



Influence of a temporary stabilization device on respiratory status in patients with severe trauma with a femoral shaft fracture treated by damage control strategy

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Abstract

Background There are few studies on the safety and respiratory consequences of the use of a skeletal traction (ST) device in the management of femoral shaft fractures with damage control orthopaedics (DCO) strategy, particularly in cases of prolonged use. The aim of this study was to assess the influence of ST compared with an external fixator (EF) on respiratory complications and mechanical ventilation requirements in patients with severe trauma with a femoral shaft fracture managed by DCO strategy.

Methods We retrospectively reviewed all patients with severe trauma patients with a unilateral femoral shaft fracture admitted to our institution from 2010 to 2015. Patients who did not undergo definitive osteosynthesis during the first 24 h were included and divided into two groups: DCO-ST group and DCO-EF group. In addition to trauma severity, global management of respiratory complications, the incidence of acute respiratory distress syndrome (ARDS) and mechanical ventilation requirements and outcome were compared.

Results Fifty-five patients were managed with DCO strategy (mean Injury Severity Score, 28.4); there were 31 in the DCO-ST group and 24 in the DCO-EF group. No significant difference in terms of the main characteristics, initial severity and associated injuries was observed between the two groups. In contrast, ARDS was found more frequently in the DCO-ST group (81% versus 54%; $P=0.035$). Number of ventilation days also tended to be higher in the DCO-ST group (9 days [IQR 3–15 days] versus 7 [IQR 2–16 days]; $P=0.24$). No difference was found for mortality and hospitalization duration between the DCO-ST and DCO-EF groups.

Conclusion The prolonged use of an ST device in the present cohort was associated with a higher incidence of impaired respiratory function. Therefore, our findings suggest that EF is preferable to ST in the DCO setting for femoral shaft fracture, especially in trauma patients at high risk of developing delayed respiratory failure.

Keywords Acute respiratory distress syndrome · External fixator · Mechanical ventilation · Multiple organ failure · Skeletal traction

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Introduction

Bone injuries occur in more than 75% of blunt trauma patients in most series [1]. Femoral shaft fractures are regarded as severe injuries because of their association with many complications; significant or massive blood loss, risk of fat embolism, soft tissue damage, and early development of a systemic inflammatory response [2, 3]. Consequently, systemic complications due to inflammatory aggression, acute lung injuries and acute respiratory distress syndrome (ARDS), multiple organ failure (MOF) and a higher mortality are more frequently observed in presence of femoral shaft fractures [4].

Surgical management of femoral shaft fractures has been well described in recent years, leading to significantly improved outcomes in this population [5]. Although many patients benefit from early definitive fixation by intra-medullary nailing, it is nowadays largely agreed that borderline and severe trauma patients have to be managed using damage control orthopaedics (DCO) and sequenced surgeries [5]. In severely injured patients, DCO was associated with reduced inflammation and “second hit” insult compared to early definitive fixation and intra-medullary nailing.

Temporary stabilization of the femoral shaft is usually allowed in a DCO strategy using an external fixator (EF) [6–9]. Some authors have also proposed an alternative device, skeletal traction (ST), described as simple, fast, and less expensive [10, 11]. The arguments for ST are that its implementation does not require general anaesthesia or transport to the operating room. Nevertheless, few studies have focused on the safety of an ST device in severe or multiple trauma patients, particularly in cases of prolonged use. Delayed fat embolism or respiratory decubitus complications may occur with ST, because this device does not prevent mobilization of the fracture site and imposes a strict dorsal position.

The aim of present study was to assess the influence of ST compared with EF on respiratory complications and mechanical ventilation requirements in severe trauma patients with a unilateral femoral shaft fracture managed by a DCO strategy.

Methods

Study design and patients

The hospital charts for the trauma intensive care unit (ICU) of Lapeyronie University Hospital (Level I Regional Trauma Centre, Montpellier, France) were studied

retrospectively from January 2010 to December 2015. This unit receives all patients directly from trauma scenes in the area suspected to be severely injured during pre-hospital assessment according to French guidelines [12].

All consecutive patients admitted to this unit with a femoral fracture were screened. Patients with a femoral shaft fracture were included if they were managed by a DCO strategy. Exclusion criteria were as follows: (1) previous admission to another hospital; (2) bilateral shaft femoral fractures; (3) data missing from the medical report; (4) early death within the first 48 h; (5) definitive osteosynthesis within the first 24 h. Because of its retrospective and observational nature, the need for written consent for this study was not required by our institutional ethical committee.

Data collection

Data on age, sex, mechanism of injuries, and informations according the femoral fracture (Gustilo scale) were extracted from the medical records, as well as information on initial transfusion management, and Glasgow coma scale score, vasopressor use, partial pressure of oxygen in arterial blood/fraction of inspired oxygen ratio ($\text{PaO}_2/\text{FiO}_2$ ratio) on admission. The Injury Severity Score (ISS), Abbreviated Injury Scale (AIS) by body region, Thoracic Trauma Severity (TTS) score, a Sepsis-related Organ Failure Assessment (SOFA) scores were calculated for each patient [13–16]. Details on femoral surgical management during hospitalization (timing and type of initial and definitive fixation) were also collected. Finally, some outcome data were recorded: (1) orthopaedic outcome (mal-union, non-union and local sepsis); (2) respiratory complications (mechanical ventilation duration, extubation failure rate, $\text{PaO}_2/\text{FiO}_2$ ratio between day 1 and day 15 (obtained daily at 8 am), ARDS during the first 15 days of hospitalization; (3) general outcome (severe bedsores, transfusion requirements, vasopressor and sedation duration, daily SOFA scores, ICU and hospital length of stay, MOF and mortality).

