Pushing advanced hemorrhage control interventions forward: Reducing prehospital mortality from traumatic hemorrhage through further adoption of effective military prehospital strategies

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ABSTRACT: Advancements in military medicine have had profound impacts on civilian trauma care. The current practices in civilian prehospital care focus on providing limited interventions in the field and rapid transport to higher levels of care. Very few prehospital emergency medical services in the United States have the capability to provide prehospital blood transfusions or advanced hemorrhage control procedures for trauma patients in hemorrhagic shock. As such, prehospital mortality from hemorrhage remains high. The United States military has adopted the use of prehospital blood transfusions during recent combat operations in the Middle East to mitigate prehospital mortality. Additionally, select military surgical teams capable of providing damage-control surgery as close to the point of injury as possible have been used to decrease the time to lifesaving interventions. This review seeks to assess current practices in civilian prehospital care within the United States while evaluating recent military medical lessons learned on prehospital blood products and minimizing time to lifesaving interventions, to identify potential opportunities to reduce mortality in civilian prehospital trauma care. (*J Trauma Acute Care Surg.* 2025;00: 00–00. Copyright © 2025 Wolters Kluwer Health, Inc. All rights reserved.)

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Hippocrates is credited with saying, "He who wishes to be a surgeon should go to war." Despite the grotesque nature of combat, the military's impact on trauma care remains unparalleled throughout history. Driven by high casualty rates in rapidly evolving environments, combat operations have forced countless clinicians to provide innovative solutions for horrific problem sets. These issues have yielded the notion that the only winner in war is medicine. As such, the medical lessons learned from military conflict have drastically influenced the practice patterns of civilian trauma care.[1,2]

In the prehospital setting, a crucial period for traumatically injured patients, many of the current civilian practices and interventions either stem from or have been strongly influenced by military practice. Some prominent examples include modern-day triage techniques, both ground- and air-based ambulance systems, early tourniquet use, hemostatic dressings, administration of tranexamic acid, and prehospital blood transfusions.[3–9] Despite these advancements, prehospital mortality secondary to hemorrhage remains high.[10]

The recent conflicts in the Middle East have led the US military to further define their prehospital practices in efforts to mitigate death on the battlefield. The ability to transfuse prehospital blood products represents a lifesaving intervention common in military settings; however, prehospital transfusions remain rare in civilian prehospital care across the United States.[11] Moreover, specifically designed military trauma teams have been used to provide advanced resuscitation and lifesaving interventions both in the field and during patient transport. These procedures, performed both by physicians and specially trained medics, typically fall outside of the traditional civilian prehospital scope of practice. The intent of this narrative review is to evaluate the principles of current US civilian prehospital trauma care, as well as select military lessons learned from the recent US conflicts in Middle East regarding prehospital blood transfusions and forward surgical capabilities, to assess for disparities and potential areas for future improvement.

CURRENT CIVILIAN PREHOSPITAL PRACTICE

Much of US civilian prehospital trauma care revolves around initial patient stabilization with rapid transport to a higher level of care. Prior to any medical care rendered by emergency medical services (EMS) personnel, assuring the scene is safe remains of utmost importance.[12] While military and combat settings may require ongoing tactical operations to limit the risk of first responders becoming combat casualties, these scenarios

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remain less likely, albeit not impossible, in civilian settings. Occasionally, there are real concerns with scene safety from ongoing hostile fire, and this must be addressed first. Other common safety concerns for civilian EMS personnel include optimization of traffic, presence of fire or smoke, unstable buildings or structures, and weather conditions or other environmental elements.

