Evaluation and management of penetrating lower extremity arterial trauma: An Eastern Association for the Surgery of Trauma practice management guideline

Nicole Fox, MD, MPH, Ravi R. Rajani, MD, Faran Bokhari, MD, MBA, William C. Chiu, MD, Andrew Kerwin, MD, Mark J. Seamon, MD, David Skarupa, MD, *and* Eric Frykberg, MD

BACKGROUND: Extremity arterial injury after penetrating trauma is common in military conflict or urban trauma centers. Most peripheral arterial injuries occur in the femoral and popliteal vessels of the lower extremity. The Eastern Association for the Surgery of Trauma first published practice management guidelines for the evaluation and treatment of penetrating lower extremity arterial trauma in 2002. Since that time, there have been advancements in the management of penetrating lower extremity arterial trauma. As a result, the Practice Management Guidelines Committee set out to develop updated guidelines.

METHODS: A MEDLINE computer search was performed using PubMed (www.pubmed.gov). The search retrieved English language articles regarding penetrating lower extremity trauma from 1998 to 2011. References of these articles were also used to locate articles not identified through the MEDLINE search. Letters to the editor, case reports, book chapters, and review articles were excluded. The topics investigated were prehospital management, diagnostic evaluation, use of imaging technology, the role of temporary intravascular shunts, use of tourniquets, and the role of endovascular intervention.

RESULTS: Forty-three articles were identified. From this group, 20 articles were selected to construct the guidelines.

CONCLUSION: There have been changes in practice since the publication of the previous guidelines in 2002. Expedited triage of patients is possible with physical examination and/or the measurement of ankle-brachial indices. Computed tomographic angiography has become the diagnostic study of choice when imaging is required. Tourniquets and intravascular shunts have emerged as adjuncts in the treatment of penetrating lower extremity arterial trauma. The role of endovascular intervention warrants further investigation. (*J Trauma Acute Care Surg*. 2012;73: S315–S320. Copyright © 2012 by Lippincott Williams & Wilkins)

KEY WORDS: Extremity trauma; arterial injury; penetrating extremity trauma; vascular trauma; computed tomographic angiography.

STATEMENT OF THE PROBLEM

Injuries to peripheral arteries are seen most commonly in the military setting or in trauma centers with a high volume of penetrating injuries. Most peripheral arterial injuries occur in the femoral and popliteal vessels of the lower extremity. The issues of how to diagnose, treat, and manage penetrating lower extremity arterial trauma were first addressed by the Eastern Association for the Surgery of Trauma (EAST) in the practice management guidelines on this topic established in 2002. During the past 10 years, there have been advances in the treatment of penetrating lower extremity arterial trauma. As a result, the Practice Management Guidelines Committee decided to develop updated guidelines for this topic.

There are several issues identified as relevant to this practice management guideline update. Specific areas of focus included the prehospital management of patients with hemorrhage from lower extremity penetrating trauma, diagnostic evaluation, choice of radiologic imaging, and the use of intravascular shunts as an adjunct to operative management. In addition, endovascular interventions are used in patients with penetrating lower extremity arterial trauma, and the role of this treatment modality was investigated. It is important to note that the 2002 guidelines were reviewed for content and validity and remain relevant as previously written. They are identified in Section 3 as the recommendation followed by "(2002)."

PROCESS

Identification of References

A search of the National Library of Medicine and the National Institutes of Health MEDLINE database was performed using PubMed (www.pubmed.gov), with citations published between the years 1998 and 2011. Search terms included "vascular trauma," "arterial injury," "extremity trauma," "penetrating

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From the Division of Trauma and Surgical Critical Care (N.F.), Department of Surgery, Cooper University Hospital, Camden, New Jersey; Division of Vascular Surgery (R.R.R.), Department of Surgery, Emory University School of Medicine, Atlanta, Georgia; Department of Trauma (F.B.), Burns and Critical Care, Stroger Hospital of Cook County, Chicago, Illinois; Program in Trauma (W.C.C.), Department of Surgery, R. Adams Cowley Shock Trauma Center, Baltimore, Maryland; Division of Trauma and Acute Care Surgery (A.K., E.F.), Shands Jacksonville, Jacksonville, Florida; Division of Trauma and Surgical Critical Care (M.S.), Department of Surgery, Cooper University Hospital, Camden, New Jersey; and Division of Trauma and Surgical Critical Care (D.S.), Department of Surgery, East Carolina University, Greenville, North Carolina.