DCO management

DCO strategy was applied in our institution following the usual recommendations (i.e., traumatic brain injury, haemorrhagic or hypoxemic injuries to the trunk, severe coagulopathy, circulatory instability, acute organ failure, etc.) [5]. During the study period, our trauma centre experienced a significant shift in practice concerning the device used for temporary fixation. This change was introduced according to an institutional protocol from 2014. If ST was initially placed in a DCO setting, EF was increasingly used following this protocol. ST was thus progressively abandoned. Choice of the DCO device, whether EF or ST, was decided by the attending surgeon. Definitive stabilization

was subsequently achieved when the clinical status of patient allowed placement of femoral intra-medullary nailing. In parallel, Patients with chest trauma were managed according a multi-disciplinary approach including respiratory management, surgical stabilization and effective physiotherapy. All intubated patients were mobilized every two hours. Backrest position with 45° angle was achieved as preconized if possible. Lateral recumbency was also used in case of backrest position was prohibited.

Study definitions

Following an initial analysis, two groups were defined according to the kind of DCO used during the first 24 h: the DCO-ST group included patients who benefited from ST for temporary stabilization; the DCO-EF group included patients who benefited from an external fixator.

Mechanical ventilation was considered if the patient was ventilated for least 24 h, excluding mechanical ventilation administrated in the operating room. Weaning failure was defined by the need to re-intubate within 24 h of extubation.

The main outcome criterion was the occurrence of ARDS during the 15 first days after admission, according to the international Berlin definition [17]. This definition implies the presence of bilateral opacity on chest imaging and hypoxia not fully explained by cardiac failure or fluid overload. ARDS was staged as mild (PaO_2/FiO_2 between 300 and 201), moderate (PaO_2/FiO_2 between 101 and 200) and severe ($PaO_2/FiO_2 \leq 100$). If the patient was not intubated, FiO_2 was determined using the rules described by Wagstaff et al. [16] to calculate the PaO_2/FiO_2 ratio.

MOF was defined by a SOFA score ≥ 10 . As in many series, SOFA was calculated without neurological status because of the wide use of sedation in this population.

Statistical analysis

The main demographic data of the patients and characteristics on admission and during hospitalization were assessed according to the DCO strategy using bivariate analysis: DCO-ST group and DCO-EF group. Respiratory status, mechanical ventilation requirements and ARDS were specifically analysed. Continuous data were expressed as means (standard deviation [SD]) when parametric, or medians [interquartile range (IQR)] when non-parametric. Comparisons between these groups were performed using the Student *t* test for continuous parametric data and the Mann–Whitney *U* test for non-parametric data. Categorical data were expressed as number (percentage) and compared using Chi square or Fisher’s exact tests as appropriate. Statistical analysis was performed using XLSTAT Pro 5.7.2 (Addinsoft, New York, NY). $P \leq 0.05$ indicated significance.

Results

Patient characteristics

During the 5-year study period, 272 severe trauma patients were admitted to our trauma centre with at least one femoral fracture. Of these, 112 were excluded from the analysis; 27 because of indirect or delayed admissions, 3 early deaths, 57 non-shaft fractures, 22 bilateral femoral shaft fractures and 3 with a lack of clinical data (Fig. 1). Of the