Once on scene and deemed safe for patient treatment, EMS personnel perform a rapid triage of the casualties to distinguish injury patterns and identify those with life-threatening injuries. During the triage process, EMS personnel follow a standardized approach to assess for ongoing external hemorrhage, airway patency, respiratory compromise, inadequate perfusion, alterations in mental status, and attempts to control environmental factors such as hypothermia.[12,13] Focusing on speed in efforts to not delay transport to higher levels of care remains common practice within the prehospital setting. Aiming to quickly address immediate life-threatening injuries, these include interventions such as wound packing, tourniquet placement, establishment of an airway, needle decompression of the chest, placement of peripheral intravenous or intraosseous line placement, initiation of resuscitation fluids, spinal motion restriction, and patient warming. Despite this, accurate prehospital triage remains a challenge resulting in high rates of under- and overtriage.[14]

It is important to note that prehospital interventions happen both on scene and en route depending on the situation at hand. Although more invasive hemorrhage control procedures may be required, they often fall outside of the scope of practice for the vast majority of EMS personnel. Rapid transport to a higher level of care remains a critical component to current prehospital trauma care.[13] This is often accomplished by ground ambulance services; however, situations where ground transport could present significant delays often lend themselves to air transport via helicopter. Much of the idea surrounding rapid transport stems from the concept of "the golden hour," a term coined by R. Adams Cowley in 1975.[15] This concept highlights the notion that the first hour after injury plays the largest impact on survivability. Although "the golden hour" was widely popularized, it lacked significant data during its inception.[16] Nevertheless, "the golden hour" changed the culture of prehospital care resulting in the current model used today.

PREHOSPITAL BLOOD PRODUCTS

Intuitively, transfusing blood products at the earliest time possible for hemorrhagic shock makes sense. Numerous reports have demonstrated the benefits of blood product transfusion, as opposed to crystalloid solutions, for restoring intravascular volume and preventing or treating coagulopathy in bleeding trauma patients.[17–19] This highlights the popular adage among clinicians that "blood is for bleeding; salt water is for cooking pasta."

Military data from recent conflicts in the Middle East have demonstrated that transfusion of prehospital blood products increases the probability of survival for combat casualties. Shackelford et al.[9] found that, in physiologically unstable combat casualties, prehospital blood product transfusions significantly improved survival at 24 hours (hazard ratio, 0.26; $p = 0.02$) and 30 days (hazard ratio, 0.39; $p = 0.03$). Prehospital blood products are now recommended in combat scenarios when available in efforts to push the principles of damage-control resuscitation further forward.[20] Moreover, military advancements in prehospital transfusion, such as the prehospital use of blood transfusions (both components and whole blood) at the point of injury and en route, continue to identify novel ways to minimize time to transfusion for hemorrhaging patients.[20,21]

Only two US randomized controlled trials have assessed the use of prehospital blood products, specifically plasma, and its impact on mortality. While the Prehospital Air Medical Plasma Trial (PAMPer), a multicenter randomized controlled trial using Food and Drug Administration–approved plasma, demonstrated prehospital plasma transfusions decreased 30-day mortality, the Control of Major Bleeding After Trauma Trial (COMBAT), a single-center trial using a non–Food and Drug Administration–approved frozen plasma product that required thawing at the scene of injury, did not show any statistically significant differences in mortality outcomes.[22,23] Differences in trial design and patient populations are postulated to atone for these incongruent findings; however, subsequent analyses combining both PAMPer and COMBAT support the use of prehospital plasma, especially in those with transport times greater than 20 minutes.[24,25] A post hoc analysis of PAMPer further demonstrated that the greatest mortality benefit was seen in patients who received both packed red blood cells and plasma in the prehospital phase of care.[26]

Despite this, only a small fraction of US ground EMS agencies have access to prehospital blood products, whether it be blood components or whole blood, and less than 1% of patients in hemorrhagic shock receive prehospital blood transfusions.[11,27–29] This lack of access results in a heavy reliance on prehospital crystalloid and vasopressor administration for hypotensive trauma patients. Although the complications associated with these resuscitation adjuncts in hemorrhagic shock are well documented, the absence of prehospital blood products stems from a multitude of barriers to include funding, fears of wastage, concerns of proper handling and storage in the prehospital environment, variations in EMS provider's scope of practice based on state, and appropriate reimbursement.[28]

