitive fixation increased the odds of developing complications by 1.05, postoperative LOS by 10 h and total hospital LOS by 27 h.

Conclusion: Early definitive fixation ($\leq$ 24 h) is preferred over delayed definitive fixation (>24 h) for patients with bilateral femur shaft fractures when accounting for age, sex, injury characteristics, additional fractures and interventions, and hospital level. Although mortality does not differ, overall morbidity and deep venous thrombosis rates, and length of hospital and intensive care unit stay are significantly lower. When early definitive fixation is not possible, early staged repair seems preferable over delayed definitive fixation.

Introduction

Femoral shaft fractures are a major cause of mortality and morbidity, with an incidence of 10 to 20 per 100,000 person-years [1,2]. Bilateral femoral shaft fractures (BFSF) indicate a high-energy mechanism, are associated with concomitant injuries, and often result in suboptimal outcomes [3–8].

A multitude of patient-, physician-, and institution-related factors influence the decision about type and timing of BFSF fixation [9–13]. Surgical options such as early definitive repair of both fractures, staged repair of one after the other, or damage-control surgery with only temporary repair at the beginning (i.e. external fixation) and definitive care at a later stage, are in the center of the debate for optimal treatment [14–17].

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Intramedullary nailing (IMN) within 24 h is the preferred method of surgical repair for unilateral femoral shaft fractures [9,18,19]. In contrast, no consensus exists for the treatment of BFSF [3,20–22]. Flagstad et al. demonstrated the influence of separate treating institutions on the treatment strategy of BFSF [22], suggesting that preferences of the surgeons may supersede clinical indications and guidelines.

The aim of this study is to evaluate the effect of early (≤ 24 h) versus delayed (>24 h) definitive fixation of BFSF on clinical outcomes, especially focusing on concomitant versus staged repair of the two femur fractures.

Methods

Data source

We performed a retrospective analysis of the American College of Surgeons Trauma Quality Improvement Program Participant Use File from 2017 to 2020 [23–25]. The International Classification of Diseases, 10th revision (ICD-10) Clinical Modification and Procedure Coding System codes was used to code for all diagnoses and procedures.

Patient selection

We included all patients who were 1) 16 years of age or older, 2) had BFSF and 3) underwent definitive fixation of both femoral shaft fractures. Patients who underwent interfacility transfer, were discharged or deceased within 24 h, or had missing data for variables used in the analyses were excluded. Temporary fixation of femoral shaft fractures was not considered an exclusion criterion, provided that patients subsequently proceeded to definitive fixation.

Clinical variables

We collected patient demographics and comorbidities, as well as injury-, clinical- and hospital-specific variables (Table 1). Demographics included age, sex, race, and insurance status. Race was reported in accordance with the National Trauma Data Standard data dictionary as White, Black or African American, Asian, and other race [26]. Insurance status was categorized as private or commercial insurance, government insurance, self-pay, or other. Patient comorbidities included body mass index, smoking status, chronic obstructive pulmonary disease, bleeding disorders, diabetes, hypertension, chronic kidney disease and functionally dependent health status, defined as the inability of the patient to complete activities of daily living. Injury-specific variables included injury severity score (ISS), regional abbreviated injury score (AIS) for head, thorax, abdomen, external and face, and Glasgow coma scale (GCS) at admission [26]. Severe traumatic brain injury (TBI), severe chest trauma, and severe abdominal trauma were defined as an AIS for head, thorax, and abdomen of ≥3 respectively. Emergency department (ED) variables included shock, respiratory assistance, and discharge disposition. Shock was defined as a systolic blood pressure equal or less than 90 mmHg.

BFSF and additional orthopedic injuries were abstracted using ICD-10 diagnosis codes (Supplementary Table 1). Definitive fixation procedures and operative procedures were abstracted using ICD-10 procedural codes (Supplementary Table 2). Additionally, we coded for early non-orthopedic interventions that may influence time to definitive fixation. Early non-orthopedic interventions were defined as laparotomy, thoracotomy, neurosurgical intervention within 24 h, or blood transfusion within 4 h. Neurosurgical intervention was defined as a craniotomy, craniectomy, intraventricular drain placement, or intracranial pressure monitoring within 24 h. Hospital characteristics such as the American College of Surgeons trauma center designated level and teaching status were reported as described within the database.

Table 1
Baseline characteristics before matching.