Fig. 1 Flow chart

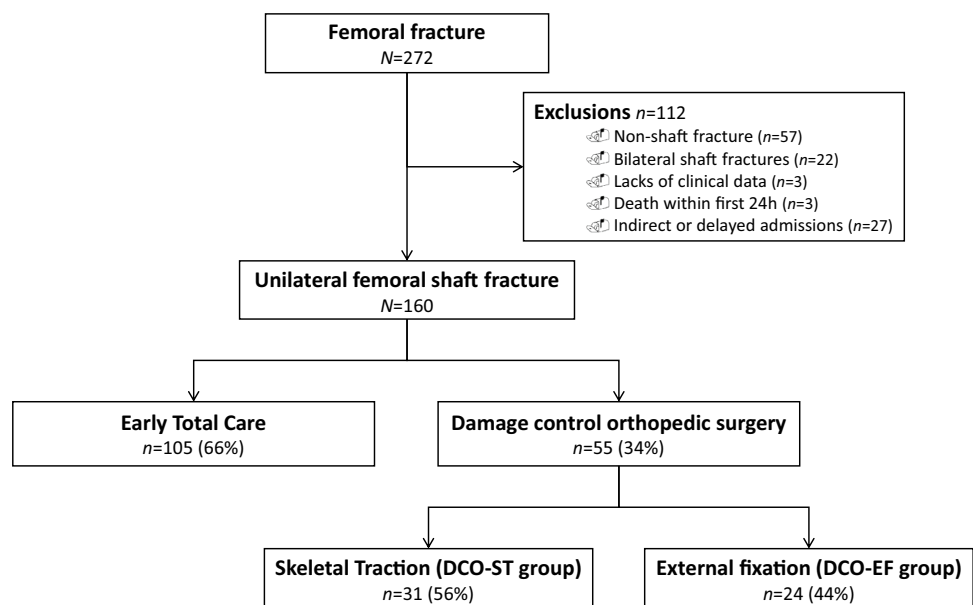
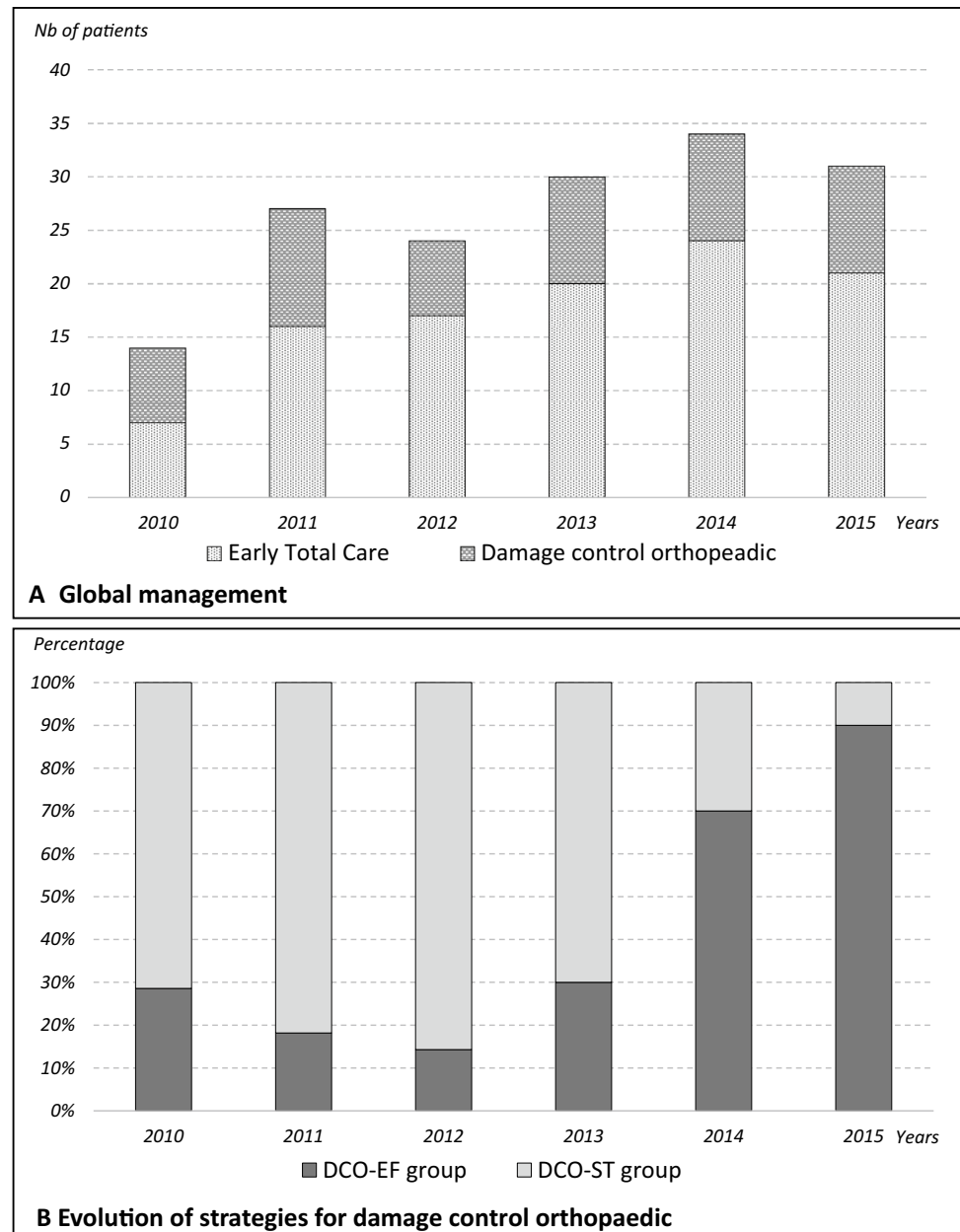


Fig. 2 Surgical management of unilateral femoral shaft fracture



160 remaining patients, 105 (66%) benefited from initial definitive osteosynthesis and 55 (34%) underwent DCO management (Fig. 2).

In the DCO population, 47 patients (85%) were male, the mean age was 32.6 years (SD 17.3 years), the mean ISS was 27 (IQR 19–34) and 28 patients (51%) had a head AIS ≥ 3 . Motor vehicle and bicycle accidents were the main mechanisms of injury. The characteristics of these patients are summarized in Table 1. A total of 47 (85%) patients received mechanical ventilation during hospitalization, with a mean duration of 10.9 days (SD 7.5 days).

Damage control orthopaedic groups

Among the cohort, 24 patients (44%) were temporary stabilized by EF (DCO-EF group) and 31 (56%) by ST (DCO-ST group). Table 1 shows the absence of a significant difference between the two groups regarding the main severity parameters on admission (severity criteria or transfusion needs) or respiratory severity (mechanical ventilation rate, PaO₂/FiO₂ or TTS score). The rate of open fractures was 29% in the DCO-EF group versus 19% in the