While some may argue that prehospital blood products are not needed during short transport times since blood products will be administered on arrival to the hospital, this notion fails to consider the ongoing shock the patient is experiencing. As such, recent data demonstrate that, in hemorrhagic shock, every minute counts and delays in prehospital and hospital blood product administration are associated with significant increases in mortality.[30–32] Moreover, only accounting for prehospital transport time fails to consider the time from injury to EMS arrival, as well as the time EMS is on the scene. Accounting for these time periods, although highly variable based on the region and access to care, multiple accounts demonstrate that a high percentage of trauma patients experience total prehospital times much longer than 20 minutes, with even longer times to operative intervention and definitive hemorrhage control.[33–37] Ultimately, this prehospital delay places patients at risk for either extensive periods of shock or subject to the harmful effects of crystalloids and vasopressors in hopes to prevent traumatic arrest.

The military's incorporation of prehospital blood products into their recommendations for combat causalities highlights the idea that survival is not predicated on time to hospital arrival, but rather time to blood products and lifesaving interventions.[30,31,38,39]

While prehospital blood transfusions do not theoretically counter the current EMS model focusing on limited interventions and rapid transport, recent studies have evaluated the addition of a prehospital advanced resuscitation care (ARC) bundle consisted of prehospital packed red blood cells, 2 g of calcium, and 2 g of tranexamic acid into EMS protocols.[31,40,41] Following the adoption of an ARC bundle, Duchesne et al.[31] report prehospital times increased by 4.5 minutes within the ARC cohort in a nonrandomized study; however, these patients received blood products 19 minutes faster than the control group, arrived to the trauma bay more physiologically stable, had significant improvements in in-hospital mortality rates (7% vs. 29%, $p < 0.01$), and demonstrated that every minute delay in blood product administration was independently associated with an 11% increase in the odds of mortality. Their reported increase in mortality risk with delays in blood product transfusion remains consistent with previous analyses.[30,32] These findings further support the concept that, while timely transport is important, a model solely focusing on limited interventions and rapid transport may not be optimal. Instead, just as the military has been aggressive at pushing blood products further forward, minimizing time to blood product transfusion in the prehospital phases of care may be a fruitful avenue toward minimizing preventable deaths due to hemorrhage. As such, the civilian sector should carefully evaluate the military's prehospital blood and lifesaving intervention protocols and identify ways to routinely incorporate these techniques into their standard practice.

PREHOSPITAL INTERVENTIONS AND SURGERY

For hemorrhaging patients, time to definitive surgical control remains paramount.[34,37,39,42,43] While the principles of damage-control resuscitation are critically important, noncompressible truncal hemorrhage frequently requires operative intervention. The current model used by EMS agencies within the United States aims to rapidly transport critically ill trauma patients to higher levels of care where surgical resources are present. Despite a widespread emphasis on maintaining "the golden hour," data suggest that EMS response times, prehospital time intervals, and trauma mortality remain largely unchanged, with at least half of hemorrhage related trauma deaths occurring in the prehospital space.[10,36,39,44]

Newer data suggest that the highest risk for mortality for hemorrhaging trauma patients occurs relatively soon following injury and often before arrival at the trauma center. Using the National Trauma Data Base, Alarhayem et al.[35] assessed patients with severe truncal hemorrhage and found that the median prehospital time was 37 minutes (40 minutes for blunt trauma and 28 minutes for penetrating trauma) with the most prominent risk for mortality within the first 30 minutes. Unpublished data from the National Emergency Medical Services Information System database between 2020 and 2023 suggest that 89% of US trauma patients with prehospital systolic blood pressures less than 90 mm Hg and heart rate greater than 108 beats per minute or systolic blood pressures less than 70 mm Hg had prehospital times greater than 20 minutes from the time of EMS arrival.

