Practice Management Guidelines for

Penetrating Trauma to the Lower Extremity

The EAST Practice Management Guidelines Work Group:

Abenamar Arrillaga, MD, Greenville Memorial Hospital, Greenville, SC

Raymond Bynoe, MD, Richland Memorial Hospital, Columbia, SC

Eric R. Frykberg, MD, University of Florida Health Science Center, Jacksonville, FL

Kimberly Nagy, MD, Cook County Hospital, Chicago, IL

Address for Correspondence and Reprints:

Abenamar Arrillaga, MD
890 W. Faris Rd.
MMOB Suite 270, Box 17
Greenville Memorial Hospital
Greenville, SC 29605
Phone: 864-455-7895
Fax: 864-455-4337
E-mail: aarrillaga@ghs.org

PRACTICE PARAMETER FOR EVALUATION AND MANAGEMENT OF COMBINED ARTERIAL AND SKELETAL EXTREMITY INJURY FROM PENETRATING TRAUMA

I. Statement of the Problem

Combined arterial and skeletal extremity injury remains a difficult management problem even for the most experienced trauma surgeons. While over 95% of extremities are now successfully salvaged following uncomplicated penetrating arterial injury, an associated skeletal injury may still result in amputation rates as high as 70% in major trauma centers. These results are most pronounced in the lower extremity, which has more tenuous vascular collaterals and more adverse consequences from nerve injury than the upper extremity.

In the past, virtually all of the combined extremity injuries have been due to blunt trauma in the civilian sector and high velocity missile trauma in the military sector. Over the last two decades their has been an increase of these injuries from a penetrating mechanism. Improved limb salvage rates have been reported recently in these difficult injuries as those factors most closely correlating with limb loss have been identified and addressed. However individual trauma centers and trauma surgeons see relatively few of these injuries, and there are virtually no scientifically sound studies of the proper approach to their management. Several issues remain unclear relating to the appropriate diagnosis, prioritization and treatment of combined arterial and skeletal injuries from penetrating trauma.

II. Process

A Medline computer search was conducted on all articles in the English Literature during the years 1980-1997 pertaining to arterial injuries of the lower extremity in combination with skeletal injuries. The subject words used included Avascular injury@, Aartery injury@, Aextremity trauma@, Apenetrating trauma@, Avascular trauma@, Aextremity fracture@, Aextremity dislocation@ and Aartery trauma@, . The references of these articles were also used to locate articles not found in the Medline search. Personal files were also used. All letters to the editor, case reports, book chapters, review articles, series involving less than 20 cases, series involving predominantly blunt trauma, and series in which the percentage and outcome of the penetrating injuries were not clearly specified were excluded. This left 25 articles of relevance to this practice parameter.

III. Recommendations

A. Level 1

There is no class I evidence to support a standard of care for this parameter.

B. Level 2

The interval between injury and reperfusion should be minimized to less than six hours in order to maximize limb salvage. Restoration of blood flow should always take priority over skeletal injury management, either by temporary shunting to allow

stabilization of unstable fractures and/or dislocations prior to definitive arterial repair, or by immediate definitive arterial repair when the skeletal injury is stable and not significantly displaced.

C. **Level 3**

Orthopedic surgeons should be involved immediately in assessment and management decisions.

1. Arteriography should be done promptly when hard signs of vascular injury are manifest.

2. There is no defined role for the use of noninvasive Doppler pressure monitoring or duplex ultrasonography to confirm or exclude arterial injury in this setting.

3. Evidence suggests that an absence of hard signs of vascular injury in this setting reliably excludes surgically significant arterial injury, and does not require arteriography.

4. Nonoperative observation of asymptomatic nonocclusive arterial injuries may be considered.

5. Four-compartment fasciotomy should be liberally applied at the time of arterial and skeletal repair. If not done compartment pressures should be monitored closely.

6. Completion arteriography should be performed.

7. External fixation is preferable for the immediate management of unstable, displaced, comminuted and open fractures or dislocations. This is especially important in those with severe contamination, extensive soft tissue injury, or in an unstable patient.

