Timing is everything: Impact of combined long bone fracture and major arterial injury on outcomes

Richard H. Lewis, Jr, MD, Meredith Perkins, MS, Peter E. Fischer, MD, Michael J. Beebe, MD, *and* **Louis J. Magnotti, MD**, *Memphis, Tennessee*

CONTINUING MEDICAL EDUCATION CREDIT INFORMATION

Accreditation

This activity has been planned and implemented in accordance with the Essential Areas and Policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint providership of the American College of Surgeons and American Association for the Surgery of Trauma. The American College of Surgeons is accredited by the ACCME to provide continuing medical education for physicians.

AMA PRA Category 1 Credits™

The American College of Surgeons designates this journal-based activity for a maximum of 1.00 *AMA PRA Category 1 Credit*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Of the *AMA PRA Category 1 Credit*™ listed above, a maximum of 1.00 credit meets the requirements for self-assessment.

Objectives

After reading the featured articles published in the *Journal of Trauma and Acute Care Surgery*, participants should be able to demonstrate increased understanding of the material specific to the article. Objectives for each article are featured at the beginning of each article and online. Test questions are at the end of the article, with a critique and specific location in the article referencing the question topic.

Disclosure Information

In accordance with the ACCME Accreditation Criteria, the American College of Surgeons must ensure that anyone in a position to control the content of the educational activity (planners and speakers/authors/discussants/moderators) has disclosed all financial relationships with any commercial interest (termed by the ACCME as "ineligible companies", defined below) held in the last 24 months (see below for definitions). Please note that first authors were required to collect and submit disclosure information on behalf all other authors/contributors, if applicable.

Ineligible Company: The ACCME defines a "commercial interest" as any entity producing, marketing, re-selling, or distributing health care goods or services used on or consumed by patients. Providers of clinical services directly to patients are NOT included in this definition.

Financial Relationships: Relationships in which the individual benefits by receiving a salary, royalty, intellectual property rights, consulting fee, honoraria, ownership interest (e.g., stocks, stock options or other ownership interest, excluding diversified mutual funds), or other financial benefit. Financial benefits are usually associated with roles such as employment, management position, independent contractor (including contracted research), consulting, speaking and teaching, membership on advisory committees or review panels, board membership, and other activities from which remuneration is received, or expected. ACCME considers relationships of the person involved in the CME activity to include financial relationships of a spouse or partner.

Conflict of Interest: Circumstances create a conflict of interest when an individual has an opportunity to affect CME content about products or services of a commercial interest with which he/she has a financial relationship.

The ACCME also requires that ACS manage any reported conflict and eliminate the potential for bias during the session. Any conflicts noted below have been managed to our satisfaction. The disclosure information is intended to identify any commercial relationships and allow learners to form their own judgments. However, if you perceive a bias during the educational activity, please report it on the evaluation.

Authors/Contributors					
There are no author disclosures.					
First Name	Last Name	Disclosure?	Name of Commercial Interest	What was Received?	What was the Role?
Michael	Nance	Yes	Endo Pharmaceuticals	Consulting fee	Consultant
Heena	Santry	Yes	NBBJ	Salary	Employee
Jose	Diaz	Yes	Acumed/Acute Innovations	Consulting fee	Consultant
Lena	Napolitnao	Yes	Merck Global Negative Advisory Board/Abbvie Critical Care Working Group	Consulting fee	Advisor/ Consultant
Roxie Albrecht, Walter Biffl, Karen Brasel, Clay Cothren Burlew, Raul Coimbra, Todd Costantini, Rochelle Dicker, Tabitha Garwe, Kenji Inaba, Rosemary Kozar, David Livingston, Ali Salim, Deborah Stein, Alex Valadka, Robert Winchell, Bishoy L. Zakhary, and Ben Zarzau have no disclosures or conflicts of interest to report. The Editorial Office staff has no disclosures to report.					

Claiming Credit

To claim credit, please visit the AAST website at http://www.aast.org/ and click on the "e-Learning/MOC" tab. You must read the article, successfully complete the post-test and evaluation. Your CME certificate will be available immediately upon receiving a passing score of 75% or higher on the post-test. Post-tests receiving a score of below 75% will require a retake of the test to receive credit.

Credits can only be claimed online

Cost

For AAST members and Journal of Trauma and Acute Care Surgery subscribers there is no charge to participate in this activity. For those who are not a member or subscriber, the cost for each credit is $25.

Questions

If you have any questions, please contact AAST at 800-789-4006. Paper test and evaluations will not be accepted.

BACKGROUND: Timing of extremity fracture fixation in patients with an associated major vascular injury remains controversial. Some favor temporary fracture fixation before definitive vascular repair to limit potential graft complications. Others advocate immediate revascularization to minimize ischemic time. The purpose of this study was to evaluate the timing of fracture fixation on outcomes in patients with concomitant long bone fracture and major arterial injury.