These prolonged prehospital times without access to blood and other lifesaving interventions suggest that many hemorrhaging patients may not have a chance for operative intervention during their highest-risk time periods. Decreasing the time to definitive hemorrhage control, which is estimated to take 2.1 hours from point of injury, remains paramount for successful outcomes.[33] As such, reevaluating the current civilian prehospital EMS model used within the US may provide an opportunity to impact mortality rates among the most critically ill trauma patients and mitigate potentially preventable prehospital deaths.[45]

Recognizing the sensitivity of time to intervention for combat casualties in hemorrhagic shock, the US military has addressed this issue. Through the use of forward surgical teams located in more austere settings than larger combat support hospitals, medical evacuation platforms have been able to rapidly access surgical care during recent conflicts. These strategically placed teams offer limited damage-control surgical capabilities with short-term holding capacity capable of bridging the gap to larger combat support hospitals, which act similarly to civilian Level 1 trauma centers. Combat casualties are transported to the closest surgical capability, whether it be a forward surgical team or combat support hospital. If evacuation occurs to the forward surgical team, they are transported to the combat support hospital following stabilization for ongoing evaluation and definitive surgery. This tiered system has allowed the military to push surgical elements further forward to minimize time to lifesaving interventions.

Although forward surgical teams offer the ability to provide lifesaving care, they are not rapidly mobile and are reliant on medical evacuation platforms to deliver patients. In contrast to this, select units within the US military have used small, highly mobile surgical teams consisted of an emergency medicine physician, a physician assistant, a surgeon, and a certified registered nurse anesthetist.[46] These small teams aim to provide timely prehospital surgical and resuscitation coverage as close as tactically feasible to the point of injury and bridge the gap between the unit-level medic and an established medical treatment facility, such as a forward surgical team or combat support hospital. Moreover, their unique ability to perform in-flight damage-control surgery during the medical evacuation process represents an unparalleled capability within military medical teams and evacuation platforms. Documented procedures performed by these teams include central venous access, prehospital blood product administration (blood components and whole blood), administration of intravenous anesthetics, emergency cricothyroidotomy, resuscitative thoracotomy, tube thoracostomy, cranial decompression, damage-control laparotomy, resuscitative endovascular balloon occlusion of the aorta, neck exploration, vascular shunting or repair, extremity amputation, and extremity fasciotomy.[46–48] Despite a paucity of published data secondary to security issues surrounding these teams, DuBose et al.[46] highlighted the success of these missions, reporting an impressive 97.1% survival rate for combat casualties who presented with signs of life.

Currently, we are unaware of any US civilian data that exist examining mobile trauma-trained surgical teams performing damage-control surgery in the prehospital environment. While data do exist suggesting improved outcomes with the incorporation of specialized physicians into prehospital teams, advanced resuscitation and surgical capabilities are not standard practice in the current US prehospital model.[49–51] Reports of in-field amputations as a "life over limb" treatment for entrapped patients are documented; however, this practice remains exceedingly rare.[52] One interesting model unique to the R. Adams Cowley Shock Trauma Center is the Shock Trauma "Go-Team," which uses a two-person prehospital team consisted of a physician trained in

anesthesiology, surgery, or critical care medicine and a certified registered nurse anesthetist, to augment EMS capabilities by providing advanced trauma interventions and specialized medications in the field. Although limited outcomes data exist surrounding the "Go-Team," Howie et al.[53] report an 82% hospital survival rate in their initial preliminary case series with prehospital interventions to include blood product transfusions, placement of tourniquets and pelvic binders, needle decompression, and cricothyroidotomy.

In contrast to the standard US prehospital model, European prehospital trauma care has adopted a "stay and play" model, in which physicians, traditionally nonsurgeons, engage in the prehospital arena to provide advanced resuscitative measures and lifesaving interventions similar to the small mobile military surgical teams described previously. Despite their similarity, no reports of civilian prehospital damage-control surgery are known, highlighting a key difference between the US military and European models. Moreover, specialized prehospital teams across Europe have documented success with complex interventions such as extracorporeal membrane oxygenation (ECMO) and resuscitative endovascular balloon occlusion of the aorta.[54–57]