8. Primary amputation should be considered in those with tibial or sciatic nerve transection, prolonged ischemia, massive soft tissue injury, severe contamination, open comminuted tib-fib fractures (Gustilo-III), or life-threatening associated injuries.

9. Mangled extremity scoring systems are not sufficiently reliable to serve as the sole determinant of extremity amputation.

IV. Scientific Foundation

All available studies of the epidemiology, diagnosis and management of combined penetrating arterial and skeletal extremity injuries are retrospective. Most civilian series report both blunt and penetrating etiologies, and in some the outcome cannot be related to the mechanism. These considerations prevent firm practice standards from being derived. Nonetheless, these studies provide enough evidence to support a number of recommended management options, as well as directions for future investigation.

Combined extremity injuries are relatively uncommon, making up only 0.2% of all civilian trauma (1). Only 1.5% to 6.5% of all extremity skeletal injuries are associated with an arterial injury (2-5), while 20% to 73% of all extremity arterial injuries may be associated with skeletal fractures or dislocations (2,6-8). Blunt trauma is the predominant mechanism for these injuries in most civilian series. However, over the last decade penetrating trauma has increased in its incidence in this setting, causing from 24% to 71% of cases (1,6-8,9,10). One recent series reported 30 combined injuries from gunshots only (11).

It is clear that combined extremity injuries pose a substantially increased risk of limb loss and limb morbidity than do isolated or skeletal extremity injuries (1,3,4,8,9,10). This is most likely due to greater disruption of collaterals, soft tissues and nerves. Combined injuries from penetrating trauma have a substantially lower amputation rate than those from blunt trauma in the civilian sector. Five civilian series over the past decade have reported the highest proportions of penetrating trauma as a cause of these complex injuries in the literature, being 50% (8), 57% (2), 67% (9), 71% (5), and 100% (11). Their combined results show a total of 39 amputations among 228 patients (17%), but only 9 amputations among the 147 patients (6%) with penetrating trauma. In three of these series reporting 88 patients with penetrating combined injuries there were remarkably no amputations (2,5,11). The apparent increasing trend in penetration as the etiology of these injuries in recent years may have made in of itself a substantial contribution to reducing limb loss. It should be noted that three recent series of combined extremity trauma showed either no difference in amputations between blunt and penetrating trauma or a higher amputation rate among the penetrating injuries (1,4,10). However, these series involved small numbers (40 total) of especially severe injuries. Nonetheless, they demonstrate that there are still other variables which affect outcome besides mechanism.

Prompt diagnosis of vascular injury in any injured extremity is essential because of the well established direct relationship between the time interval from injury to treatment and the chance of limb loss. This principle is confirmed by several series which cite prolonged ischemia, delay in restoration of blood flow, or failure of vascular repair as the most common reasons for limb loss in combined arterial and skeletal extremity injuries (3,4,6-8,10). Arteriography is the modality of choice to confirm or exclude arterial injury, although the indications for its use are debated. Unlike isolated arterial injuries, an associated skeletal injury significantly decreases the predictive value of physical exam findings, since hard signs of vascular injury may be due solely to the bone injury or associated soft tissue injury, without any damage to major vessels, in as many as 60% to 70% of cases (2,3,17). Therefore, immediate arteriography is warranted in combined extremity trauma manifesting hard signs , in order to avoid up to a 70% rate of unnecessary limb exploration (10).

Several recent series suggest that a negative physical examination following combined injury (i.e. no hard signs present) reliably excludes vascular injury which requires repair. Nonocclusive

vascular injuries with benign natural history, however, may occur. Three series report a total of 98 asymptomatic combined extremity injuries from both blunt and penetrating trauma, of which only one underwent surgical repair: an intimal flap of a distal radial artery which may have not required surgery (5,11,17). One series followed 15 asymptomatic nonocclusive arterial injuries from combined extremity trauma for a mean of 6.5 months, none requiring intervention (5). Authors now recommend that arteriography is not necessary for combined extremity trauma with no hard signs of vascular injury.