METHODS: Patients with a combined long bone fracture and major arterial injury in the same extremity requiring operative repair over 11 years were identified and stratified by timing of fracture fixation. Vascular-related morbidity (rhabdomyolysis, acute kidney injury, graft failure, extremity amputation) and mortality were compared between patients who underwent fracture fixation prerevascularization (PRE) or postrevascularization (POST).

RESULTS: One hundred four patients were identified: 19 PRE and 85 POST. Both groups were similar with respect to age, sex, Injury Severity Score, admission base excess, 24-hour packed red blood cells, and concomitant venous injury. The PRE group had fewer penetrating injuries (32% vs. 60%, $p = 0.024$) and a longer time to revascularization (9.5 vs. 5.8 hours, $p = 0.0002$). Although there was no difference in mortality (0% vs. 2%, $p > 0.99$), there were more vascular-related complications in the PRE group (58% vs. 32%, $p = 0.03$): specifically, rhabdomyolysis (42% vs. 19%, $p = 0.029$), graft failure (26% vs. 8%, $p = 0.026$), and extremity amputation (37% vs. 13%, $p = 0.013$). Multivariable logistic regression identified fracture fixation PRE as the only independent predictor of graft failure (odds ratio, 3.98; 95% confidence interval, 1.11–14.33; $p = 0.03$) and extremity amputation (odds ratio, 3.924; 95% confidence interval, 1.272–12.111; $p = 0.017$).

CONCLUSION: Fracture fixation before revascularization contributes to increased vascular-related morbidity and was consistently identified as the only modifiable risk factor for both graft failure and extremity amputation in patients with a combined long bone fracture and major arterial injury. For these patients, delaying temporary or definitive fracture fixation until POST should be the preferred approach. (*J Trauma Acute Care Surg.* 2022;92: 21–27. Copyright © 2021 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Prognostic study, Level IV.

KEY WORDS: Vascular trauma; amputation; long bone fracture.

Combined orthopedic and major arterial injuries of the extremities continue to represent complex injury patterns requiring multispecialty coordination for their management. The appropriate order (or operative sequence) for their management remains a point of contention among trauma, vascular, and orthopedic surgeons.

Many have argued that long bone fixation should be performed *before* revascularization.[1–5] This emphasis on orthopedic repair preceding revascularization has been driven, in large part, by a fear of iatrogenic graft injury (e.g., graft thrombosis or disruption). Conversely, others have argued for performing long bone fixation *after* vascular repair in an effort to limit ischemia time.[6–8]

Given the continued controversy surrounding the appropriate operative sequence for patients with concomitant long bone fractures and major arterial injuries, we sought to better identify the impact of operative sequence on outcomes. Specifically, we hypothesized that revascularization before fracture fixation would lead to decreased extremity-related morbidity (e.g., amputations) without increasing vascular graft complications (e.g., thrombosis). Thus, the purpose of this study was to evaluate the timing of fracture fixation on outcomes in patients with concomitant long bone fractures and major arterial injury.

Submitted: August 8, 2021, Revised: October 2, 2021, Accepted: October 6, 2021, Published online: October 19, 2021.

From the Department of Surgery University of Tennessee Health Science Center, Memphis, Tennessee.

To be presented at the 80th Annual Meeting of the American Association for the Surgery of Trauma and Clinical Congress for Acute Care Surgery, Atlanta, Georgia, September 29 to October 2, 2021.

Address for reprints: Richard H. Lewis, Jr, MD, Department of Surgery, University of Tennessee Health Science Center, Room 220, 910 Madison Ave., Memphis, TN 38163; email: richard.h.lewis@gmail.com.

DOI: 10.1097/TA.0000000000003430

PATIENTS AND METHODS

Study Design, Identification of Patients, and Data Collection

After approval from the institutional review board at the University of Tennessee Health Science Center, a cohort study design was used to evaluate the study population (adult patients requiring operative repair of both a long bone fracture and a major artery located in the same extremity) from an 11-year period (April 2009 to June 2020). The study population was identified from the trauma registry of a Level I Trauma Center (the Presley Regional Trauma Center in Memphis, TN) (see Fig. 1) and stratified by exposure (fracture fixation before vs. after revascularization). The minimum size of the study population (n ≥ 86) was determined via a power analysis (alpha = 0.05 and beta = 0.8) to detect a change in the proportion of patients undergoing amputation from 0.1 to 0.35. The charts were reviewed for patient characteristics, mechanism and severity of injury, severity of shock, time to revascularization, and outcomes, including extremity amputation and mortality. These data were merged with patient data from the trauma registry (NTRACS version 3.5, Digital Innovations) to compile the database for this study.