Table 1 Characteristics of patients treat by damage control orthopaedic surgery

	All patients <i>N</i> =55	DCO-EF group <i>n</i> =24	DCO-ST group <i>n</i> =31	<i>P</i> value
<i>No patients</i>				
Main characteristics				
Age (Years)	28.0 [21.3–44.0]	27.5 [19.0–47.4]	33.0 [22.0–44.0]	0.70†
Age ≥ 55 years, <i>n</i> (%)	8 (15%)	3 (13%)	5 (16%)	0.99‡
Male, <i>n</i> (%)	47 (85%)	20 (83%)	27 (87%)	0.99‡
Mechanism of trauma, <i>n</i> (%)				
Motor vehicle crash	35 (64%)	16 (67%)	19 (61%)	0.32‡
Bicycle	11 (20%)	6 (25%)	5 (16%)	
Pedestrian	3 (5%)	1 (4%)	2 (6%)	
Fall	3 (5%)	1 (4%)	2 (6%)	
Assault	3 (5%)	0 (0%)	3 (10%)	
Injury severity				
ISS	27 [19–34]	26 [17–34]	27 [22–36]	0.43†
ISS ≥ 16, <i>n</i> (%)	48 (87%)	21 (88%)	27 (87%)	0.72‡
Severe anatomical injuries, <i>n</i> (%)				
Any AIS ≥ 3	50 (91%)	22 (92%)	28 (90%)	0.62‡
Head AIS ≥ 3	28 (51%)	10 (42%)	18 (58%)	0.23‡
Face AIS ≥ 3	8 (15%)	3 (13%)	5 (16%)	0.99‡
Chest AIS ≥ 3	17 (31%)	10 (42%)	7 (23%)	0.13‡
Abdominal ≥ 3	13 (24%)	5 (21%)	8 (26%)	0.67‡
Bones* AIS ≥ 3	48 (87%)	22 (92%)	26 (84%)	0.65‡
Open femoral shaft fracture, <i>n</i> (%)				
Overall open fracture	13 (24%)	7 (29%)	6 (19%)	0.40‡
Gustilo 1	3 (5%)	2 (8%)	1 (3%)	
Gustilo 2	7 (13%)	3 (13%)	4 (13%)	
Gustilo 3	3 (5%)	2 (8%)	1 (3%)	
GCS score on arrival	10.0 [6.0–15.0]	10.5 [6.0–15.0]	9.0 [5.0–15.0]	0.76†
Admission vasopressor use, <i>n</i> (%)	45 (82%)	19 (79%)	26 (84%)	0.92‡
Admission SOFA score	2.0 [0.0–5.0]	3.0 [1.0–6.0]	2.0 [0.0–4.0]	0.11†
TRISS score	2.6 [1.0–3.5]	3.1 [1.6–3.8]	2.4 [1.0–3.0]	0.10†
Admission SAPS II score	34 [26–43]	33 [25–43]	34 [27–44]	0.92†
Respiratory severity criteria				
TTS score	5 [2–8]	5 [3–9]	4 [2–8]	0.75†
Number of ribs fracture	3 [0–7]	3 [2–9]	3 [0–7]	0.35†
Flail chest (%)	9 (16%)	4 (17%)	5 (16%)	0.67‡
Lung contusion (%)	18 (33%)	9 (38%)	9 (29%)	0.51‡
Admission PaFi	330 [232–407]	334 [231–436]	323 [232–380]	0.54†
Prehospital mechanical ventilation, <i>n</i> (%)	34 (62%)	13 (54%)	21 (68%)	0.30‡
Mechanical ventilation in first 24 h, <i>n</i> (%)	43 (78%)	18 (75%)	25 (81%)	0.62‡
Initial transfusion management				
Requirements in the first 24 h				
Number of RBC (Units)	4.0 [0.0–6.0]	4.0 [1.0–8.5]	3.0 [0.0–5.0]	0.24†
Number of FFP (Units)	2.0 [0.0–6.0]	3.0 [0.0–6.5]	2.0 [0.0–5.0]	0.40†
Number of platelets (Units)	0.0 [0.0–1.0]	0.0 [0.0–1.0]	0.0 [0.0–0.0]	0.03†
Massive transfusion, <i>n</i> (%)	9 (16%)	6 (25%)	3 (10%)	0.13‡

Data are expressed as median [IQR] or as number of patients (percentage) as appropriate

* Not including femoral fracture

† Mann–Whitney test

‡ Chi-square or Fisher test as appropriate

ISS injury severity score, AIS Abbreviated Injury Scale, GCS score Glasgow coma scale score, SOFA sepsis-related organ failure assessment, TRISS score Trauma Related Injury Severity Score, SAPS II simplified acute physiology score, PaFi PaO₂/FiO₂ ratio, TTS score, Thoracic trauma severity score, RBC red blood cells, FFP fresh frozen plasma

Table 1 (continued)Massive transfusion: ≥ 10 CGR during first 24 h**Table 2** Surgical management during hospitalization

	All patients	DCO-EF group	DCO-ST group	<i>P</i> value
No patients	<i>N</i> = 55	<i>n</i> = 24	<i>n</i> = 31	
Late femoral management				
Time to definitive fixation (Hours)	117 [59–256]	161 [96–267]	95 [39–220]	0.046 [†]
Definitive fixation, <i>n</i> (%)				
External Fixator	6 (11%)	6 (25%)	0 (0%)	0.004 [‡]
Intramedullary nailing	49 (89%)	18 (75%)	31 (100%)	
Extracortical surgical management, <i>n</i> (%)				
Any intervention	41 (73%)	18 (71%)	23 (74%)	0.95 [‡]
Orthopaedic surgery	36 (65%)	17 (71%)	19 (61%)	0.46 [‡]
Neurosurgery	5 (9%)	2 (8%)	3 (10%)	0.39 [‡]
Laparotomy	6 (11%)	4 (17%)	2 (6%)	0.65 [‡]
Thoracotomy	2 (4%)	1 (4%)	1 (3%)	1.00 [‡]
Vascular surgery	3 (5%)	2 (8%)	1 (3%)	0.57 [‡]
Maxillofacial surgery	5 (9%)	3 (13%)	2 (6%)	0.64 [‡]
Trans-arterial embolization	1 (2%)	1 (4%)	0 (0%)	0.43 [‡]
Other	3 (5%)	2 (8%)	1 (3%)	0.57 [‡]
Mean of extracortical intervention	1 [0–2]	1 [0–2]	1 [0–2]	0.97 [†]

Data are expressed as median [IQR] or as number of patients (percentage) as appropriate

[†]Mann–Whitney test[‡]Chi-square or Fisher test as appropriate

DCO-ST group ($P=0.40$), and the rate of massive transfusion was 25% versus 10%, respectively ($P=0.13$).

Surgical management

Definitive femoral management and details of other surgical management are summarized in Table 2. The delay in definitive shaft fixation was significantly longer for the DCO-EF group versus the DCO-ST group: 161 h [IQR 96–267 h] versus 95 h [IQR 39–220 h] ($P=0.046$). For 6 patients in the DCO-EF group (25%), EF was the definitive treatment of the femoral fracture.