	Early definitive fixation $N = 702$	Delayed definitive fixation $N = 416$	p-value
Age, median (IQR)	27 (21–38)	32 (24–44.5)	**<0.001**
Male gender, n (%)	416 (59.3%)	275 (66.1%)	**0.023**
Race, n (%)			0.56
White	436 (62.1%)	239 (57.5%)	
Black or African American	168 (23.9%)	107 (25.7%)	
Asian	15 (2.1%)	9 (2.2%)	
Other Race	64 (9.1%)	46 (11.1%)	
Insurance, n (%)			0.10
Private/Commercial Insurance	359 (51.1%)	206 (49.5%)	
Government	184 (26.2%)	130 (31.3%)	
Self-Pay	97 (13.8%)	38 (9.1%)	
Other	48 (6.8%)	32 (7.7%)	
Smoker, n (%)	160 (22.8%)	93 (22.4%)	0.87
BMI, median (IQR)	27.3 (23.6–32.0)	27.3 (23.3–32.9)	0.86
COPD, n (%)	8 (1.1%)	9 (2.2%)	0.18
Bleeding disorder, n (%)	1 (0.1%)	1 (0.2%)	0.71
Diabetes, n (%)	36 (5.1%)	37 (8.9%)	**0.014**
Hypertension, n (%)	63 (9.0%)	60 (14.4%)	**0.005**
Dependent in ADL, n (%)	12 (1.7%)	17 (4.1%)	**0.016**
Chronic kidney disease, n (%)	2 (0.3%)	9 (2.2%)	**0.002**
ISS, median (IQR)	16 (10–22)	25 (16–34)	**<0.001**
GCS, median (IQR)	15 (14–15)	14 (6–15)	**<0.001**
Severe head injury, n (%)	88 (12.5%)	114 (27.4%)	**<0.001**
Severe thorax injury, n (%)	195 (27.8%)	199 (47.8%)	**<0.001**
Severe abdomen injury, n (%)	77 (11.0%)	125 (30.0%)	**<0.001**
Severe external injury, n (%)	1 (0.1%)	1 (0.2%)	0.71
Severe face injury, n (%)	3 (0.4%)	10 (2.4%)	**0.003**
Open Fracture type I or II, n (%)	161 (22.9%)	111 (26.7%)	0.16
Open Fracture type III, n (%)	50 (7.1%)	44 (10.6%)	**0.044**
Pelvic fracture, n (%)	133 (18.9%)	131 (31.5%)	**<0.001**
Spinal cord injury, n (%)	6 (0.9%)	15 (3.6%)	**0.001**
Tibia or fibula fracture, n (%)	237 (33.8%)	214 (51.4%)	**<0.001**
Shock in ED, n (%)	56 (8.0%)	104 (25.0%)	**<0.001**
Respiratory assistance in ED, n (%)	50 (7.1%)	104 (25.0%)	**<0.001**
Early neurosurgical intervention, n (%)	4 (0.6%)	22 (5.3%)	**<0.001**
Early blood transfusion, n (%)	225 (32.1%)	237 (57.0%)	**<0.001**
Early laparotomy, n (%)	39 (5.6%)	83 (20.0%)	**<0.001**
ED discharge disposition, n (%)			**0.008**
General Floor	104 (14.8%)	32 (7.7%)	
Stepdown	2 (0.3%)	3 (0.7%)	
ICU	192 (27.4%)	129 (31.0%)	
OR	237 (33.8%)	144 (34.6%)	
ACS designated level, n (%)			0.39
1	375 (53.4%)	238 (57.2%)	
2	171 (24.4%)	88 (21.2%)	
3	156 (22.2%)	90 (21.6%)	
Teaching Status, n (%)			0.28
Community	234 (33.3%)	142 (34.1%)	
Non-teaching	85 (12.1%)	35 (8.4%)	
University	374 (53.3%)	234 (56.3%)	

Exposure

The time to definitive fixation of a femoral shaft fracture was defined as the interval in minutes between the time of admission and time of the procedure. Early definitive fixation (EDF) was defined as fixation of both femoral shaft fractures within 24 h; delayed definitive fixation (DDF) was defined as fixation of both femoral shaft fractures after 24 h. Early staged fixation (ESF) was defined as fixation of one femur within 24 h and the other femur after 24 h, capturing all patients not included by our EDF or DDF definitions. DDF was further characterized into simultaneous DDF (sDDF), defined as fixation of both femurs after 24 h but at the same operation, and delayed staged fixation (DSF), defined as fixation of both femurs after 24 h but on two separate operations. The choice of using 24 h as a cutoff point was based on previous studies investigating the optimal timing of femoral shaft fracture fixation, as well as current clinical guidelines [11,23,28].

Outcomes

The primary outcome was all-cause in-hospital mortality. Secondary outcomes included overall morbidity, defined as any of the following complications: compartment syndrome, unplanned return to the operating room, osteomyelitis, ventilator acquired pneumonia, acute respiratory distress syndrome, pulmonary embolism, deep venous thrombosis, catheter associated urinary tract infection, and decubitus ulcer. Other secondary outcomes included post-procedural length of stay, intensive care unit (ICU) length of stay and total hospital length of stay. Post-procedural length of stay was defined as the interval in days between the time of fixation and time of discharge.

Statistical analysis

In univariate analysis, patient-, injury-, and hospital variables were reported using medians with interquartile range (IQR) for continuous variables and frequencies with percentages for categorical variables.

Propensity score matching was performed using covariates that play a role in surgical decision making for operative management and may act as potential confounders. Patients were attributed a propensity score using a multivariable logistic regression model that matched for the following covariates: age, sex, ISS score, GCS, shock in the ED, respiratory assistance in the ED, open fractures, additional tibia, fibula, or pelvic fracture, spinal cord injury, additional early (surgical) interventions and ACS designated level. Patients were 1:1 matched using a nearest-neighbor algorithm without replacement and a caliper width of 0.2 of the logit of the score's standard deviation [27]. Standardized differences were calculated before and after matching, and absolute values equal or smaller than 0.15 were used to indicate balance between the cohorts. The primary and secondary outcomes were then compared between the matched cohorts using univariate analysis.

Due to the heavy impact that institutional practice has on clinical decision making in patients with BFSF, an additional multilevel mixed-effects regression analysis was performed to assess the association between time to definitive fixation and all-cause mortality, overall morbidity, postprocedural length of stay and total hospital length of stay, while accounting for the hierarchical nature of the data by using the hospital-specific identifier as a random effect. In this analysis, timing to fixation was defined as mean time to fixation of both femurs: (time to fixation left femur + time to fixation right femur) / 2. Mixed effects logistic regression was used to model categorical binary outcomes, mixed effects linear regression was used to model continuous outcomes. The model was adjusted for patient and injury specific characteristics using the same variables used in propensity score matching. Collinear variables were not included in the model. For example, AIS scores were not used as covariates, as the model already accounted for ISS. In the model, mean time to fixation, ISS score and GCS were used as continuous variables, all others were used as categorial variables. For categorical outcomes, adjusted odds ratios (aOR) and 95% confidence intervals (CI) were calculated. For continuous outcomes, we determined the beta coefficient (β) and its associated 95% CI, indicating the magnitude of change in the outcome for each additional 24-hour increment.