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Address for reprints: Nicole Fox, MD, MPH, Department of Surgery, Cooper University Hospital, 3 Cooper Plaza, Ste. 411, Camden, NJ 08103; email: fox-nicole@cooperhealth.edu.

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trauma," and "vascular injury." Articles were limited to those in the English language involving human subjects. Letters to the editor, case reports, book chapters, and review articles were excluded. These articles were reviewed by the com mittee chair for relevance, and the final reference list of 43 citations was distributed to the remainder of the study group for review. Of these, 20 articles were felt to be useful for construction of these guidelines, and an evidentiary table was constructed (Table, Supplemental Digital Content 1, at http://links.lww.com/TA/A185).

Quality of the References

Articles were classified as Class I, II, or III as described in the EAST primer on evidence-based medicine as follows:

Class I: Prospective randomized clinical trials.
Class II: Clinical studies in which data were collected prospectively or retrospective analyses based on clearly reliable data.
Class III: Studies based on retrospectively collected data.

Several of the references identified as relevant to this update were investigating a diagnostic test. These were classified based on the *Journal of Trauma* guidelines on level of evidence for diagnostic studies (those investigating a diagnostic test):

Level I: Testing of previously developed diagnostic criteria in a series of consecutive patients (with universally applied reference "gold" standard) or systematic review of Level I studies.
Level II: Development of diagnostic criteria on the basis of consecutive patients (with universally applied reference gold standard) or systematic review of Level II studies.
Level III: Study of nonconsecutive patients (without consistently applied reference gold standard) or systematic review of Level III studies.

Recommendations were then classified as Level 1, 2, or 3 according to the following definitions:

Level 1: The recommendation is convincingly justifiable based on the available scientific information alone. This recommendation is usually based on Class I data; however, strong Class II evidence may form the basis for a Level 1 recommendation, especially if the issue does not lend itself to testing in a randomized format. Conversely, low quality or contradictory Class I data may not be able to support a Level 1 recommendation.
Level 2: The recommendation is reasonably justifiable by available scientific evidence and strongly supported by expert opinion. This recommendation is usually supported by Class II data or a preponderance of Class III evidence.
Level 3: The recommendation is supported by available data, but adequate scientific evidence is lacking. This recommendation is generally supported by Class III data. This type of recommendation is useful for educational purposes and in guiding future clinical research.

RECOMMENDATIONS

Level 1

1. Computed tomographic angiography (CTA) may be used as the primary diagnostic study for evaluation of penetrating lower extremity vascular injury when imaging is required.

Level 2

1. Patients with hard signs of arterial injury (pulse deficit, pulsatile bleeding, bruit, thrill, expanding hematoma) should be surgically explored. There is no need for arteriogram in this setting unless the patient has an asociated skeletal or shotgun injury. Restoration of perfusion to an extremity with an arterial injury should be performed in less than 6 hours to maximize limb salvage (2002).
2. Patients (without hard signs of vascular injury) who have abnormal physical examination findings and/or an Ankle-Brachial Index (ABI) < 0.9 should have further evaluation to rule out vascular injury.
3. Patients with normal physical examination findings and an ABI > 0.9 may be discharged (in the absence of other injuries requiring admission).