The "stay and play" model has started to be introduced into US practice for select nontrauma conditions such as strokes and out-of-hospital cardiac arrest (OHCA), where time to intervention remains exceedingly important.[58–60] The University of Minnesota's mobile ECMO unit represents an example of this. Here, specialized teams embark on a custom ambulance in order to cannulate OHCA patients for ECMO in efforts to restore perfusion to vital organs prior to transport to a centralized ECMO-capable facility.[59] Restoring perfusion via ECMO has demonstrated promise with regard to mortality improvements with good neurologic status in OHCA, a scenario traditionally plagued with dismal outcomes.[56,61–65] By bringing physicians and specialized equipment to the patient, these teams provide an avenue to decrease time to intervention and mitigate the effects of ongoing ischemia.[59] These efforts highlight a novel approach for decreasing time to treatment and suggest that complex interventions should not necessarily be restricted to the confines of tertiary care centers.

Similarly, hemorrhaging trauma patients are at risk for poor outcomes because of ongoing ischemic insult from malperfusion and cardiovascular collapse prior to hospital arrival. Time to definitive surgical control represents one of the most critical potentially modifiable variables for hemorrhaging patients. Once time in the prehospital space has passed, it is impossible to get it back. Deploying advanced resuscitative and surgical capabilities to select patients, while rapidly transporting them to the trauma center, may offer an opportunity to minimize time to intervention and provide more stabilized patients on arrival to the trauma center. Just as the military has been able to incorporate these capabilities in contested environments, it remains plausible that similar opportunities for more advanced resuscitative interventions could benefit select civilian trauma patients in nonhostile environments.[66,67]

FUTURE CONSIDERATIONS

Trauma remains unique among most surgical specialties in that minutes, and even seconds, truly matter.[30,31,34,35] The one-dimensional idea that "the most important fluid in trauma is diesel" likely does not hold true for many patients, especially those in densely populated urban settings with congested traffic patterns or geographically distant rural environments. For many critically injured patients in hemorrhagic shock throughout the United States, the luxury of surviving the prehospital period cannot be guaranteed. In trying to achieve "zero preventable deaths after injury," a goal set forth by the National Academy of Science, Engineering, and Medicine in 2016, the civilian trauma sector must constantly reevaluate and challenge current trauma practices in efforts to improve.[68]

Bringing lifesaving interventions further forward in the spectrum of care will offer critically ill trauma patients a fighting chance for survival. While practices such as activation of massive transfusion protocols, damage-control resuscitation, and incorporation of prehospital blood transfusions have demonstrated incremental improvements in hemorrhage-related mortality, prehospital and overall mortality rates for trauma patients in hemorrhagic shock, by in large, remain consistently high, suggesting that alternative frameworks to our current practices should be assessed.[10,33,34,36,69–75] As such, a critical evaluation of the current prehospital EMS model may prove to be an ideal target. This is not to say that it should be outright abandoned, but rather challenged to see if we can improve the care of our patients.

Prehospital blood products, which are currently only being used by a small subset of EMS agencies (<5% of ground agencies), stabilize patients and could save thousands of lives every year.[11,27–29,76] The current barriers in place surrounding prehospital blood are not insurmountable, and policy level changes are being sought to break down these obstacles.[28,29,77] Just as bringing blood to patients minimizes delays in resuscitation, extending surgical (truncal hemorrhage control) capabilities into the field may help improve timely access to lifesaving interventions and decrease the number of prehospital hemorrhage-related deaths. While we recognize that this concept differs drastically from current practice, the benefits of having trauma-trained providers on scene to augment triage, guide resuscitation efforts, and perform lifesaving interventions would offer unique benefits not currently used in standard EMS practice. Moreover, having trauma-trained providers in the prehospital space may help better identify patients who would benefit from a "direct to operating room" approach where the emergency department is bypassed to decrease time to intervention.[78]