Although noninvasive vascular studies, Doppler pressure measurements and duplex ultrasonography, have been used in this setting, there is no evidence of any benefit or role for these studies in this setting (2,17,18). In fact, the significant swelling, soft tissue and bone disruption, bulky splints and dressings that characterize these injuries cast doubt on the utility and validity of these tests. Arteriography is clearly the modality of choice for evaluation of high risk extremity skeletal trauma for vascular injury.

Studies have shown that restoration of blood flow within six hours, both with and without skeletal injury significantly improves limb salvage (3,10). There are studies which fail to show a clear correlation between time delay and outcome and some with average treatment delays in excess of eight hours which report amputation rates equivalent to those with prompt treatment within six hours (1,2,4,5,8,9,10). This again stresses that multiple variables affect outcome, and they cannot be controlled in retrospective reports. However, the weight of evidence indicates that rapid diagnosis must be followed as expeditiously as possible by restoration of blood flow.

Studies in the past have recommended that skeletal repair should be done routinely prior to vascular repair (19). More recent studies have advocated selective initial vascular repair only when limb ischemia is clinically evident (1,2,4,7). The rationale for orthopedic priority was the potential disruption of a fresh vascular anastomosis by subsequent manipulation of bone fragments, or length discrepancies in the vascular repair caused by subsequent stabilization of comminuted, unstable skeletal injuries. However, evidence has refuted these conjectures. Snyder et al, noted vascular repair disruption in only 2/29 (7%) cases, neither of which affected outcome as they were repaired immediately (6). Howe et al, found no cases of vascular disruption in 21 combined injuries with subsequent orthopedic repair (3). This data is further supported by studies showing significantly lower amputation rates in those undergoing restoration of blood flow prior to skeletal repair than in those undergoing skeletal repair first (19,22). Although some studies showed either a higher amputation rate, or no difference in amputations, when revascularization was done first, their validity is suspect because vascular priority was only applied to the most ischemic limbs (1,4,8). Howe et al, emphasize that the known importance of a short time interval to revascularization, as discussed above, as well as the absence of any demonstrable disadvantage, should be enough justification to always revascularize first, which is the current consensus (3,5,6,9,14,23).

Restoration of blood flow does not have to be through immediate definitive vascular repair. Temporary vascular shunts effectively solve the dilemma of severely comminuted and unstable fractures/dislocations, in which setting definitive vascular repair cannot be accomplished until the skeleton is stabilized. Shunting still allows immediate restoration of blood flow, without worry of anastomotic disruption. It should also be considered in unstable patients who will not tolerate

further surgery. The definitive vascular and skeletal repair may then follow whenever appropriate (3,6,7,18,23).

It is reasonable to recommend that orthopedic surgeons be consulted and actively participate in the management decisions immediately after combined extremity injury is diagnosed, although there is no firm evidence to prove benefit. Smooth interdisciplinary teamwork is essential to achieving the primary goal of rapid diagnosis and treatment.

In order to document anastomotic patency and distal flow, performance of intra-operative completion arteriography is considered critical following arterial repair in combined extremity trauma (6,23). This is especially important when palpable pulses and signs of distal perfusion are uncertain. Bishara et al, reported that routine completion arteriograms led to detection of unsuspected problems which required revision of repairs in 16% of cases (2). Certainly any loss of pulses postoperatively mandates immediate investigation by either arteriography or surgery, as further ischemia will threaten limb salvage.

The proper method of fracture management has been debated, although it is probably not affected by the concomitant arterial injury to any great extent. Military series have demonstrated a clear advantage of external fixation over internal fixation in the immediate management of these complex, open and highly contaminated combat fractures. Civilian series, which involve lower risk and less complex wounds, have shown good results with internal fixation, although some exclusively applied external fixation (2,9,10). This evidence suggests that combined injuries with a substantial risk of infection (i.e. open, comminuted, severe soft tissue damage), with very comminuted or unstable skeletal injuries, or those in unstable patients who require rapid treatment, are best managed with external fixation, either as a definitive or temporizing measure.