During the hospital stay, 61 extra-femoral interventions were achieved in 41 patients (Table 2). The median rate of extra-femoral interventions was similar in the two groups: 1.0 [IQR 0–2] versus 1.0 [IQR 0–2], respectively ($P=0.97$).

Local complications

Nine patients (16%) in this cohort experienced at least one local complication: non-union, mal-union or local sepsis. The overall rate of femoral re-operation was 12% in the DCO-EF group versus 19% in the DCO-ST group ($P=0.75$;

Table 3). No difference was observed concerning the kind of local complication.

Respiratory status and mechanical ventilation

Mechanical ventilation requirements during hospitalization was 92% in the DCO-EF group versus 81% in the DCO-ST group ($P=0.84$). The daily mechanical ventilation requirements for each group are presented in Fig. 3a. Duration of ventilation tended to be shorter in the DCO-EF group than in the DCO-ST group (6.75 days [IQR 1.75–16 days] versus 8.5 days [IQR 3.0–14.75 days]) but without a significant difference ($P=0.24$) (Table 3). During the first 2 weeks, ARDS was less frequent in the DCO-EF group than in the DCO-ST group: all ARDS, 54% versus 81% ($P=0.035$); moderate or severe ARDS, 29% versus 48% ($P=0.14$) (Fig. 4a; Table 3). Median time for onset of ARDS was comparable between the two groups: 1.0 days [IQR 0–2.5 days] versus 1.5 days [IQR 0–3.0 days] ($P=0.76$). The median duration of ARDS was 2.5 days [IQR 1.0–5.0 days] versus 3.5 days [IQR 1.0–6.5 days] ($P=0.17$). Median worst PaO₂/FiO₂ ratio was 260 mmHg [IQR 160–342 mmHg] in the DCO-EF group versus 206 mmHg [IQR 152–281 mmHg] in the DCO-ST group ($P=0.21$) (Table 3).

Table 3 Complications and outcomes

	All patients	DCO-EF group	DCO-ST group	P value
No patients	N = 55	n = 24	n = 31	
Local complications, n (%)				
Overall local complications	9 (16%)	3 (12%)	6 (19%)	0.75*
Non-union	5 (9%)	1 (4%)	4 (13%)	0.37*
Mal-union	1 (2%)	0 (0%)	1 (3%)	1.00*
Local sepsis	3 (5%)	2 (8%)	1 (3%)	0.57*
Respiratory evolution				
Respi SOFA				
Admission	0.0 [0.0–1.0]	0.5 [0.0–1.5]	0.0 [0.0–1.0]	0.15 [†]
J1	1.0 [0.0–1.5]	0.5 [0.0–1.0]	1.0 [0.0–2.0]	0.13 [†]
J2	1.0 [0.0–2.0]	1.0 [0.0–2.0]	1.0 [0.0–2.0]	0.25 [†]
J3	1.0 [0.0–1.0]	0.0 [0.0–1.0]	1.0 [0.0–2.0]	0.06 [†]
J7	1.0 [0.0–2.0]	1.0 [0.0–2.0]	1.0 [0.0–2.0]	0.57 [†]
J10	1.0 [0.0–2.0]	1.0 [0.0–2.0]	1.0 [0.0–2.0]	0.91 [†]
J15	0.0 [0.0–2.0]	0.0 [0.0–2.0]	0.0 [0.0–2.0]	0.76 [†]
J30	0.0 [0.0–0.0]	0.0 [0.0–0.0]	0.0 [0.0–0.0]	0.88 [†]
Worst PaFi in first 10 days	221 [157–301]	260 [160–342]	206 [152–281]	0.21 [†]
MV requirements, n (%)	47 (85%)	22 (92%)	25 (81%)	0.84*
MV duration (Days)	8 [3–15]	7 [2–16]	9 [3–15]	0.24 [†]
Extubation failure, n (%)	3 (5%)	1 (4%)	2 (6%)	0.60*
ARDS occurrence, n (%)				
All ARDS	38 (69%)	13 (54%)	25 (81%)	0.035*
Moderate and severe ARDS	22 (40%)	7 (29%)	15 (48%)	0.14*
Pneumonia, n (%)	14 (25%)	5 (21%)	9 (29%)	0.53*
General outcome				
Severe bedsores, n (%)	2 (4%)	1 (4%)	1 (3%)	0.69*
Hospitalization transfusion requirements				
Number of RBC (units)	7.0 [2.5–13.0]	8.5 [3.5–17.5]	6.0 [2.0–11.0]	0.21 [†]
Number of FFP (units)	3.0 [0.0–6.5]	3.5 [0.0–7.5]	3.0 [0.0–5.0]	0.46 [†]
Number of platelets (units)	0.0 [0.0–0.5]	0.0 [0.0–1.5]	0.0 [0.0–0.0]	0.09 [†]
Sedation duration (h)	142 [54–221]	96 [20–192]	160 [72–240]	0.21 [†]
Catecholamines duration (days)	2.75 [1.0–7.75]	2.5 [0.6–8.5]	2.75 [1.25–7.25]	0.91 [†]
Acute kidney injury (stage 1 or more)	15 (27%)	7 (29%)	8 (26%)	0.78*
Renal replacement therapy, n (%)	5 (9%)	3 (13%)	2 (6%)	0.38*
LOS in ICU (Days)	13 [8–22]	12 [7–23]	13 [10–20]	0.54 [†]
LOS in hospital (Days)	28 [21–36]	30 [19–45]	24 [21–34]	0.75 [†]
MOF, n (%)	13 (24%)	6 (25%)	7 (23%)	0.83*
Hospital mortality, n (%)	7 (13%)	3 (13%)	4 (13%)	0.96*