Sub analyses were performed for patients who had an ISS score of ≥25, who had severe chest trauma and patients who underwent staged fixation. For all sub analyses, an identical propensity score matching and univariate analysis were used as described for the main analysis. A two-sided p-value of less than 0.05 was considered statistically significant. All analyses were conducted using STATA statistical software version 17.0 (CollegeStation, TX).

Ethical oversight

This study was exempted from the institutional review board (IRB) approval due to the de-identified nature of the dataset. All methods and results were reported adhering to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) and REporting of studies Conducted using Observational Routinely-collected Data (RECORD) statements [28]

Results

Baseline characteristics

Of a total of 1118 patients 702 (62.8 %) underwent EDF and 416 (37.2 %) underwent DDF. Patients who received DDF were older, more likely to be male, had more comorbidities, a higher ISS and lower GCS at admission, more additional injuries, more additional interventions, and a higher ICU admission rate (Table 1). There were no differences in hospital characteristics.

Main analysis

Following propensity score matching, 279 balanced pairs were formed. No difference was seen in mortality (1.8% vs 2.2%, $p = 0.76$) between EDF and DDF. However, the EDF group had lower rates of overall morbidity (12.9% vs 22.6%, $p = 0.003$), lower rates of deep venous thrombosis (2.2% vs 6.5%, $p = 0.012$), a shorter ICU length of stay (median: 5 days vs 7 days, $p < 0.001$) and a shorter hospital length of stay (median: 10 days vs 15 days, $p < 0.001$) (Table 2).

Multilevel mixed-effects regression

In the adjusted analysis, no significant association with mortality was seen [aOR 0.95, 95% CI: 0.84–1.08]. However, timing to definitive fixation was associated with a significant increase in overall morbidity [aOR 1.05, 95% CI: 1.002–1.10] as well as post-procedural [β 9.93, 95% CI: 5.4–14.5] and total hospital length of stay [β 26.7, 95% CI: 21.6–31.7]. Each additional 24-hour period to the time to fixation after

Table 2
Outcomes main analysis.

	Early definitive fixation *N = 279*	Delayed definitive fixation *N = 279*	p-value
Mortality, n (%)	5 (1.8%)	6 (2.2%)	0.76
Morbidity, n (%)	36 (12.9%)	63 (22.6%)	**0.003**
Deep venous thrombosis, n (%)	6 (2.2%)	18 (6.5%)	**0.012**
Decubitus ulcer, n (%)	6 (2.2%)	11 (3.9%)	0.22
Pulmonary embolism, n (%)	11 (3.9%)	15 (5.4%)	0.42
Acute respiratory distress syndrome, n (%)	4 (1.4%)	6 (2.2%)	0.52
Ventilator acquired pneumonia, n (%)	6 (2.2%)	11 (3.9%)	0.22
Unplanned return to OR, n (%)	8 (2.9%)	16 (5.7%)	0.095
Osteomyelitis, n (%)	1 (0.4%)	2 (0.7%)	0.56
Compartment syndrome, n (%)	1 (0.4%)	1 (0.4%)	1.00
Catheter associated urinary tract infection, n (%)	5 (1.8%)	5 (1.8%)	1.00
Hospital length of stay, median days (IQR)	10 (5–16)	15 (7–25)	**<0.001**
ICU length of stay, median days (IQR)	5 (3–9)	7 (5–14)	**<0.001**
Post procedure length of stay, median days (IQR)	11 (7–18)	14 (8–21)	**0.045**

the first day was associated with a 5% increase in morbidity, a 9.93 h increase in postoperative LOS and a 26.7 h increase in total hospital length of stay (Supplementary Fig. 1a and 1b).

Subgroup analyses

For the subgroup of patients with an ISS score ≥25 (99 balanced pairs), EDF was associated with a shorter intensive care length of stay (median: 7 days vs. 11 days, $p < 0.001$) and a shorter total hospital length of stay (median: 13 days 16 days, $p = 0.012$). No differences were seen in mortality and other outcomes (Table 3). For patients with severe chest injury (113 balanced pairs), EDF was associated with lower overall morbidity (18.6% vs 30.1%, $p = 0.044$), a shorter ICU length of stay (median: 6 days vs 9 days, $p = 0.001$) and total hospital length of stay (median: 12 days vs 16 days, $p = 0.017$). There was no effect for any of the other outcomes (Table 4). When comparing patients who had EDF versus ESF (133 pairs, though still unbalanced (Table 5)), simultaneous EDF was associated with a lower rate of deep venous thrombosis (0.8% vs 6.8%, $p = 0.010$). Similarly, when performing a sub analysis within the DDF group comparing patients with simultaneous DDF versus DSF (214 balanced pairs), simultaneous DDF was associated with a lower rate of acute respiratory distress syndrome (0.9% vs 5.1%, $p = 0.024$). When comparing ESF to DSF (101 balanced pairs), ESF was associated with a shorter ICU length of stay (6 days vs 8 days, $p = 0.035$) and a shorter hospital length of stay (13 days vs 16 days, $p = 0.039$). Additionally, when comparing ESF versus DDF (142 balanced pairs), early staged fixation was associated with lower rates of ventilator acquired pneumonia (0.0% vs 4.9%, $p = 0.007$), but a longer ICU length of stay (median: 8 vs 6 days, $p = 0.004$). The summary of our comparisons between the groups is shown in Table 6.