Patient characteristics evaluated included age (years), sex (male or female), extremity injured (upper or lower), presence of major venous injury (yes or no), fasciotomy performed (yes or no), and intraoperative heparinization (yes or no). Mechanism of injury was defined as penetrating or blunt. The Injury Severity Score (ISS) was used to measure severity of injury. Admission systolic blood pressure (mm Hg), base excess ($mEq \cdot L^{-1}$), and total packed red blood cells (PRBC) transfused over 24 hours (units) were used to evaluate severity of shock. Time to revascularization was measured in hours.

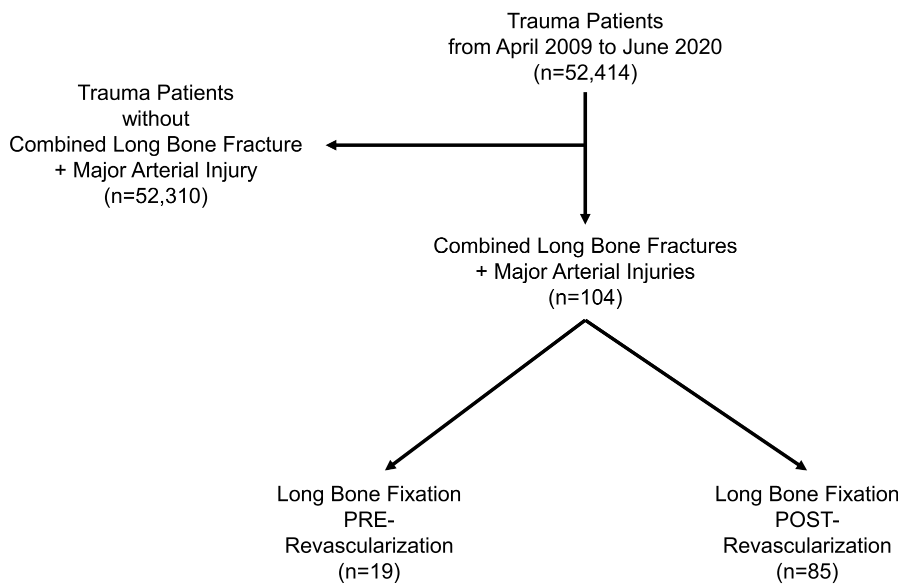

Figure 1. Incidence and management of long bone fractures with concomitant major arterial injury.

Outcomes

Outcomes including amputation, rhabdomyolysis, graft failure, acute kidney injury, and in-hospital mortality were recorded and compared by group. Amputation was defined as patients requiring amputation of the extremity where the combined vascular and long bone injuries were located. Rhabdomyolysis was defined as those patients with a positive urine myoglobin. Graft failure was defined as those vascular repairs with evidence of hemorrhage requiring reoperation or occlusion. Acute kidney injury was defined as those patients with stage 3 acute kidney injury as defined by Kidney Disease: Improving Global Outcomes (serum creatinine three times baseline, increase in serum creatinine to ≥4 $mg \cdot dL^{-1}$, initiation of renal replacement therapy, urine output <0.3 $mL \cdot kg^{-1} \cdot h^{-1}$ for ≥24 hours, or anuria for ≥12 hours).

Patient Management and Technique

Physical examination in combination with radiographic imaging was used for the diagnosis of long bone fractures. The diagnosis of associated vascular injuries relied predominantly on physical examination (e.g., active arterial hemorrhage, nonpalpable distal pulses, or abnormal ankle-brachial indexes) with only selective use of arteriography (either via computer tomography or angiography). The sequence of surgical intervention was determined by the attending trauma/vascular surgeons. Long bone fractures either underwent temporary or definitive stabilization at the index operation. External fixation or percutaneous pinning was used to temporize, while external fixation or surgical fixation (e.g., open reduction internal fixation) was used as definitive treatment modalities. The choice of which approach to use was at the discretion of the attending orthopedic surgeon. Initial revascularization was performed via temporary shunt placement or surgical repair at the discretion of the operative surgeon. Vascular shunts were used either as a temporizing measure (to allow fracture reduction and fixation) or for damage control in hemodynamically unstable patients. Arterial repairs were performed with simple suture repair, resection and anastomosis, reverse saphenous vein graft (as either an interposition or bypass graft), patch repair, or polytetrafluoroethylene bypass. Patients underwent intraoperative intravenous heparinization at the discretion of the surgeon performing the repair (either the attending trauma or vascular surgeon). Postoperatively, all patients were admitted to the trauma intensive care unit.

Statistical Analysis

All analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC). Comparisons between the two groups were performed using a Student's *t* test and χ^2 analysis or Wilcoxon rank sum test where appropriate. Variables exhibiting a significance less than 0.05 were considered for inclusion in the full multiple regression model. Multivariable logistic regression analysis was then performed to identify significant predictors of extremity amputation in the study population. A *p* value less than 0.05 was considered statistically significant.