Data are expressed as median [IQR] or as number of patients (percentage) as appropriate

SOFA sepsis-related organ failure assessment, PaFi PaO₂/FiO₂ ratio, MV mechanical ventilation, ARDS acute respiratory distress syndrome, RBC red blood cells, FFP fresh frozen plasma, LOS length of stay, ICU intensive care unit, MOF multi organ failure (SOFA score ≥ 10)

*Chi-square or Fisher test as appropriate

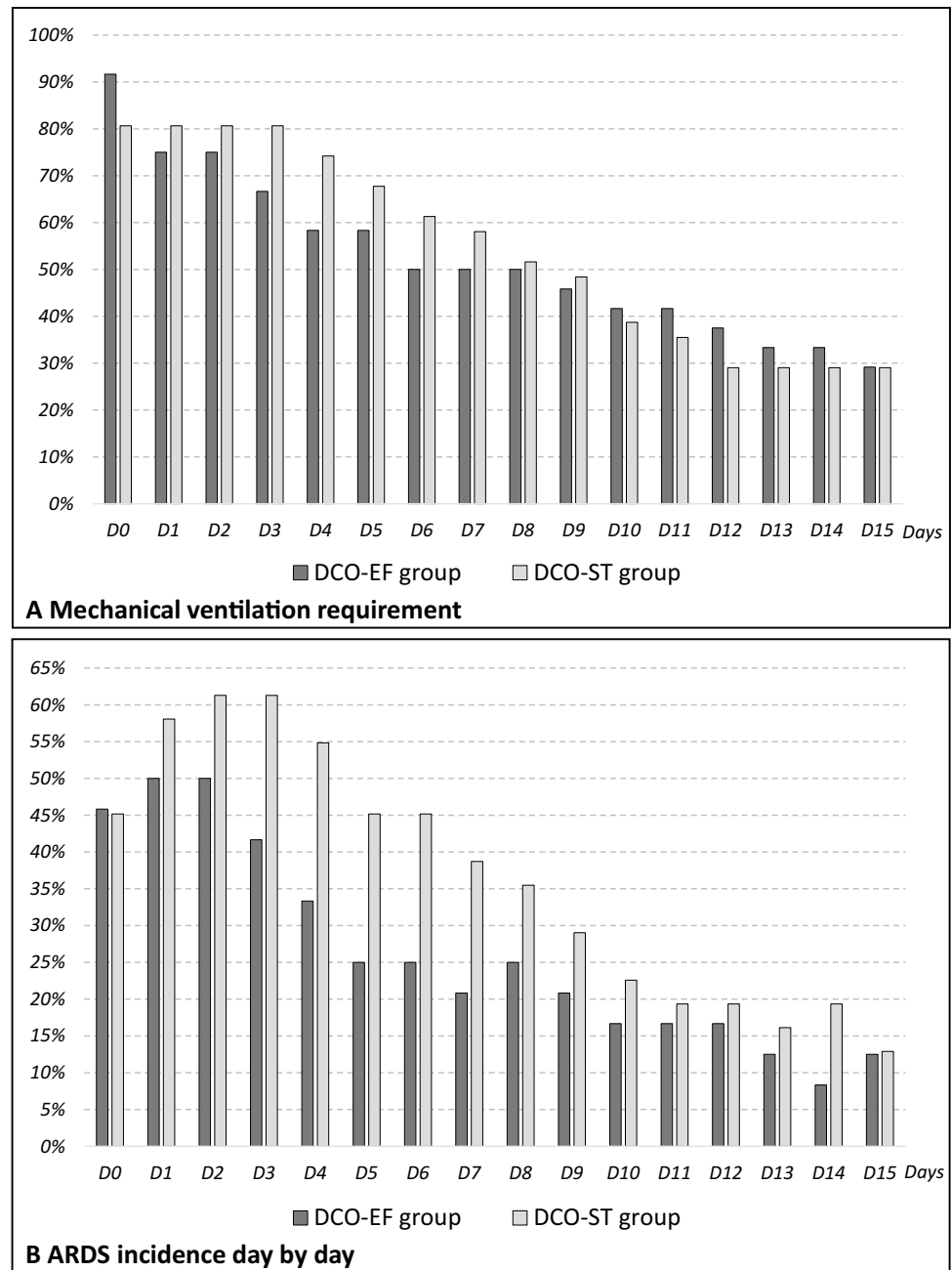
[†]Mann–Whitney test

General complications and outcomes

Median duration of sedation tended to be shorter in the DCO-EF group than in the DCO-ST group: 92 h [IQR 20–192 h] versus 160 h [IQR 72–240 h] ($P = 0.21$).

Occurrence of MOF in the first 2 weeks was comparable between the two groups (25 versus 23, respectively; $P = 0.83$) (Table 3). Median duration of use of catecholamines was also comparable (2.5 days [IQR 0.6–8.5 days] versus 2.75 days [IQR 1.25–7.25 days]; $P = 0.91$). Similarly,