Discussion

For polytrauma patients with BFSF, there is currently no consensus on the optimal timing of surgery [3,20–22]. To provide a guideline for determining the optimal timing of treatment, we assessed the impact of timing to definitive fixation of BFSF (within 24 h versus after 24 h) on clinical outcomes in a nationwide retrospective database study using propensity score matching analysis. We found that definitive fixation of both femurs within the first 24 h from admission was associated with decreased overall morbidity (1 in 8 patients vs. 1 in 4 patients), lower rates of deep venous thrombosis, and decreased length of stay in the intensive care unit and hospital compared to definitive fixation after 24 h. Every 24-hour delay to definitive fixation led to higher odds of developing complications and staying longer in the hospital. Even among severely injured patients (ISS ≥25, AIS thorax >3), early definitive fixation (EDF) produced better outcomes than delayed definitive fixation (DDF). Furthermore, in situations where EDF might not be an option, early staged fixation (ESF) is associated with less complications compared to DDF. For all other circumstances, when comparing simultaneous fixation of both femurs to staged fixation, the simultaneous fixation group was associated with lower morbidity.

Table 3
Outcomes sub analysis ISS ≥25.

	Early definitive fixation *N = 99*	Delayed definitive fixation *N = 99*	p-value
Mortality, n (%)	4 (4%)	5 (5%)	0.73
Morbidity, n (%)	22 (22%)	34 (34%)	0.058
Deep venous thrombosis, n (%)	3 (3.0%)	9 (9.1%)	0.12
Decubitus ulcer, n (%)	3 (3.0%)	10 (10.1%)	0.077
Pulmonary embolism, n (%)	7 (7.1%)	5 (5.1%)	0.51
Acute respiratory distress syndrome, n (%)	4 (4.0%)	4 (4.0%)	0.60
Ventilator acquired pneumonia, n (%)	5 (5.1%)	8 (8.1%)	0.41
Unplanned return to OR, n (%)	3 (3.0%)	10 (10.1%)	0.077
Osteomyelitis, n (%)	1 (1.0%)	1 (1.0%)	0.60
Compartment syndrome, n (%)	0 (0.0%)	1 (1.0%)	0.36
Catheter associated urinary tract infection, n (%)	4 (4.0%)	2 (2.0%)	0.43
Hospital length of stay, median days (IQR)	13 (2–20)	16 (9–29)	**0.012**
ICU length of stay, median days (IQR)	7 (4–14)	11 (7–19)	**<0.001**
Post procedure length of stay, median days (IQR)	15 (10–22)	14 (11–23)	0.98

Table 4
Outcomes sub analysis severe chest trauma (AIS ≥3).

	Early definitive fixation *N = 113*	Delayed definitive fixation *N = 113*	p-value
Mortality, n (%)	1 (0.9%)	6 (5.3%)	0.055
Morbidity, n (%)	21 (18.6%)	34 (30.1%)	**0.044**
Deep venous thrombosis, n (%)	2 (1.8%)	8 (7.1%)	0.052
Decubitus ulcer, n (%)	2 (1.8%)	7 (6.2%)	0.089
Pulmonary embolism, n (%)	7 (6.2%)	6 (5.3%)	0.78
Acute respiratory distress syndrome, n (%)	4 (3.5%)	6 (5.3%)	0.52
Ventilator acquired pneumonia, n (%)	3 (2.7%)	3 (2.7%)	1.00
Unplanned return to OR, n (%)	5 (4.4%)	11 (9.7%)	0.12
Osteomyelitis, n (%)	1 (0.9%)	0 (0.0%)	0.32
Compartment syndrome, n (%)	0 (0.0%)	2 (1.8%)	0.16
Catheter associated urinary tract infection, n (%)	3 (2.7%)	2 (1.8%)	0.65
Hospital length of stay, median days (IQR)	12 (4–20)	16 (8–25)	**0.017**
ICU length of stay, median days (IQR)	6 (4–12)	9 (6–15)	**0.001**
Post procedure length of stay, median days (IQR)	13 (9–22)	15 (9–23)	0.72

For unilateral femoral shaft fractures, the consensus is that EDF is preferred over DDF [9]. Studies demonstrate that fixation of femoral shaft fractures within 24 h minimizes the risk of developing complications, such as acute respiratory distress syndrome, and decreases hospital length of stay [13,16,17,29–31]. The surgical decision making for BFSF is complex, as these patients often present in physiologic extremis, and with multiple severe injuries [32]. This was confirmed in our study population, which had a mean ISS of 21, with 3 out of 4 patients having at least one additional severe injury and almost 2 out of 3 patients being transferred from the emergency department directly to the intensive care or operating room. For this patient population, there is currently no consensus on the optimal timing of surgical care. Earlier studies demonstrated that the timing of definitive fixation was mainly dependent on the institution, suggesting that surgeon's preference and institutional policies may be more important than clinical or sociodemographic variables [22]. This variation between trauma centers is problematic because the lack of evidence-based management guidelines use is associated with poorer patient outcomes, less efficient patient care, and higher health care costs [33,34].