RESULTS

Patient Characteristics

Over the study period (April 2009 to June 2020), 104 patients with long bone fractures requiring operative management and concomitant major arterial injury requiring repair were identified. These patients ranged in age from 18 years to 73 years (mean, 34 years) and included 88 men (85%) and 16 women (15%). Mean admission systolic blood pressure (SBP) and ISS were 120 (range, 61–180) and 15, respectively. Mechanism of injury was penetrating in 55% (n = 57) of patients. Seventy-nine percent (n = 82) of injuries were located in the lower extremity. All long bone fixations were performed by attending orthopedic surgeon. Sixty percent (n = 62) of vascular repairs were performed by attending trauma surgeons. The remaining 40% (n = 42) were performed by attending vascular surgeons.

TABLE 1. Comparison of Patients Managed With Fracture Fixation Based on Time to Revascularization

	PRE	POST	p
n	19	85	
Age	34 (24, 52)	27 (22, 43)	0.18
Male (%)	17 (89)	71 (84)	0.52
Penetrating (%)	6 (32)	51 (60)	0.024
ISS	10 (9, 18)	10 (9, 19)	0.49
Lower extremity injury (%)	15 (79)	67 (80)	>0.99
Time to revascularization, h	9.5 (6.5, 14.5)	5.8 (4.0, 7.8)	0.0002
Venous injury (%)	7 (37)	31 (36)	0.98
Fasciotomy (%)	12 (63)	60 (71)	0.53
Intraoperative heparin (%)	14 (74)	78 (92)	0.026
SBP	112 (107, 144)	123 (105, 140)	0.81
BE	−3.4 (−5.8, −2.7)	−4 (−7.6, −2)	0.57
24-h PRBC, units	4 (2, 14)	8 (4, 13)	0.35
Mortality (%)	0 (0)	2 (2)	>0.99
Morbidity (%)	11 (58)	27 (32)	0.033
Amputation (%)	7 (37)	11 (13)	0.013
Rhabdomyolysis (%)	8 (42)	16 (19)	0.029
Graft failure (%)	5 (26)	7 (8)	0.026
Acute kidney injury (%)	0 (0)	3 (3.5)	>0.99
Dialysis (%)	0 (0)	2 (2)	>0.99

BE, admission base excess; Morbidity, vascular-related morbidity defined as any of the following: postoperative amputation, graft failure, rhabdomyolysis, acute kidney injury, and dialysis (defined as new need for renal replacement therapy).

Categorical variables are listed as numbers with percentage in parentheses. All continuous variables are listed as medians with interquartile range in parentheses.

The overall mean time to revascularization was 18 hours (median, 6 hours), and 69% (n = 72) underwent fasciotomies. The most common artery injured was the popliteal artery (40%, n = 42) followed by the superficial femoral artery (31%, n = 33) and the brachial artery (13%, n = 14). The remaining injuries involved the tibial vessels (7%, n = 7), axillary artery (5%, n = 5), and the radial artery (3%, n = 3). Associated major venous injury was identified in 37% (n = 38) of patients, of which 61% (n = 23) were managed with ligation. Only 8% (n = 8) had an associated nerve injury.

Approaches to revascularization varied. Eighty-eight percent (n = 92) underwent intraoperative heparinization, and 70% (n = 72) had completion angiography. Only 10% (n = 10) of patients underwent shunt placement. Reverse saphenous vein (64%) (n = 67) used as an interposition graft or a bypass conduit served as the most common operative technique for repair of arterial injuries. Resection and anastomosis was utilized in 29% (n = 30) of cases. The remainder underwent primary repair (1%, n = 1), patch angioplasty (1%, n = 1), or bypass/interposition graft creation with polytetrafluoroethylene (PTFE) (2%, n = 2).

Eighteen percent (n = 19) of all patients underwent fracture fixation (either temporary or definitive) before undergoing revascularization. Of those, 11% (n = 2) underwent primary definitive fixation (i.e., open reduction internal fixation or intramedullary nailing). The remaining 89% (n = 17) underwent initial stabilization with external fixator (84%, n = 16) or traction pin placement (5%, n = 1). Simple linear regression was performed, and fixation prerevascularization (PRE) did not vary over time (beta = −0.07762, $p = 0.5648$).

Comparison

Table 1 demonstrates a comparison of demographics, injury characteristics and outcomes between patients managed with fracture fixation PRE and those with fracture fixation postrevascularization (POST). The groups were similar with respect to age, sex, severity of initial shock (as measured by initial base excess, systolic blood pressure and 24-hour PRBC transfusions), ISS, injury location (i.e., lower vs. upper extremity), associated major venous injury, and fasciotomy formation. Those in the POST group were more likely that have a penetrating mechanism of injury (60% [n = 51] vs. 32% [n = 6], $p = 0.024$). Those in the PRE group were more likely to undergo extremity amputation (37% [n = 7] vs. 13% [n = 11] $p = 0.013$), develop rhabdomyolysis (42% [n = 8] vs. 19% [n = 16], $p = 0.029$), and suffer failure of their arterial repair (26% [n = 5] vs. 8% [n = 8], $p = 0.026$). There was also no difference in acute kidney injury, new need for hemodialysis, or mortality between the two groups.