Fig. 3 Comparison of respiratory status between DCO-EF and DCO-ST groups



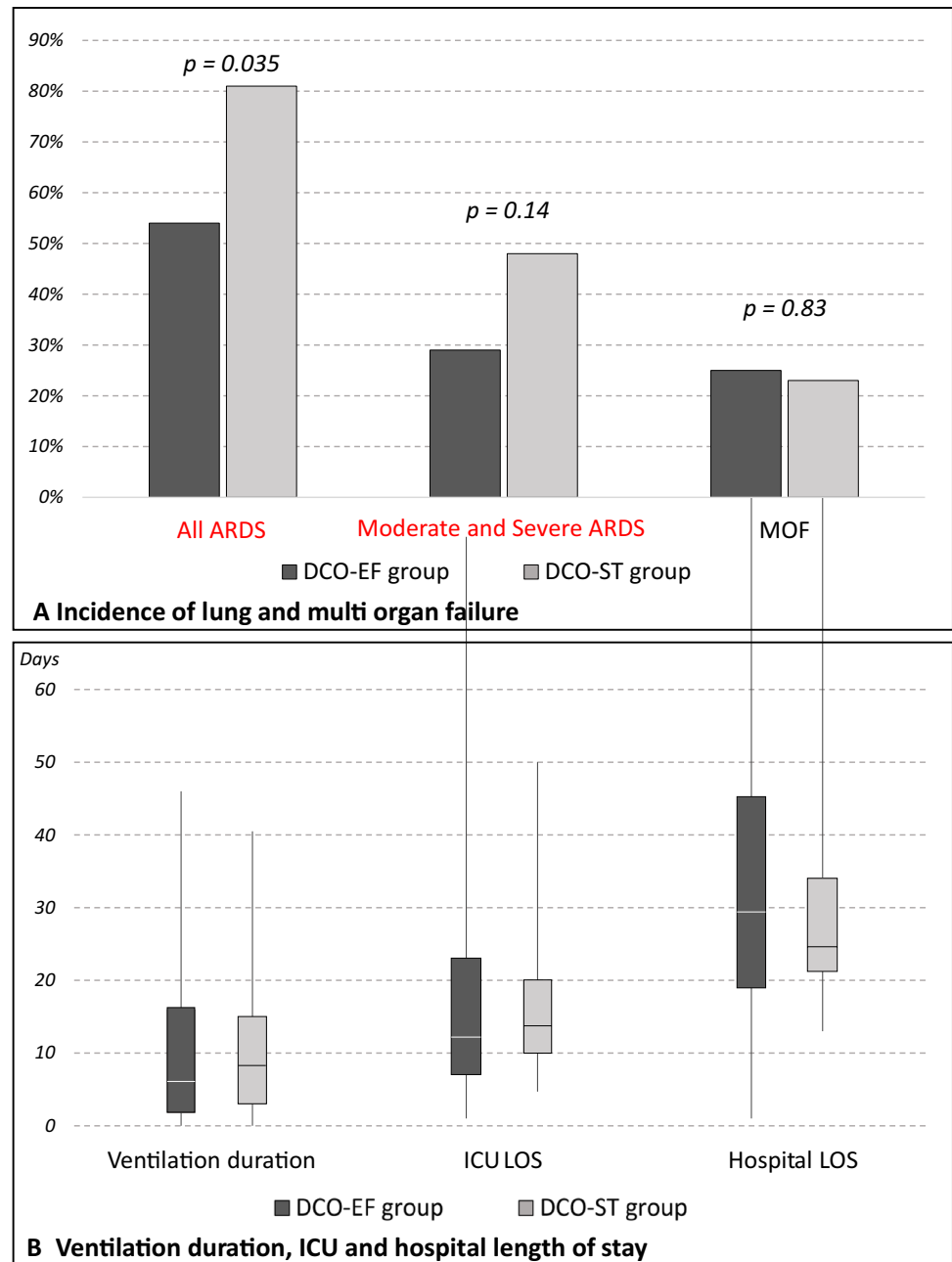
no significant difference was found regarding hospitalization duration and mortality between the two groups (Table 3).

Discussion

In the present study, we report on a cohort of 55 consecutive patients with multiple trauma including a unilateral femoral shaft fracture and managed by a DCO strategy. The ventilation rate in the overall population was high (85) and trauma severity was also high (mean ISS 27). Median delay of definitive femoral osteosynthesis was 117 h [IQR

59–256 h] and median duration of mechanical ventilation was 8.0 days [IQR 3.0–15.5 days]. Of this population, 24 (44) were allocated to the DCO-EF group and 31 (56) to the DCO-ST group. Among the main findings, ARDS incidence was higher in the DCO-ST group despite comparable initial severity (81 versus 54; $P=0.035$). Duration of mechanical ventilation tended to be higher in the DCO-ST group (8.5 versus 6.75 days; $P=0.24$). Conversely, no statistical difference was found for hospitalization duration, MOF incidence or mortality.

For many years, early total care was the standard of care for most femoral shaft fractures. The main goal of

Fig. 4 Respiratory and general outcomes

this surgical strategy was to fix the fracture site rapidly and reduce respiratory complications generated by a fat embolism [18, 19]. The development of the “inflammatory concept” in the late 1990s, introduced the principle of operative burden caused by aggressive and early surgical interventions, especially intra-medullary nailing [20, 21]. This second aggression following severe trauma, also called “second hit”, was indeed incriminated in the generation of a post-operative inflammatory response responsible for clinical systemic disorders, ARDS and MOF [20-22].

Consequently, the DCO strategy was developed and is now recommended by most experts for borderline and severe

trauma patients with long bone fractures [5, 6, 23-25]. In these patients, DCO has proved to be time saving, effective and safe [8]. DCO permits effective temporary stabilization while focusing on resuscitation and restoration of homeostasis in critical patients [5, 6, 23-26]. DCO management is associated with a decrease in the systemic inflammatory insult that results from early orthopaedic surgery and intra-medullary hyperpressure [27].