Combined arterial and skeletal trauma poses a high risk for compartment syndrome. Its presence must be considered in every case. Several series of lower extremity vascular trauma have partially attributed excellent limb salvage rates to aggressive use of early fasciotomy (14,19). In combined injuries, fasciotomy has been applied in 30% to 71% of combined cases (2,5,9,10). In virtually all reported cases its application has been recommended either at the time of, or before, the vascular repair is undertaken (2,5,6,8,9,23). It is widely agreed that prophylactic rather than therapeutic fasciotomy, offers the best opportunity for limb salvage and limb function. The nonspecific clinical manifestations of compartment syndrome are late manifestations which are not reliable in helping to avoid limb morbidity (18). When fasciotomy is not performed, compartment pressures should be closely monitored.

Current evidence suggests that nonoperative observation of asymptomatic nonocclusive extremity arterial injuries found on arteriography is safe (21). This appears true in the specific setting of combined arterial and skeletal trauma, where some arterial injuries have been observed (2,5,10,11). In two studies, only one of 45 nonocclusive arterial injuries in this setting underwent surgery, without a single amputation or complication related to arterial injury. Fifteen

of these occult vascular injuries were followed for an average of 6.5 months, and the avoidance of vascular exploration in these severely injured limbs was felt to contribute to the low (7.3%) overall amputation rate (5).

Early amputation may sometimes provide better long term outcome, in terms of cost and function, than overly extensive attempts at limb salvage (1). Gustilo III-C injuries (open comminuted tib-fib fractures with arterial injury), sciatic or tibial nerve transection, severe prolonged ischemia, older age with comorbidity, multiple long bone fractures, crush or extensive soft tissue trauma and severe contamination are factors predicting a high rate of amputation (3,8,24). Although several scoring systems for predicting the need for early amputation have been proposed, none have yet shown sufficient prospective reliability to permit a firm decision for amputation (3,4,25). Initial revascularization and skeletal stabilization should be done in most cases before a decision is made.

V. Summary

There is an increased risk of limb loss with combined skeletal/arterial extremity injuries. The associated skeletal injury will significantly decrease the value of physical examination, thus warranting immediate angiography in patients with hard signs of vascular injury. Patients with a negative physical examination or soft signs of arterial injury do not need angiography.

It is extremely important that blood flow to the distal extremity be restored within six hours. This may be accomplished through use of a temporary vascular shunt while the orthopedic stabilization is accomplished, followed by definitive vascular repair.

Combined injuries are at a high risk for compartment syndrome. Prophylactic fasciotomies should be performed early to reduce the incidence of limb loss.

VI. Future Investigation

Several issues in diagnosis and management of combined arterial and skeletal extremity injuries remain unresolved. Future studies should focus on prospective evaluation of the following:

1. Proper sequence of vascular and skeletal repair in stable, nonischemic extremities
2. Indications for internal fixation of extremity skeletal trauma in this setting
3. Prophylactic vs. Therapeutic fasciotomy
4. Role of arteriography in extremity skeletal trauma with no signs of vascular injury
5. Nonoperative observation of asymptomatic nonocclusive arterial injuries
6. Role of noninvasive tests to evaluate extremities with skeletal injuries for vascular trauma
7. Prognosis and implications of penetrating vs. Blunt mechanisms
8. Indications for immediate or early amputation