Level 3

1. In cases of hemorrhage from penetrating lower extremity trauma in which manual compression is unsuccessful, tourniquets may be used as a temporary adjunct for hemorrhage control until definitive repair.
2. The use of temporary intravascular shunts (TIVSs) may be indicated to restore arterial flow in combined vascular/orthopedic injuries (Gustillo IIIC fractures) to facilitate limb perfusion during orthopedic stabilization.
3. TIVSs may be indicated in "damage control" situations to facilitate limb perfusion when the physiologic status of the patient or operative capabilities prevent definitive repair.
4. There are no data to support the routine use of endovascular therapies following infrainguinal trauma.
5. Embolization of profunda branches or tibial vessels is acceptable, and there are no data to support preferential use of coils or n-butyl-2-cyanoacrylate (NCBA) glue.
6. The role of noninvasive Doppler pressure monitoring or duplex ultrasonography to confirm or exclude arterial injury is not well defined. There may be a role for these studies in patients with soft signs of vascular injury or with proximity injuries (2002).
7. Nonoperative observation of asymptomatic nonocclusive arterial injuries is acceptable (2002).
8. Repair of occult and asymptomatic nonocclusive arterial injuries managed nonoperatively that subsequently require repair can be done without significant increase in morbidity (2002).
9. Simple arterial repairs fare better than grafts. If complex repair is required, vein grafts seem to be the best choice. PTFE, however, is also an acceptable conduit (2002).
10. PTFE may be used in a contaminated field. Effort should be made to obtain soft tissue coverage (2002).
11. Tibial vessels may be ligated if there is documented flow distally (2002).
12. Early four-compartment lower leg fasciotomy should be applied liberally when there is an associated injury or there has been prolonged ischemia. If not performed, compartment pressures should be closely monitored (2002).

13. Arteriography for proximity is indicated only in patients with shotgun injuries (2002).
14. Completion arteriogram should be performed after arterial repair (2002).

SCIENTIFIC FOUNDATION

Initial Evaluation

It is widely accepted that any patient with "hard signs" of vascular injury, defined as active hemorrhage, rapidly expanding hematoma, absent pulses, or palpable thrill/bruit, should proceed immediately to the operating room without imaging, as outlined in the original practice management guidelines on this topic. Patients with penetrating lower extremity trauma who do not have hard signs of vascular injury, however, require further evaluation. Some patients may present with "soft signs" of vascular injury, which refers to a nonexpanding hematoma, history of arterial bleeding, proximity of the wound to an artery, and a neurologic deficit. The incidence of any arterial injury in these patients ranges from 3% to 25%.[2]

Dennis and colleagues[3] demonstrated that the absence of hard signs of vascular injury on physical examination essentially excludes a clinically significant arterial injury. Two hundred eighty-seven patients with penetrating lower extremity trauma who did not have hard signs of vascular injury were evaluated by physical examination alone and 24 hours of hospital observation. Four patients (1.3%) had delayed onset of hard signs and ultimately required surgical repair. The remaining 283 patients were discharged after 24 hours, and follow-up was obtained on 90 patients (29.3%). No issues were identified on follow-up.

The Ankle-Brachial Index (ABI) or Arterial Pressure Index (API) may be used as an adjunct to physical examination for rapid triage of patients without hard signs of vascular injury. This is useful in situations where the physical examination is equivocal or where practitioners with variable levels of experience are performing the physical examination. Lynch and Johansen[4] calculated arterial pressure indices in 93 consecutive trauma patients. All of these patients then had angiographic evaluation performed. They demonstrated that an API of less than 0.9 had a sensitivity of 87% and specificity of 97% for arterial injury. When clinically insignificant arterial injuries were excluded from the analysis, the sensitivity and specificity rose to 95% and 97%, respectively. The results of this article led to a follow-up study in which angiography was reserved only for extremities with an API of less than 0.9. Sixteen of 17 limbs with an API of less than 0.9 had positive angiography findings; seven of which required reconstruction. Of the 83 limbs that had an API of more than 0.9, minor lesions were identified in five patients on follow-up. The authors cited a 9% decrease in the use of angiography based on these results.[5]

Sadjadi and colleagues[6] retrospectively reviewed 182 patients with penetrating lower extremity wounds; all had an initial ABI > 0.9. Only one patient had a delayed presentation of compartment syndrome, which manifested 2 days after discharge. They concluded that an ABI > 0.9 was 100% specific in predicting safe discharge. The authors subsequently prospectively evaluated the practice of discharging patients with an ABI > 0.9 and no evidence of fracture. Ninety patients were enrolled in the prospective study, 86 of whom had an ABI > 0.9. These patients were discharged home, and the overall complication rate was 5.5%. Most of the complications were soft tissue infections. Bleeding, limb loss, and ischemia did not develop in any patient. The authors concluded that their algorithm of discharging patients home with an ABI > 0.9 and imaging those with an ABI < 0.9 had a 100% positive predictive value for a safe discharge home.