Table 2 demonstrates a comparison of demographics, injury characteristics and outcomes between patients who underwent extremity amputation versus those who did not. Both groups were similar with respect to sex, mechanism of injury, ISS, intraoperative heparin administration, initial base excess, and admission systolic blood pressure. Those who underwent amputation were older (41 years vs. 27 years, $p = 0.033$), had higher 24-hour PRBC transfusion requirements (13 units vs. 6 units, $p = 0.0066$), more likely to undergo fasciotomy (89% [n = 16] vs. 65% [n = 56], $p = 0.047$), and more likely to undergo fracture fixation before revascularization (39% [n = 7] vs. 14% [n = 12], $p = 0.013$). There was no difference in mortality between the two groups.

Regression Analysis

The results of a logistic regression model developed using the database to predict amputation are shown in Table 3. After adjusting for fixation PRE, time to revascularization, use of intraoperative heparin bolus infusion, and penetrating mechanism of

TABLE 2. Comparison of Patients WITH and WITHOUT Amputation

	With	Without	p
n	18	86	
Age	41 (25, 53)	27 (22, 39)	0.033
Male (%)	15 (83)	73 (85)	>0.99
Penetrating (%)	7 (39)	50 (58)	0.14
ISS	10 (7, 10)	10 (9, 14)	0.43
Lower extremity injury (%)	16 (89)	66 (77)	0.25
Time to revascularization, h	8.2 (5.5, 11.2)	6.2 (4.1, 8.8)	0.25
Venous injury (%)	7 (39)	31 (36)	0.82
Fasciotomy (%)	16 (89)	56 (65)	0.047
Intraoperative heparin (%)	18 (100)	74 (86)	0.092
SBP	111 (93, 143)	124 (108, 141)	0.46
BE	−5.2 (−11, −2.8)	−4 (−7, −2)	0.34
Fixation PRE	7 (39)	12 (14)	0.013
24-h PRBC, units	13 (6, 32)	6 (2, 12)	0.0066
Mortality (%)	1 (6)	1 (1)	0.32

Categorical variables are listed as numbers with percentage in parentheses. All continuous variables are listed as medians with interquartile range in parentheses.

TABLE 3. Predictors of Amputation

	Adjusted OR	95% CI	*p*
Fixation PRE	6.38	1.62–25.13	0.008
Penetrating mechanism of injury	0.59	0.18–1.91	0.38
Time to revascularization	0.98	0.94–1.03	0.39
Intraoperative heparin	999	0.01–999	0.96

injury, multivariable logistic regression found only fracture fixation before revascularization (odds ratio [OR], 6.38; 95% confidence interval [CI], 1.62–25.13; $p = 0.008$) to be significantly associated with amputation. Furthermore, stepwise multivariable logistic regression identified fracture fixation before revascularization (OR, 3.924; 95% CI, 1.272–12.111; $p = 0.017$) as the only independent predictor of extremity amputation.

The results of a logistic regression model developed using the database to predict graft failure are shown in Table 4. After adjusting for fixation PRE, time to revascularization, use of intraoperative heparin bolus infusion, and penetrating mechanism of injury, multivariable logistic regression found only fracture fixation before revascularization (OR, 4.2; 95%, CI, 1.05–16.87; $p = 0.04$) to be significantly associated with amputation. Subsequently, stepwise multivariable logistic regression identified fracture fixation before revascularization (OR, 3.98; 95% CI, 1.11–14.33; $p = 0.03$) as the only independent predictor of subsequent graft failure.

DISCUSSION

Long bone fractures have historically represented grim diagnoses with mortality rates as high as 26% during the American Civil War.[9,10] Subsequent decades saw the introduction of antiseptic technique, antibiotics, and improved methods of soft tissue coverage. As a result, modern civilian series have seen mortality rates improve to less than 5%.[11] Similarly, extremity arterial injuries conferred significant morbidity with amputation rates greater than 40% reported during the Second World War.[12] As operative approach transitioned from ligation to revascularization at the conclusion of World War II and the beginning of the Korean War, amputations markedly declined with recent civilian series reporting limb loss rates of only 3%.[13–16] Although outcomes have improved in patients with isolated long bone fracture and major vascular injuries of the extremity, they remain especially morbid diagnoses when presenting simultaneously in the same extremity. In these patients amputation and mortality rates remain as high as 36% and 7%, respectively, highlighting the added complexity of patients with combined vascular and orthopedic injuries and underscoring the role that operative sequence and timing may play in optimizing outcomes.[6,17,18]