9. Role of intraoperative arteriography

VII. References

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First Author	Reference	Class	Findings
Snyder WH	Vascular Injuries Near the Knee: An Updated Series and Overview of the Problem. Surgery 91: 502-506, 1982	III	Review of 110 popliteal artery injuries over 14 yr., 75% from penetrating trauma , 57 (52%) w/ combined injuries though not clear how many combined injuries were from pen. Mech. Revascularization was always done first -only 2/29 (7%) were disrupted during subsequent skeletal repair , but rapidly corrected w/o morbidity. Use shunt first for unstable fx=s, then ex-fix, then definitive vascular repair. Only two amputations (9%) in pen gp. Fasciotomy should be done liberally before vascular repair. All amputations were in limbs presenting w/ severe ischemia, delayed dx & Tx. Completion angio essential.
Keeley SB, et al	Arterial Injuries Below the Knee: Fifty-one Patients with 82 Injuries. J Trauma 23: 285-292, 1983	III	Review of 82 tibial & peroneal a.a. injuries in 51 pts, 67% from penetrating trauma over 13 yrs. 30 (60%) assoc. w/ skeletal injuries, though not clear how many of combined injuries were from penetrating mech. Late dx and blunt mechanism were greatest contributors to 16% amputation rate. Vascular repair first is most important in ischemic limb.
Bishara RA, et al	Improved Results in the Treatment of Civilian Vascular Injuries Associated with Fractures and Dislocations. J Vasc Surg 3: 707-711, 1986	III	Review of 51 combined skeletal and vascular extremity injuries over six years, 57% from penetrating trauma. Combined injuries occurred in 29% of all extremity vascular injuries and 6.5% of all skeletal trauma. Fasciotomy only performed in 19% of isolated vascular injuries. Overall 2.6% amputation rate, none in pen. Gp. Skeletal repair done first in 79%, by ex-fix in 12/23 cases, 11 by int. fixation. Completion angio. Essential-in 16% led to revision of repair. Vascular repair first only w/ ischemia. No difference in outcome related to ex-fix or int. fixation. Early recognition and Tx essential.
Swetnam JA, et al	Successful Management of Trifurcation Injuries. Am Surg 52: 585-587, 1986	III	Review of 36 combined skeletal and popliteal vascular injuries over 15 yrs., w/ 16 amputations (44%). 24 (67%) were penetrating, in whom only 8 (33%) underwent amputation. Primary immediate amputation was done in 8 (only 2 w/ penetrating injury), and fasciotomy in 20 of the remaining 28 (71%) undergoing revascularization. Prompt arterial repair & early fasciotomy emphasized. All orthopedic repairs used ex-fix. Avg. 95 mins. From injury to OR.

Howe HR, et al	Salvage of Lower Extremities Following Combined Orthopedic and Vascular Trauma: A Predictive Salvage Index. Am Surg 53: 205-208, 1987	III	Review of 21 combined skeletal and vascular extremity trauma over six years, making up to 2.2% of all extremity skeletal injuries, resulting in amputation in 9 (43%). Penetrating trauma in 5 (24%), in which gp three had amputations (60%). All had vascular repair first, w/ no subsequent disruptions from skeletal repair. Scoring system derived showed 78% sensitivity and 100% specificity for predicting the need for primary amputation. Uses shunt to revascularize unstable fractures. Interval to revascularization over 6 hours has significantly greater chance of poor outcome, thus vascular repair should always come first.
Bongard FS, et al	Management Strategy of Complex Extremity Injuries. Am J Surg 158: 151-155, 1989	III	Review of 37 combined skeletal/vascular extremity injuries over 6 yrs., 11 (30%) penetrating. 32/37 had vascular repair done prior to skeletal fixation, and 11/37 had prophylactic fasciotomy. No early amputations, 5/31 late amputations (16%), 2 (40%) amps in penetrating injuries, 6 lost to f/u, no deaths. Emphasized importance of early recognition & Tx of a.a. inj, aggressive fasciotomy. Avg. 2.9 hr interval injury to presentation. A-gram only necessary in bone fx when clinical signs of a.a. inj. present.
Drost TF, et al	Outcome of Treatment of Combined Orthopedic and Arterial Trauma to the Lower Extremity. J Trauma 29: 1331-1334, 1989	III	Review of 22 pts w/ combined LE skeletal/vascular injuries over 6 yrs. Out of total 10,000 total trauma pts (0.2%). 8 (36%) were from penetrating trauma. Avg. ischemic time 9.6 hr. , 15 had revascularization before ortho repair (4 shunts, 11 definitive repairs) due to concerns of prolonged ischemia. 8 amputations, 4 in pts w/ penetrating trauma, and 6/8 (75%0 were in those revascularized first. Thus ortho first 2/9 (22%) amputation, revascularization first 6/13 (46%) amputations the latter having significant ischemia. Sequence of repair, type of reconstruction and ischemic interval had no impact on outcome, though location of inj. did- popliteal injuries had the best salvage rate, though high incidence of subsequent permanent disability. Those w/ amputation all w/o problems. Concludes liberal use of amputation may better serve this population- more cost effective and better quality of life.