In summary, a reliable physical examination that documents an absence of hard signs of vascular injury is sufficient evidence to discharge patients without further imaging. It should be noted that 1% to 4% of patients with normal physical examination findings will have delayed presentation of an undetected injury. Therefore, follow-up of these patients is critical but often difficult in the trauma population. In some instances, physical examination alone may not be adequate or reliable. The measurement of an ABI is an important adjunct to the physical examination that can be used to determine which patients require further evaluation. Any patient with an abnormal physical examination and/or an ABI < 0.9 should have imaging performed to evaluate the presence of an arterial injury. Patients with normal physical examination findings and an ABI > 0.9 may be safely discharged home with instructions to follow up in the clinic.

Imaging

As demonstrated in studies published by Frykberg et al.[7], there is no role for routine imaging in penetrating lower extremity trauma. Physical examination findings determine which patients warrant further imaging. Traditionally, angiography was the primary imaging modality used to evaluate patients suspected of sustaining an arterial injury from penetrating lower extremity trauma. Limitations of angiography include the risk of associated complications, including damage to the access vessel and hematoma formation, as well as the fact that it is resource intensive and may require specialized personnel. Overall, intra-arterial contrast injection has a complication rate of 1% to 4%. During the past decade, multidetector row helical CTA has been studied as an alternative to conventional angiography. The advantages of CTA are that it is readily available in most centers and uses intravenous contrast only. In addition, it can be performed along with other CT evaluations that may be required. There are several limitations to CTA when compared with catheter angiography, including scatter from artifacts, poor visualization of the tibial vessels, and the inability to perform therapeutic interventions during the study.

Peng and colleagues[8] retrospectively reviewed 52 trauma patients who underwent peripheral vascular imaging for extremity trauma. Fourteen had conventional angiograms, and 38 patients underwent CTA. There was a 68% follow-up of these patients at 4 weeks after discharge. The authors reported that there were no false-negatives or missed injuries with CTA, and that operative findings correlated with imaging studies. Based on these results, CTA became the primary imaging modality for extremity vascular trauma at their institution.

Inaba et al.[9] also retrospectively evaluated trauma patients with lower extremity trauma to determine the sensitivity and specificity of CTA. During a 3-year period, 59 patients had 63 CTA studies performed: 22 were positive for injury, 40 were negative, and one was nondiagnostic. Three of the patients who had positive CTA findings had a confirmatory angiography that correlated with the CTA results in all three cases. Of the 40 patients with negative CTA results, confirmatory imaging was obtained in five patients; all studies were normal. The authors concluded that when considering clinically significant injuries, CTA achieved a sensitivity and specificity of 100% and may replace angiography in most patients.

Inaba et al.[10] followed their retrospective review with the results of a prospective study investigating the diagnostic capability of CTA for extremity trauma. Thirty-five patients had hard signs of vascular injury and went immediately to the operating room. Five hundred twenty-seven patients had no signs of vascular injury and were observed. Seventy-three patients had soft signs (venous oozing, nonexpanding hematoma, diminished pulses, or abnormal ABI or brachial-brachial index) and underwent CTA. The authors noted that 11 of 73 patients in the soft signs group actually did not have any sign of vascular injury but were protocol violations and screened at the surgeon's discretion. Consistent with their previous study, the authors found that the sensitivity and specificity rate of CTA for detecting clinically significant arterial injuries was 100%. It should be noted that patient follow-up was difficult in this study; only 18 of the 44 patients with negative studies were evaluated after discharge.

Seamon et al.[11] published the results of the only prospective study that directly compared CTA to conventional angiography. Twenty-one patients with potential extremity vascular injuries were prospectively enrolled. Patients without hard signs of vascular injury had ABIs measured, and imaging was reserved for patients with an ABI < 0.9. All patients underwent CTA, followed by conventional angiography, with the exception of two patients who had evidence of limb-threatening injuries on CTA and underwent confirmatory operative exploration rather than angiography. The authors found that CTA had a 100% sensitivity and specificity for the detection of clinically significant arterial injuries. Furthermore, the use of CTA saved $12,922 in patient charges and $1,166 in hospital costs per extremity.

In summary, CTA is demonstrated in retrospective and prospective studies to have a sensitivity and specificity rate that is equivalent to conventional angiography. CTA is readily available and noninvasive and is associated with lower overall costs. In patients with penetrating lower extremity injury who require imaging to assess for arterial injury, CTA may be used as the primary imaging modality.