Several studies in the existing literature have reported findings similar to ours. Flagstad et al. compared EDF to DDF and found that DDF patients had higher in-hospital mortality and complication rates [22]. Similar to our study, the delayed fixation cohort exhibited greater severity of injuries, more additional injuries, and an increased likelihood of undergoing secondary procedures. However, the comparison between early and delayed fixation outcomes lacked adjustment for these baseline differences, as neither propensity score matching nor regression analysis was used. Moreover, our study and Flagstad et al.'s approach to defining early and delayed definitive fixation differed. While early definitive fixation was characterized in the same manner as in our study, Flagstad et al. defined delayed definitive fixation as all patients not meeting the criteria for early fixation. This broad definition resulted in a

Table 5
Baseline characteristics after matching EDF vs ESF.

	Early definitive fixation *N* = 133	Early staged fixation (one early, one delayed) *N* = 133	p-value
Age, median (IQR)	35 (26–48)	29 (22–44)	**0.006**
Male gender, n (%)	51 (38.3%)	51 (38.3%)	1.00
race, n (%)			0.66
White	89 (66.9%)	80 (60.2%)	
Black or African American	27 (20.3%)	37 (27.8%)	
Asian	3 (2.3%)	3 (2.3%)	
Other Race	12 (9.0%)	10 (7.5%)	
Insurance, n (%)			0.62
Private/ Commercial Insurance	68 (51.1%)	70 (52.6%)	
Government	34 (25.6%)	25 (18.8%)	
Self-Pay	16 (12.0%)	23 (17.3%)	
Other	13 (9.8%)	13 (9.8%)	
Smoker, n (%)	45 (33.8%)	35 (26.3%)	0.18
BMI, median (IQR)	27.5 (24.2–32.9)	28.1 (24.6–32.8)	0.90
COPD, n (%)	6 (4.5%)	3 (2.3%)	0.31
Bleeding disorder, n (%)	0 (0.0%)	0 (0.0%)	
Diabetes, n (%)	22 (16.5%)	11 (8.3%)	**0.041**
Hypertension, n (%)	30 (22.6%)	17 (12.8%)	**0.037**
Dependent in ADL, n (%)	2 (1.5%)	3 (2.3%)	0.65
Chronic kidney disease, n (%)	1 (0.8%)	1 (0.8%)	1.00
ISS, median (IQR)	22 (14–27)	17 (10–22)	0.033
GCS, median (IQR)	15 (14–15)	15 (14–15)	0.13
Severe head injury, n (%)	20 (15.0%)	14 (10.5%)	0.27
Severe thorax injury, n (%)	58 (43.6%)	43 (32.3%)	0.058
Severe abdomen injury, n (%)	28 (21.1%)	15 (11.3%)	**0.030**
Severe external injury, n (%)	0 (0.0%)	0 (0.0%)	
Severe face injury, n (%)	1 (0.8%)	2 (1.5%)	0.56
Open fracture, n (%)	82 (61.7%)	56 (42.1%)	**0.001**
Pelvic fracture, n (%)	40 (30.1%)	32 (24.1%)	0.27
Spinal cord injury, n (%)	1 (0.8%)	1 (0.8%)	1.00
Tibia or fibula fracture, n (%)	100 (75.2%)	71 (53.4%)	**<0.001**
Shock in ED, n (%)	27 (20.3%)	18 (13.5%)	0.14
Respiratory assistance, n (%)	18 (13.5%)	13 (9.8%)	0.34
Early intervention, n (%)	70 (52.6%)	55 (41.4%)	0.065
ED discharge disposition, n (%)			0.086
General Floor	9 (6.8%)	16 (12.0%)	
ICU	43 (32.3%)	34 (25.6%)	
OR	49 (36.8%)	38 (28.6%)	
ACS designated level, n (%)			0.50
1	58 (43.6%)	66 (49.6%)	
2	41 (30.8%)	33 (24.8%)	
3	34 (25.6%)	34 (25.6%)	
Teaching Status, n (%)			0.13
Community	54 (40.6%)	42 (31.6%)	
Non-Teaching	17 (12.8%)	11 (8.3%)	
University	60 (45.1%)	79 (59.4%)	

heterogeneous group, as it did not distinguish between patients who may have had one femur fixated within 24 h and the other a day later, and those who underwent fixation after a span of several weeks. Similarly, Steinhausen et al. compared early total care, defined as bilateral primary definitive osteosynthesis, to damage control orthopedics, defined as bilateral temporary external fixation [20].The rate of systemic complication (organ failure, multiorgan failure and sepsis) was higher in the damage control group. However, like beforementioned studies, the treatment groups presented significant differences between them. One could argue that the differences in outcomes might relate to the different group characteristics, ranging from higher injury severity scores to worse lab values, and not the timing of the BFSF. Furthermore, it is noteworthy that this study was conducted using data spanning from 1993 to 2008, a timeframe that may not fully capture the current landscape of advancing healthcare practices.

In contrast, Willett et al. found a potential benefit for a delayed approach [3]. When comparing different fracture fixation methods, several damage-control methods outperformed intramedullary nailing in patients with a New ISS >40. However, this analysis only included a small number of patients, increasing the risk of type I and II errors, and, like the beforementioned studies, did not adjust for any potential confounders that may play a role in surgical decision making, such as age, comorbidities and need for additional procedures.

Our study considered patient, injury, and hospital characteristics as potential confounders and performed a careful propensity score matching to make two comparable cohorts. We found that there was no difference in mortality between early and delayed definitive fixation of bilateral femur fractures. We also demonstrated that EDF of BFSF was associated with a reduction in overall morbidity, particularly in the incidence of deep venous thrombosis. We hypothesize that minimizing the operative delay to definitive fixation of bilateral femoral shaft fractures serves to mitigate risk factors by stabilizing the fractures, decreasing pain, and facilitating early mobilization. As prevention of deep venous thrombosis plays a crucial role in trauma care, patients who are not eligible for immediate definitive femur fracture fixation should be considered for prophylactic measures while being closely monitored.