Poole GV, et al	The Mangled Lower Extremity: Can Salvage be Predicted? Am Surg 60: 50-55, 1994	III	Review of 48 mangled lower extremities w/ combined arterial/skeletal injuries, 21 (43.7%) penetrating making up only 1.5% of all LE fractures, w/ overall 50% amputation rate (8 primary). Amputation rate did not differ between blunt or penetrating mechanism, age, shock, level of inj., or ischemic time. Vascular-ortho repair sequence had twice the amputation rate as the converse (52% vs. 26%) although not statistically significant. Vascular went first in the most ischemic cases. Failure of arterial repair was leading cause of limb loss. Scoring systems do not correlate close enough w/ risk of amputation to be used solely in decision for primary amputation-degree of bone, vascular, nerve, and soft tissue injury determines salvage.
Norman J, et al	Occult Vascular Injuries Following Gunshot Wounds Resulting in Long Bone Fractures of the Extremities. Am Surg 61: 146-150, 1995	III	Review of 75 extremity fx=s from gsw over a 6 yr pd among 331 gsw=s in proximity to major limb a.a. (23%), to examine the incidence of occult vascular injury. 41% had abnormal a-grams. 14 pts (19%) had absent or decreased pulses, w/ 13 993%) abnl agram. 17/61 pts w/ nl vasc exam had abnl agram (28%). 83% of agram abnormalities were minor and never underwent surgery. Only 1 major abnormality had surgery (1.6% of asymptomatic limbs). No limb loss or morbidity in any of the observed occult injuries over mean f/u of 5.4 months. Physical exam is accurate in confirming and excluding those vascular injuries requiring surgery even in presence of bone fx.
Russell WL, et al	Limb Salvage Versus Traumatic Amputation: A Decision Based on a Seven-Part Predictive Index. Ann Surg 213: 473-481, 1991 Am Surg 61: 146-150, 1995	III	Review of 70 LE a.a. injuries, 50% (35) from penetrating trauma 51 of which had concomitant bone injuries (73%0 over 5 years. There were 19 (27%) amputations , all among those w/ bone injuries (37%). Only 1 amputation was in the gp w/ pen trauma (3%). Of 22 Gustillo III-C injuries, 13 (59%) required amputation. Avg. injury-Tx interval was 4.6 hrs. Combined vascular/skeletal repair in 29 limbs, 23 w/ revascularization first (4 amps-17%), 6 w/ ortho repair first (17%). A limb salvage index accurately predicted amputation. Index > 6, Gustillo III-C injuries, tibial or sciatic nerve transection should mandate amputation. 22 fasciotomies. Early dx essential to limb salvage.
Attebery LR, et al	Changing Patterns of Arterial Injuries Associated with Fractures and Dislocations. J Am Coll Surg 183: 377-383, 1996	III	Review of 41 combined skeletal/vascular injuries out of 1091 pts over 4.5 yrs w/ skeletal extremity trauma (3.8%). 29 (71%) were due to penetrating trauma. Mean interval from injury to vascular repair was 1.1 hrs. Three amputations (7.3%) all among blunt injuries. 15/41 (37%) had occult nonocclusive vascular injuries , which were nonoperatively followed for mean of 6.5 months w/o complications. New trend toward predominance of penetrating trauma and non-op management of occult injuries may account for low amputation rate. Physical exam can reliably exclude surgically significant vascular injury.