Tourniquets

The use of tourniquets for hemorrhage control in extremity wounds was documented as early as the 17th century. During World War I, military personnel drew attention to the complications of tourniquet use, including nerve damage and limb loss, and their use was strongly discouraged. The debate over the role of tourniquets continued during World War II, the Korean War, and in Vietnam. Recently, the conflicts in Afghanistan (Operation Enduring Freedom) and Iraq (Operation Iraqi Freedom) have provided more experience and data regarding tourniquet use because of the significant numbers of peripheral arterial injuries secondary to explosive devices.[12] Current advanced trauma life support (ATLS) recommendations are to attempt all other means to control hemorrhage before consideration of a tourniquet, including direct pressure and pressure dressings. There are circumstances, however, in which tourniquet use may be appropriate and lifesaving.

In 2002, Lakstein and colleagues[13] published the results of a retrospective analysis of tourniquet use from the Israeli Defense Force experience during a 4-year period. Five hundred fifty soldiers were treated in the prehospital setting; 91 (16%) of whom had tourniquets applied. "Effective" use was described as absolute control of hemorrhage distal to the injury site. Ninety-eight percent of the patients had a penetrating mechanism of injury, and 68% of the injuries were in the lower extremities. Overall, 71% of the tourniquet applications to the lower extremities were effective. There was not a single death from uncontrolled limb hemorrhage reported during a 4-year period, and the overall complication rate associated with tourniquet use was 5.5%. The authors recommended that ischemic time be kept as short as possible and that tourniquets be replaced with bandages when appropriate.

Beekley et al.[14] performed a retrospective analysis of the experience with tourniquet use in Operation Iraqi Freedom. One hundred sixty-five patients with extremity injuries met criteria for review; 40% arrived at the site of initial care with a tourniquet in place and 60% arrived without tourniquets. The mean prehospital tourniquet time was 70 minutes in these patients. Overall, there was an 83% rate of effective bleeding control in patients with tourniquets placed versus a 60% rate of bleeding control in patients without tourniquets. On further analysis, the authors concluded that 57% of the number of deaths in this patient population may have been prevented by earlier tourniquet use. They did not identify any complications related specifically to tourniquet use.

The only prospective study of tourniquet use was conducted in 2006 by Kragh and colleagues[15] at a combat support hospital in Baghdad. The authors found that tourniquet use was strongly associated with survival particularly when they were applied before the onset of shock. In these patients, there was a 90% survival rate as compared with a 10% survival rate in patients who had tourniquets applied in the presence of shock. In addition, survival was increased in patients who had tourniquets placed in the prehospital setting rather than in the emergency department. Field tourniquet use was associated with an 11% mortality rate, whereas the mortality rate in patients who had tourniquets placed in the emergency department was 24%. The complication rate in this study was 1.7% and limited to transient nerve palsy.

In summary, despite the historical debate over the role of tourniquets in extremity vascular injuries, recent military literature demonstrates that tourniquets, when applied correctly, can be lifesaving. The initial approach to an arterial injury should be manual compression or a compression dressing, and the primary indication for tourniquet use should be the failure of direct pressure to control hemorrhage from an extremity vascular injury. Tourniquet time should be limited and tourniquets should be removed when definitive care is available.

When correctly used, the complication rate from tourniquet use is exceedingly low.

Temporary Intravascular Shunts

In 1971, Eger et al.[16] were among the first to document the use of TIVSs in vascular trauma. They used polyethylene tubing with an average time from injury to definitive repair of 10 hours and an amputation rate of 8%.

Since this time, TIVS use has expanded. Shunts may be used in arteries and/or veins to maintain arterial inflow or venous outflow. When placed intra-arterially, shunts facilitate perfusion until definitive repair is possible. For venous injuries, a temporary shunt provides drainage and decreases venous hypertension. Recent military conflicts have provided more insight into the use and efficacy of TIVS that has led to increased use in the civilian population.

In 2006, Rasmussen and colleagues[17] retrospectively reviewed their experience with TIVS at a central Echelon III facility in Iraq. Fifty-three patients were operated on at forward locations, 57% of whom had TIVS in place on arrival. The patency rate for shunts in proximal vascular injuries was 86% versus 12% for shunts placed distally. All shunted injuries were subsequently reconstructed with a 92% viability rate. The authors concluded that the use of TIVS is preferable to attempted reconstruction in austere environments.