Given the significant literature about damage control orthopedics for severely injured patients, advocating temporary immobilization and delayed definitive repair [14,15,35–39], we set to do subgroup analysis of certain populations within our sample size. Typically, patients considered to be appropriate for such an approach are those with high ISS, severe brain injury, and severe chest injury. Therefore, we analyzed separately these three subgroups and created propensity-score-matched couples for outcomes comparison. In the ISS>25 subgroup and the chest AIS>3 subgroup, we again detected a morbidity and length of stay benefit for EDF patients compared to DDF. Unfortunately, we could not examine the severe brain injury subgroup due to the lack of an adequate sample size to allow appropriate matching of patients.

Given that our main analysis targeted patients who had *both* fractures repaired before or after 24 h, we sought to also analyze patients who had one of the fractures repaired within 24 h and the other one after 24 h. Again, early fixation of both femurs simultaneously showed superior outcomes compared to staged repair. However, ESF was superior to delayed repair, whether it was sDDF or DSF. This data shows that, if early fixation of both femurs simultaneously is not possible, a staged repair with at least one of the two fixed within 24 h is preferred over delayed repair.

To the best of our knowledge, this study is the first nationwide study to investigate the impact of timing of definitive fixation of BFSF while considering not only injury characteristics but patient demographics and comorbidities, physiologic variables upon hospital arrival, and hospital characteristics as well. Single institutional studies are unlikely to produce numbers for credible statistical analysis, given the low incidence of BFSF. A national database can produce a large sample size for that purpose.

This study is subject to several limitations. Its retrospective nature and database-derived dataset does not allow a great degree of granularity on multiple parameters. Important information, such as lactate levels, is missing and other data is incomplete. Outcomes are limited to those captured by the database: bone-specific outcomes like non-union, pseudoarthrosis, or need for repeat orthopedic operations are not available. Additionally, the outcomes that are available in TQIP are described in a binominal fashion without allowing judgments on the

Table 6
Summary of sub analyses.

	Early definitive fixation (EDF)	Early staged fixation (ESF)	Delayed definitive fixation (DDF)	Delayed staged fixation (DSF)
Early definitive fixation (EDF)	x	EDF was associated with a lower rate of DVT (0.8% vs 6.8%, $p = 0.010$)	EDF is associated with lower overall morbidity (12.9% vs 22.6%, $p = 0.003$), lower DVT rate (2.2% vs 6.5%, $p = 0.012$) and a shorter postoperative (11 vs 14 days, $p = 0.045$), ICU (5 days vs 7 days, $p < 0.001$) and total hospital LOS (10 days vs 15 days, $p < 0.001$)	–
Early staged fixation (ESF)	EDF was associated with a lower rate of DVT (0.8% vs 6.8%, $p = 0.010$)	x	ESF is associated with lower rates of ventilator acquired pneumonia (0.0% vs 4.9%, $p = 0.007$) and decubitus ulcer (0.0% vs 3.5%, $p = 0.024$), but a longer ICU LOS (8 vs 6 days, $p = 0.004$)	ESF is associated with a shorter ICU (6 days vs 8 days, $p = 0.035$) and total hospital LOS (13 days vs 16 days, $p = 0.039$)
Delayed definitive fixation (DDF)	EDF is associated with lower overall morbidity (12.9% vs 22.6%, $p = 0.003$), lower DVT rate (2.2% vs 6.5%, $p = 0.012$) and a shorter postoperative (11 vs 14 days, $p = 0.045$), ICU (5 days vs 7 days, $p < 0.001$) and total hospital LOS (10 days vs 15 days, $p < 0.001$)	ESF is associated with lower rates of ventilator acquired pneumonia (0.0% vs 4.9%, $p = 0.007$) and decubitus ulcer (0.0% vs 3.5%, $p = 0.024$), but a longer ICU LOS (8 vs 6 days, $p = 0.004$)	*x*	*Simultaneous DDF* vs *DSF:* sDDF is associated with a lower rate of ARDS (0.9% vs 5.1%, $p = 0.024$)
Delayed staged fixation (DSF)	–	ESF is associated with a shorter ICU (6 days vs 8 days, $p = 0.035$) and total hospital LOS (13 days vs 16 days, $p = 0.039$)	*Simultaneous DDF* vs *DSF:* sDDF is associated with a lower rate of ARDS (0.9% vs 5.1%, $p = 0.024$)	x

severity of each outcome and its impact on the final result. We tried to minimize confounding variables by using ICD-10 diagnosis codes to identify important details, such as the presence of an open fracture, or additional injuries and interventions that may impact surgical timing. Moreover, we used robust statistical techniques such as propensity score matching and multilevel mixed-effects regression to account for injury-, patient-, and hospital characteristics. Secondly, the TQIP dataset includes data from a heterogenous range of hospitals, each adhering to its own patient management protocols. While our analysis effectively adjusted for factors such as ACS-designated level and hospital random effect, policies, procedures, expertise, and surgeon volume may vary among trauma centers. Furthermore, this study does not capture long-term outcomes, such as functional status or pain scores. Therefore, it is not possible to allow comparisons of outcomes after hospital discharge nor for any patient-reported outcomes. Lastly, in our main analysis we categorized the study population into two cohorts: early versus delayed definitive care. While patients in the early group will likely have had simultaneous repair of both femur fractures because of the clinically improbability of two separate orthopedic surgeries within a 24-hour timeframe, the delayed group comprised cases involving both simultaneous and staged repair. The inclusion of only simultaneous repair was precluded by sample size constraints, and this approach was deemed satisfactory for addressing our primary research question. Moreover, in recognition of the inherent limitation of potentially comparing disparate groups, we conducted additional sub analyses comparing EDF to ESF and ESF to both sDDF and DSF. This stratified analysis aimed to provide a more nuanced understanding and mitigate potential confounding factors associated with the diverse nature of the cohorts.