Given the long-standing association between ischemia time and subsequent morbidity in patients with major arterial injuries of the extremity, we expected that complications typically associated with tissue ischemia (e.g., limb loss and rhabdomyolysis) would be lower by prioritizing extremity revascularization over surgical fixation of long bones.[19,20] In this study, only 13% of those who underwent revascularization before fracture fixation ultimately required amputation compared with 37% of those who underwent a "fracture first" management strategy. In addition, rhabdomyolysis rates were significantly lower in the "vascular first" when compared with the "fracture first" group (Table 1). These findings were in line with our hypothesis that limb salvage would be improved and rhabdomyolysis would be limited by prioritizing revascularization over surgical fixation of long bones.[6,7,21]

The "vascular first" approach to the management of these injuries has not been previously embraced by others, in part, because of the theoretical risk of subsequent iatrogenic graft injury during fracture fixation.[5,7] This is thought to occur via manipulation of the injured extremity after vascular repair (e.g., further fracture reduction or hardware placement) resulting in either graft thrombosis or disruption. We hypothesized that this would not be the case for two reasons. First, routine practice at our institution has been to ensure that fractures are adequately manually reduced before performing vascular repair, which should provide a degree of protection from subsequent manipulation. Second, any benefit conferred by preventing further manipulation through a "fracture first" approach would likely be superseded by the deleterious effects of further delaying extremity revascularization. Our results were consistent with our expectations, as those who underwent "fracture first" management had significantly higher graft failure rates than those who underwent a "vascular first" approach (26% vs. 8%, respectively).

The use of temporary vascular shunts has grown in use and popularity from its initial introduction in 1971.[22,23] It can be used as a means of damage control, allowing surgeons to perform formal vascular reconstruction after the patient's metabolic derangements have been corrected. Conversely, shunts may be used in a semielective fashion, allowing for rapid revascularization before formal orthopedic fixation. After operative fracture fixation has been performed, the shunt can then be removed and formal revascularization can be performed at the conclusion of the case. In our study, only nine patients underwent shunt placement. Of these, six were placed semielectively to allow for rapid revascularization before orthopedic fixation. The remaining three patients underwent shunt placement for damage control.

Based on these results, we recommend revascularization before surgical fracture fixation as it is not only associated with decreased limb loss and rhabdomyolysis, but also with fewer graft failures. The type of revascularization (shunt vs. formal arterial repair) should be tailored to the patient's hemodynamic status and overall injury pattern. Given the low number of patients managed semi-electively with shunts, we cannot definitively advocate for shunt use in this fashion. What we do know, however, is that early revascularization (either via shunt placement or definitive repair)—before fracture fixation—decreases ischemia time and improves outcomes in these patients, regardless of hemodynamic status.

TABLE 4. Predictors of Graft Failure

	Adjusted OR	95% CI	*p*
Fixation PRE	4.2	1.05–16.87	0.04
Intraoperative heparin	2.36	0.25–22.47	0.45
Penetrating mechanism of injury	0.76	0.2–2.81	0.68
Time to revascularization	1.0	0.99–1.01	0.96

LIMITATIONS

The primary limitation of this study is that it was retrospective. Specifically, timing and method of revascularization was performed at the discretion of the operative surgeon, potentially introducing bias into the results. Lastly, as this study examined trauma patients exclusively from a single Level I Trauma Center (The Presley Regional Trauma Center in Memphis, TN), application of the results to other populations should be done cautiously, especially when treatment modalities other than those described above are applied.

CONCLUSION

Concomitant long bone fractures and major arterial injuries represent complex injury patterns that require coordinated multispecialty care to achieve optimal results. We recommend that revascularization (either via temporary shunt or definitive repair) be performed *before* operative fracture fixation in order to minimize the risk of adverse outcomes, especially subsequent extremity amputation and graft failure.

AUTHORSHIP

R.H.L. participated in the study design, data analysis, writing, and critical revision. M.P. participated in the data interpretation and critical revision. P.E.F. participated in the critical revision. M.J.B. participated in the critical revision. L.J.M. participated in the study design, writing, data analysis, and critical revision.

DISCLOSURE

The authors declare no conflicts of interest.
The authors have not received funding from the National Institutes of Health (NIH), Wellcome Trust, or the Howard Hughes Medical Institute (HHMI).