All the evidences on the benefits of DCO were reported using EF for temporary stabilization. EF is a device that allows fixation of the fracture site, maintaining the anatomic axis of broken bones. On the other hand, ST was proposed as

an alternative to EF because of its simplicity and the speed with which it can be applied. However, only one series has described the safety and efficiency of ST in DCO management. Scannel et al. [11] thus reported a retrospective study comparing EF versus ST in terms of pulmonary complications, MOF and mortality. These authors did not highlight statistical differences for the main endpoints and, therefore, concluded that ST could be a valuable and safe alternative to EF. However, these conclusions must be regarded with caution because of important limitations in this study. First, it was monocentric, retrospective study with a small sample. Second, the definition of ARDS in this study was questionable (i.e., $\text{PaO}_2/\text{FiO}_2 \leq 200$ mmHg for 5 consecutive days or more), which explains the low incidence of ARDS of around 5%. The incidence of ARDS in DCO management is usually around 15–30 in the literature [5, 6, 25, 26]. This methodological bias probably led to a significant lack of statistical power and an erratic prevalence of ARDS. Finally, severity of respiratory criteria probably does not allow objective assessment of all respiratory changes. The safety of ST use in patients at high risk of respiratory failure must consequently still be demonstrated, especially when its use is prolonged. Many constraints have been suggested in the case of ST implantation. First, continuous fixation of the fracture site is not ensured, which may promote delayed fat embolism, supplementary soft injuries and higher blood loss, mal-union and non-union. Second, the traction device strongly limits mobilization of the patient because of unreliable continuous stabilization and risk of micro-displacement at the fracture site. Therefore, it is reasonable to wonder about potential risks of respiratory impairments induced by ST in patients with severe trauma.

In our series of severe trauma patients (mean ISS 27), where 91% had at least one extra-femoral severe injury and 85 required mechanical ventilation, the ARDS incidence was significantly higher in the DCO-ST group than in the DCO-EF group (81% versus 54%; $P=0.035$). This difference would seem to be maximal in the first week (Fig. 3). Moreover, the duration of ventilation tended to be longer in the DCO-ST group (8.5 days [IQR 3.0–14.75 days] versus 6.75 days [IQR 1.75–16 days]; $P=0.24$). This comparison probably lacks statistical power to highlight a significant difference. The worse outcome was thus observed in the DCO-ST group even though the two groups were comparable in terms of initial respiratory status and trauma severity on admission (Table 1). Our data, therefore, support a potential adverse risk to respiratory function with prolonged use of an ST device. One explanation could be that ST requires a permanent dorsal decubitus and limits mobilization, favouring alveolar derecruitment, atelectasis and posture lung injuries. Based on these findings, it seems difficult to recommend the ST for trauma patients at high-risk of developing delayed respiratory failure, when multiple emergent surgeries or

ventral decubitus are planned, or when definitive stabilization is not expected in first days. EF has been shown to be in contrast reliable and relevant in these specific cases, with a possible maintaining during 3 weeks without compromising definitive osteosynthesis [26]. A prospective randomized study would be, however, necessary to confirm the superiority of EF on respiratory function.

Some limitations apply for the present series. First, as in other studies, there is a lack of statistical power, with a retrospective and monocenter design. Second, our study is somewhat comparable to a before/after study because of the change in DCO strategy during the study period (Fig. 2). The usual biases associated with this kind of design could, therefore, apply, particularly the associated changes in clinical practices. However, except during the admission period, trauma severity and the main admission characteristics were comparable between the two groups (Table 1). Third, timing until definitive fixation was slightly longer in the DCO-EF group (161 h versus 95 h, $P=0.046$) (Table 2). The limits of ST that applied previously probably encouraged clinicians to anticipate performing definitive osteosynthesis. Furthermore, EF was the definitive treatment of the femoral fracture in our cohort for 6 patients. The maintaining of these patients may lead to analysis bias. We hypothesize that the timing may have been inappropriate or premature in some patients, promoting lung injuries and ARDS. This phenomenon could explain the differences observed between days 3 and 6 (Fig. 3a, b). Fourth, our high incidence of ARDS may seem surprising at first glance, because it was higher than in other series on DCO strategy [5, 6, 27]. This higher rate is certainly consequence of the definition of ARDS that we chose. The Berlin international definition highlights mild respiratory failure. The rate of moderate and severe ARDS ($\text{PaO}_2/\text{FiO}_2 < 200$) was thus nearly similar to that in previous studies [5, 6, 27]. We assume that the detection of mild and moderate ARDS is one of the main strengths of our study. Previous work suggest when $\text{PaO}_2/\text{FiO}_2$ ratio assessed under standardized ventilator settings, numerous patients with severe ARDS were reclassified as moderate, mild and non-ARDS. Consequently, ARDS diagnosis based on $\text{PaO}_2/\text{FiO}_2$ ratio at ARDS onset may underestimated severity of ARDS [28]. Fifth, isolated contusions may not be properly considered as an ARDS. Indeed, lung contusion may be considered as a confusion factor and leads to false-positives for ARDS diagnosis. However, among the pathophysiological pathways involved in trauma-related ARDS, the activation of local and systemic inflammatory mechanisms, resulting from the activation of innate immunity, plays a key role. Nosological entities are numerous and potentiate themselves, such as contusion, fat embolism, alveolar collapse or pneumonia in later phase. All these entities may be superimposed and the distinction between each one of them is almost impossible. Sixth, we could not demonstrate a significantly higher risk

of pseudarthrosis and inadequate consolidation with the ST device (Table 3). Our analysis certainly lacked statistical power regarding this. Consequently, no definitive conclusion can be drawn on these observations.

Conclusion

In this cohort of severe trauma patients with unilateral shaft fracture, we observed a higher incidence of ARDS in the DCO-ST group than in the DCO-EF group. Therefore, our data support that the prolonged use of ST might generate more lung injuries and ARDS. Consequently, the EF device would seem to be preferable in the setting of a DCO strategy for trauma patients at risk of delayed respiratory failure. A prospective randomized study is necessary to confirm this.

Compliance with ethical standards

Conflict of interest All the authors declare that they do not have any financial and personal relationships with people or organization that can inappropriately influence the work. There is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position of the authors.

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