In conclusion, among BFSF patients, EDF seems to produce better outcomes compared to DDF. Mortality is not different but morbidity rates, especially deep venous thrombosis, and length of hospital and intensive care unit stay are lower with EDF. Furthermore, when EDF is not possible, an early staged repair is preferable over delayed fixation. A prospective multi-institutions study would be needed to confirm these conclusions.

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CRediT authorship contribution statement

Suzanne C. Arnold: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Emanuele Lagazzi:** Conceptualization, Methodology, Software, Validation, Formal analysis, Writing – review & editing. **Robert K. Wagner:** Conceptualization, Methodology, Writing – review & editing. **Wardah Rafaqat:** Conceptualization, Methodology, Writing – review & editing. **May Abiad:** Conceptualization, Methodology, Writing – review & editing. **Dias Argandykov:** Conceptualization, Methodology, Software, Writing – review & editing. **Anne H. Hoekman:** Writing – review & editing. **Vahe Panossian:** Writing – review & editing. **Ikemsinachi C. Nzenwa:** Writing – review & editing. **Mark Cote:** Writing – review & editing. **John O. Hwabejire:** Supervision, Project administration, Writing – review & editing. **Inger B. Schipper:** Conceptualization, Methodology, Writing – review & editing. **Thuan V. Ly:** Supervision, Project administration, Writing – review & editing. **George C. Velmahos:** Supervision, Project administration, Writing – review & editing.

Declaration of competing interest

The authors have no conflict of interest to disclose.

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Supplementary materials

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References

[1] Enninghorst N, McDougall D, Evans JA, Sisak K, Balogh ZJ. Population-based epidemiology of femur shaft fractures. J Trauma Acute Care Surg 2013;74(6): 1516–20.
[2] Weiss RJ, Montgomery SM, Al Dabbagh Z, Jansson KA. National data of 6409 Swedish inpatients with femoral shaft fractures: stable incidence between 1998 and 2004. Injury 2009;40(3):304–8.