REFERENCES

1. Bassett F, Silver D. Arterial injury associated with fractures. *Arch Surg*. 1966;92(1):13–19.
2. Starr AJ, Hunt JL, Reinert CM. Treatment of femur fracture with associated vascular injury. *J Trauma Acute Care Surg*. 1996;40(1):17–21.
3. Rehman S, Salari N, Codjoe P, Rehman M, Gaughan J. Gunshot femoral fractures with vascular injury: a retrospective analysis. *Orthop Surg*. 2012; 4(3):166–171.
4. Paryavi E, Pensy RA, Higgins TF, Chia B, Eglseder WA. Salvage of upper extremities with humeral fracture and associated brachial artery injury. *Injury*. 2014;45(12):1870–1875.
5. Keeley J, Koopmann M, Yan H, DeVirgilio C, Putnam B, Plurad D, Kim D. Factors associated with amputation after popliteal vascular injuries. *Ann Vasc Surg*. 2016;33:83–87.
6. Rosental J, Gaspar M, Gjerdrum T, Newman J. Vascular injuries associated with fractures of the femur. *Arch Surg*. 1975;110(5):494–499.
7. McHenry TP, Holcomb JB, Aoki N, Lindsey RW. Fractures with major vascular injuries from gunshot wounds: implications of surgical sequence. *J Trauma*. 2002;53(4):717–721.
8. Cakir O, Subasi M, Erdem K, Eren N. Treatment of vascular injuries associated with limb fractures. *Ann R Coll Surg Engl*. 2005;87(5):348–352.
9. Blaisdell FW. Medical advances during the Civil War. *Arch Surg*. 1988; 123(9):1045–1050.
10. Pape H, Webb L. History of open wound and fracture management. *J Orthop Trauma*. 2008;22(Suppl 10):S133–S134.
11. 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):1527–1535.
12. DeBakey ME, Simeone FA. Battle injuries of the arteries in World War II; an analysis of 2,471 cases. *Ann Surg*. 1946;123(4):534–579.
13. Ziperman HH. Acute arterial injuries in the Korean war; a statistical study. *Ann Surg*. 1954;139(1):1–8.
14. Barr J, Cherry KJ, Rich NM. Vascular surgery in World War II: the shift to repairing arteries. *Ann Surg*. 2016;263(3):615–620.
15. Barr J, Cherry KJ, Rich NM. Vascular surgery in the Pacific Theaters of World War II: the persistence of ligation amid unique military medical conditions. *Ann Surg*. 2019;269(6):1054–1058.
16. Siracuse JJ, Farber A, Cheng TW, Jones DW, Kalesan B. Lower extremity vascular injuries caused by firearms have a higher risk of amputation and death compared with non-firearm penetrating trauma. *J Vasc Surg*. 2020; 72(4):1298–1304.e1.
17. Al-Salman MM, Al-Khawashki H, Sindigki A, Rabee H, Al-Saif A, al-Salman Fachartz F. Vascular injuries associated with limb fractures. *Injury*. 1997;28(2):103–107.
18. Drost TF, Rosemurgy A, Proctor D, Kearney R. Outcome of treatment of combine orthopedic and arterial injury. *J Trauma Acute Care Surg*. 1989; 29(10):1331–1334.
19. Lang NW, Joestl JB, Platzer P. Characteristics and clinical outcome in patients after popliteal artery injury. *J Vasc Surg*. 2015;61(6):1495–1500.
20. Magnotti LJ, Sharpe JP, Tolley B, Thomas F, Lewis RH Jr., Filiberto DM, Evans C, Kokorev L, Fabian TC, Croce MA. Long-term functional outcomes after traumatic popliteal artery injury: a 20-year experience. *J Trauma Acute Care Surg*. 2020;88(2):197–206.
21. Kauvar DS, Miller D, Walters TJ. Tourniquet use is not associated with limb loss following military lower extremity arterial trauma. *J Trauma Acute Care Surg*. 2018;85(3):495–499.
22. Eger M, Golcman L, Goldstein A, Hirsch M. The use of a temporary shunt in the management of arterial vascular injuries. *Surg Gynecol Obstet*. 1971;132(1):67–70.
23. Mathew S, Smith BP, Cannon JW, Reilly PM, Schwab CW, Seamon MJ. Temporary arterial shunts in damage control: experience and outcomes. *J Trauma Acute Care Surg*. 2017;82(3):512–517.

DISCUSSION

DAVID T. EFRON, M.D. (Baltimore, Maryland): Dr. Henry, Dr. Malhotra, members. Thank you for the privilege of discussing this paper, this very well, clearly presented paper.

Limb salvage remains one of the most important relevant topics in trauma surgery today. It is truly a multi-disciplinary mission that requires not only seamless cooperation with caregivers but smooth and timely interventions, as well.

The authors examined their experience and compare the outcomes from injured limbs when definitive orthopedic fixation as performed first versus reestablishment of vascular flow first.

Ultimately, they conclude that definitive orthopedic first approach is associated with a greater incidence of limb loss. It is my bias that the premise is correct. Time to vascular restoration is paramount.

I have many questions regarding the study but I'll limit it to just a few.

Help me understand better some of your definitions. External fixation was used to bring some of the patients out to length as a temporary measure prior to vascular repair but was also used as definitive fixation management in others. How do you hand these?

You report in the manuscript that 61 percent of the patients were managed in this way. This suggests that a majority of the patients got an orthopedic procedure that at times would be considered definitive.

Sixty-eight percent of those 61 percent underwent subsequent definitive fixation but, ultimately, 11 percent were definitively managed with an external fixator. Again, how do you include these in your analysis?