In 2008, Subramanian et al.[18] published the largest series examining the use of TIVS in civilian patients to date. Sixty-seven patients had a total of 101 TIVS placed to either allow damage control surgery in patients with physiologic derangement (44%) or to facilitate reconstruction of Gustillo IIIc fractures or limb replantation (42%). Gustillo IIIc fractures are fractures associated with an arterial injury requiring repair regardless of degree of soft tissue injury. In this patient population, the thrombosis rate for TIVS was 5%, the amputation rate was 18%, and overall survival was 73%. The authors concluded that in the two populations of patients described, TIVSs are an important adjunct to definitive repair and should be used liberally. The authors recommend using the largest caliber shunt possible and did not recommend the use of anticoagulation because the patients studied were inherently coagulopathic and patency rates were high.

Taller et al.[19] prospectively studied the use of shunts in extremity vascular injuries at an Echelon II facility during a 7-month period. Twenty-three proximal shunts were placed in 16 patients at initial operation. Twenty were placed in the lower extremity. All patients were subsequently transferred to an Echelon III facility for reconstruction. All shunts were patent on arrival, and the limb preservation rate was 100%. The authors concluded that all proximal extremity vascular injuries not amenable to primary repair should be shunted and transported to a higher level of care.

In 2010, Borut and colleagues[20] published the results of a retrospective review of the use of TIVS with a 2-year follow-up. This is the longest follow-up period provided in any study on the use of TIVS. Eighty patients were reviewed; 57% of whom had TIVS placed whereas 43% underwent repair at initial operation. There was no difference in amputation rates between patients who had a TIVS placed and those that had immediate repair. These findings led the authors to conclude that the use of TIVS does not compromise the injured limb and is an important adjunct in the treatment of extremity vascular injury.

In summary, the use of TIVS has increased in the military and civilian settings and represents an important operative adjunct in extremity vascular injury. The use of TIVS is primarily indicated in patients undergoing damage control surgery in which their physiologic status precludes immediate definitive vascular repair. In addition, patients with Gustillo IIIc fractures who require orthopedic stabilization before vascular repair may benefit from the placement of a TIVS. The results of the studies outlined above also support the fact that the largest available shunt should be used and routine anticoagulation is not indicated.

Endovascular Intervention

Whereas there are limited data regarding the routine use of endovascular techniques following lower extremity penetrating arterial trauma, selective use of coil embolization has been described by several groups. As expected, arterial embolization is reserved for branch vessel occlusions, most commonly for internal iliac, profunda femoris, or tibial branch bleeding. There are three small series describing arterial embolization of bleeding lower extremity branches following penetrating trauma. Thirty patients were treated with coils (n = 16), NCBA (n = 13), or thrombin (n = 1). Treated vessels were not always specified but included branches of the internal iliac, profunda femoris, and tibial arteries. Hemostasis appeared to be obtained in all cases, and nontarget embolization occurred in two patients. Overall, lower extremity branch vessel embolization for hemostasis seems safe and therapeutic for selected victims of penetrating extremity arterial trauma. There is insufficient evidence to support one type of embolization medium over another, and most reported cases involve selective embolization as opposed to the main vessel.[21–24]

There are currently no large series describing infrainguinal stent grafting following penetrating extremity arterial trauma. As such, consideration of these procedures should only be made on an individual case-by-case basis.

FUTURE INVESTIGATIONS

There are several issues that require further investigation. For nonocclusive arterial injuries managed nonoperatively, the role and duration of anticoagulation are not clear. The appropriate follow-up of patients managed nonoperatively remains an area of debate. This issue is complicated by the overall difficulty of follow-up in the trauma population. In addition, there is no consensus regarding the use of anticoagulation in patients who have had arterial repair performed.

Finally, further investigation into endovascular interventions for penetrating lower extremity trauma is warranted. The data reviewed for this practice management guideline on endovascular management were limited. Although well established in the elective setting, it is not clear what role endovascular treatment will ultimately have in the treatment of traumatic arterial injuries.

DISCLOSURE

The authors declare no conflicts of interest.

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