[3] Willett K, Al-Khateeb H, Kotnis R, Bouamra O, Lecky F. Risk of mortality: the relationship with associated injuries and fracture treatment methods in patients with unilateral or bilateral femoral shaft fractures. J Trauma: Injury Inf Critical Care 2010;69(2):405–10.
[4] Cosgrove CT, Wolinsky PR, Berkes MB, McAndrew CM, Stwalley DL, Miller AN. A comparison of the prevalence of, demographics of, and effects on outcomes of bilateral versus unilateral femoral shaft fractures: a retrospective cohort analysis from the national trauma data bank. J Orthop Trauma 2022;36(7):349–54.
[5] O'Toole RV, Lindbloom BJ, Hui E, Fiastro A, Boateng H, O'Brien M, et al. Are bilateral femoral fractures no longer a marker for death? J Orthop Trauma 2014;28 (2):77–81. discussion 81-2.
[6] Copeland CE, Mitchell KA, Brumback RJ, Gens DR, Burgess AR. Mortality in patients with bilateral femoral fractures. J Orthop Trauma 1998;12(5):315–9.
[7] Nork SE, Agel J, Russell GV, Mills WJ, Holt S, Routt MLC. Mortality after reamed intramedullary nailing of bilateral femur fractures. Clin Orthop Relat Res 2003; (415):272–8.
[8] Lane MK, Nahm NJ, Vallier HA. Morbidity and mortality of bilateral femur fractures. Orthopedics 2015;38(7):e588–92.
[9] Gandhi RR, Overton TL, Haut ER, Lau B, Vallier HA, Rohs T, et al. Optimal timing of femur fracture stabilization in polytrauma patients. Journal of Trauma and Acute Care Surg 2014;77(5):787–95.
[10] Pape HC, Halvachizadeh S, Leenen L, Velmahos GD, Buckley R, Giannoudis PV. Timing of major fracture care in polytrauma patients – An update on principles, parameters and strategies for 2020. Injury 2019;50(10):1656–70.
[11] Janssen SJ, Teunis T, Guitton TG, Ring D. Do surgeons treat their patients like they would treat themselves? Clin Orthop Relat Res 2015;473(11):3564–72.
[12] Birkmeyer JD, Reames BN, McCulloch P, Carr AJ, Campbell WB, Wennberg JE. Understanding of regional variation in the use of surgery. Lancet 2013;382(9898): 1121–9.
[13] Byrne JP, Nathens AB, Gomez D, Pincus D, Jenkinson RJ. Timing of femoral shaft fracture fixation following major trauma: a retrospective cohort study of United States trauma centers. PLoS Med 2017;14(7):e1002336.
[14] Guerado E, Bertrand ML, Cano JR, Cerván AM, Galán A. Damage control orthopaedics: state of the art. World J Orthop 2019;10(1):1–13.
[15] Scalea TM, Boswell SA, Scott JD, Mitchell KA, Kramer ME, Pollak AN. External fixation as a bridge to intramedullary nailing for patients with multiple injuries and with femur fractures: damage control orthopedics. J Trauma: Injury Inf Critical Care 2000;48(4):613–23.
[16] Bone LB, Johnson KD, Weigelt J, Scheinberg R. Early versus delayed stabilization of femoral fractures. A prospective randomized study. J Bone Joint Surg Am 1989; 71(3):336–40.
[17] Harvin JA, Harvin WH, Camp E, Caga-Anan Z, Burgess AR, Wade CE, et al. Early femur fracture fixation is associated with a reduction in pulmonary complications and hospital charges: a decade of experience with 1,376 diaphyseal femur fractures. J Trauma Acute Care Surg 2012;73(6):1442–8. discussion 1448-9.
[18] Nahm NJ, Como JJ, Wilber JH, Vallier HA. Early appropriate care: definitive stabilization of femoral fractures within 24 h of injury is safe in most patients with multiple injuries. J Trauma 2011;71(1):175–85.
[19] O'Brien PJ. Fracture fixation in patients having multiple injuries. Can J Surg 2003; 46(2):124–8.
[20] Steinhausen E, Lefering R, Tjardes T, Neugebauer EAM, Bouillon B, Rixen D, et al. A risk-adapted approach is beneficial in the management of bilateral femoral shaft fractures in multiple trauma patients: an analysis based on the trauma registry of the German Trauma Society. J Trauma Acute Care Surg 2014;76(5):1288–93.
[21] Mansour A, Vivace BJ, Nyland J, Rashid SF, Wilson A, Engorn JR, et al. Early intramedullary nailing of bilateral femur fractures: who might benefit most? Eur J Orthop Surg Traumatol 2023;33(6):2473–80.
[22] Flagstad IR, Tatman LM, Albersheim M, Heare A, Parikh HR, Vang S, et al. Factors influencing management of bilateral femur fractures: a multicenter retrospective cohort of early versus delayed definitive Fixation. Injury 2021;52(8):2395–402.
[23] American College of Surgeons Committee on Trauma. Trauma quality programs participant use file [Internet]. 2022 [cited 2023 Jul 29]. Available from: https://www.facs.org/media/adujvrqx/tqp-puf-user-manual-2021.pdf.
[24] National Center for Health Statistics. International classification of diseases, tenth revision, clinical modification (ICD-10-CM) [Internet]. 2023 [cited 2023 Aug 30]. Available from: https://www.cdc.gov/nchs/icd/icd-10-cm.htm.
[25] American College of Surgeons. National trauma data bank (NTDB) [Internet]. [cited 2023 Aug 30]. Available from: https://www.facs.org/quality-programs/trauma/quality/national-trauma-data-bank/.
[26] Gennarelli TA, Wodzin E. AIS 2005: a contemporary injury scale. Injury 2006;37 (12):1083–91.
[27] Austin PC. Optimal caliper widths for propensity-score matching when estimating differences in means and differences in proportions in observational studies. Pharm Stat 2011;10(2):150–61.
[28] von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet 2007;370(9596): 1453–7.
[29] O'Toole R V O, Brien M, Scalea TM, Habashi N, Pollak AN, Turen CH. Resuscitation before stabilization of femoral fractures limits acute respiratory distress syndrome in patients with multiple traumatic injuries despite low use of damage control orthopedics. J Trauma 2009;67(5):1013–21.
[30] Lefaivre KA, Starr AJ, Stahel PF, Elliott AC, Smith WR. Prediction of pulmonary morbidity and mortality in patients with femur fracture. J Trauma 2010;69(6): 1527–35. discussion 1535-6.
[31] Flierl MA, Stoneback JW, Beauchamp KM, Hak DJ, Morgan SJ, Smith WR, et al. Femur shaft fracture fixation in head-injured patients: when is the right time? J Orthop Trauma 2010;24(2):107–14.
[32] Denis-Aubrée P, Dukan R, Karam K, Molina V, Court C, Bouthors C. Bilateral femoral shaft fracture in polytrauma patients: can intramedullary nailing be done on an emergency basis? Orthopaedics Traumatol: Surg Res 2021;107(3):102864.
[33] Sevransky JE, Agarwal A, Jabaley CS, Rochwerg B. Standardized care is better than individualized care for the majority of critically ill patients. Crit Care Med 2021 1; 49(1):151–5.
[34] Sobrino J, Barnes SA, Dahr N, Kudyakov R, Berryman C, Nathens AB, et al. Frequency of adoption of practice management guidelines at trauma centers. Proc (Bayl Univ Med Cent) 2013;26(3):256–61.
[35] Roberts CS, Pape HC, Jones AL, Malkani AL, Rodriguez JL, Giannoudis PV. Damage control orthopaedics: evolving concepts in the treatment of patients who have sustained orthopaedic trauma. Instr Course Lect 2005;54:447–62.
[36] Pape HC. Effects of changing strategies of fracture fixation on immunologic changes and systemic complications after multiple trauma: damage control orthopedic surgery. J Orthop Res 2008;26(11):1478–84.
[37] Pape HC, Hildebrand F, Pertschy S, Zelle B, Garapati R, Grimme K, et al. Changes in the management of femoral shaft fractures in polytrauma patients: from early total care to damage control orthopedic surgery. J Trauma 2002;53(3):452–61. discussion 461-2.
[38] Pape HC, Rixen D, Morley J, Husebye EE, Mueller M, Dumont C, et al. Impact of the method of initial stabilization for femoral shaft fractures in patients with multiple injuries at risk for complications (borderline patients). Ann Surg 2007;246(3): 491–501.
[39] Morshed S, Miclau T, Bembom O, Cohen M, Knudson MM, Colford JM. Delayed internal fixation of femoral shaft fracture reduces mortality among patients with multisystem trauma. J Bone Joint Surg Am 2009;91(1):3–13.