This is potentially problematic because placing an ex-fix should take about the same amount of time, whether it's definitive or temporary. One can also imagine that a truly mangled extremity only has an ex-fix as an option.

By the way, how, also, did you treat the shunts? In what arm were they included when they were used as a temporary? Was that considered vascular restoration or not?

It leads me to my second question. Ultimately, what were the reasons for amputation? How many patients had severe enough injury to include nerve damage or severe muscle damage? And when did they actually fail?

When I hear this debate I relive the recurring dream of when my orthopedic colleagues start playing their version of "Name that Tune," that is, "I can fix this limb in 20 minutes," "15 minutes."

This is shortly followed by the argument over the potential for graft disruption during subsequent fracture manipulation. Can the authors tell us actually how many times this happened in the group that underwent vascular repair first?

Finally, I would like to hear the authors comments on their inclusion criteria. Both lower and upper extremities were included with 13 percent brachial artery injuries included. The upper extremity is often more forgiving with regard to collateral flow.

They also included distal vessels such as tibial vessels, 7 percent, and radial artery, 3 percent. Should these really be included for this type of analysis when the limb salvage is on the line?

Thank you, again, for the privilege of the podium.

DAVID P. BLAKE, M.D., M.P.H. (McLean, Virginia): Thank you very much. That was a nicely presented study and it does open some more questions, perhaps, than it may have answered completely. But I do have a couple of questions for you.

First of all, Dr. Efron alluded to the placement of shunts. My question is how many of those shunts were patent at the time you went back to actually definitively re-vascularize these limbs?

Secondly, and you perhaps may have commented on it in your presentation and I may have missed it, how many of these limb injuries included a concomitant venous injury? And how were those managed? Were those ligated or were those also shunted since they may have been large vessels?

Again, I thank you very much for presenting that and thanks for the floor.

DAVID LIVINGSTON, M.D. (Newark, New Jersey): Yes, this is really very nice work. But the manuscript may have a lot more data than the presentation, Dr. Efron touched a little bit but is there a philosophical bias in Memphis about shunts because a lot of these?

To me the best management of these cases are like tag team wrestling. Especially in places around the knee where the displaced fractures really make fixing the vascular injury challenging. You control the hemorrhage and put in the shunt then my ortho colleagues put on a couple of pins that may or may not be perfect from an anatomic standpoint but they stabilize the limb and then they tag you back. We come in and fix the blood vessel, do a fasciotomy and then orthopedics come back bring the limb into a more anatomic alignment.

If you've got a vascular injury in the mid-SFA in the setting of a femur fracture it is far easier as bone lines up easily and don't move much even without fixation.

So I think anatomic location and mechanism (blunt versus penetrating) are really important. In some cases, I have put shunts in and then debrided a perfused limb only to find out that everything was injured and everything was ischemic. These patients then underwent amputation because there was no soft tissue to re-vascularize.

As with a lot of trauma issues, it's complicated and the approach has to be both flexible and situational. I am in total agreement that time to restoration of blood flow is of paramount importance. Shunting allows the you to stop the clock on ischemia.

RICHARD H. LEWIS, JR., M.D., M.A. (Memphis, Tennessee): Thank you, Dr. Efron, and the floor for the insightful questions.

So the first about the definitive versus temporizing fixation, essentially the comparison made here was that all patients underwent some sort of orthopedic stabilization during the initial operation. It was either an external fixator or a traction pin or primary ORIF.

Whether or not the ex-fix was used definitively, that's referring to whether or not the external fixator placed at that time was ultimately definitive management for that patient that left the hospital.

And so why that would be, typically that was more related to orthopedic concerns such as soft tissue injury, et cetera.

With regards to shunts and to what arm did they fall, the shunt could have fallen in either group depending on the timing it was placed. If it was placed prior to long-bone fixation it fell in the pre group. If it was placed in the after fixation, it fell in the post group.

Given that there was such low numbers of shunts used over the study period there was no significant difference between the two groups.

Reasons for amputation/timing of failure, we did not look at timing of amputation. Reasons for amputation were typically largely associated with soft-tissue injury, rhabdiomyolysis and graft failure.

With the question about the number of times the graft failure was present in the post group, I don't have an exact number but it was very rare.

With upper versus lower extremity, that's a good point about including those. We might include tibial injuries but there was no difference in upper versus lower extremity between the groups. They were overall similar, which was the reason we kept them in comparison.

With the question of shunt failures, none of the shunts failed. They were all quite successful.

With regards to venous injury, there were 37 percent of the population sustained a concomitant venous injury and 61 percent of these underwent ligation.

And then why not more shunts? I wouldn't say that there is a dogma against shunts but shunts can present their own complications.

If you place an external fixator that can make performing your subsequent vascular repair quite complicated so the bias of many of the vascular surgeons at our institution has been typically – except in damage control circumstances – to perform definitive repair first.

I'd like to thank you for your questions.