In practically, there would need to be a fine balance between the current model focusing on limited intervention with rapid transport and "stay and play." While the most critical of patients may benefit from bringing operative skills to the field, these efforts would not be necessary for a high percentage (>85%) of trauma patients. Dedicated thought on operationalizing this type of program would need to be heavily discussed, as this would require committed substantial financial and logistical assets. These would likely include a mobile operating room and detailed communication plans, along with an understanding that prehospital damage-control surgery may not be best for all patients and in fact could harm others. It remains crucial to have the understanding that just because one can do prehospital surgery does not mean they should.[45,79,80] In reality, the goal should be not to operate in the prehospital space, but rather be ready and trained if absolutely needed. Just as performing all procedures in the trauma bay is not as ideal as doing them in the operating room, damage-control procedures in the prehospital theater represents an even less optimized space and should be done out of absolute necessity, not convenience. Surgeons would need to have a nuanced understanding of not only the patient's underlying physiology but also in-depth

TABLE 1. Key Recommendations and Takeaways for Civilian Prehospital Trauma Care

Key Recommendations and Takeaways	
Recommendation	**Considerations/Limitations**
1. Blood products should be the resuscitation fluid of choice for prehospital hemorrhagic shock	– Funding and reimbursement patterns need to be established – Regional and state variations in EMS scope of practice – Improved coordination and sourcing with blood banks – Resource intensive
2. Prehospital trauma-trained teams should be evaluated as a potential option to reduce time to damage-control surgery	– Identification of target locations without proximity to trauma centers need to be established – Resource intensive – Ideal implementation processes need to be defined – Difficult to study
3. Increased access to lifesaving interventions should be prioritized at a national level	– Policy-level reforms required for nationwide equity

knowledge of their resource limitations and time constraints in order to optimize the potential for survival. Equally important, ongoing communicative efforts between the prehospital and in-hospital trauma teams may allow for a better understanding of the patient's physiology and injury patterns prior to arrival, ultimately leading to better opportunities for resource optimization. Until further research is conducted in this space, thoughtful considerations regarding the totality of these tactics and their implications are necessary.

It is important to note that the deployment of prehospital surgical teams may not be ideal for all trauma centers. Identification of regions high in violence without close proximity to trauma centers may represent ideal target areas for the deployment of prehospital trauma teams. Moreover, using certain emergency response criteria to deploy hospital-based teams in parallel with EMS providers to meet at prehospital rendezvous points for patient transport may provide an interesting implementation strategy for rural settings or regions with low incidences of major trauma. While this concept would certainly be a shift away from current prehospital care, it may allow prehospital patients in hemorrhagic shock to regain valuable time that would otherwise be lost. Implementing these approaches may have the potential to drastically decrease prehospital deaths secondary to hemorrhage; however, its downstream effects on in hospital care remain unknown, and implantation, resource allocation, patient selection, and operationalizing civilian prehospital trauma teams should not be hastily performed.

National policy-level reforms such as the National Trauma Emergency Preparedness System advocated by the American College of Surgeons Committee on Trauma, which largely falls outside the scope of this review, may offer the potential for vast improvements in trauma management at all levels, including EMS. Briefly, National Trauma Emergency Preparedness System seeks to promote nationwide equitable access to high-quality trauma care by offering resources, funding, planning for mass population events, training, injury prevention strategies, military-civilian integration, and process improvement to create a more unified approach to reduce death and disability in trauma patients. Although these national policy reform programs on trauma care are still being evaluated, it remains reasonable to believe that their impact could substantially change the scope of prehospital care.

LIMITATIONS

This review is not without its limitations. First and foremost, both military trauma systems and combat casualties inherently differ from civilian trauma systems and patients. While the focus of this review revolves around the possibility of bringing blood products and surgical capabilities further forward in the prehospital space, there remains limited prospective randomized controlled data supporting these concepts. Moreover, the military data supporting the use of prehospital surgical teams remain narrow in its scope because of operational security concerns. As such, detailed characteristics of patients treated, injury patterns, and factors surrounding the decision to operate in the prehospital space remain largely unknown. While this discussion focuses on prehospital blood transfusion and the potential for prehospital surgical interventions, optimal strategies for the ideal implementation need to be further studied prior to any widespread consideration. Currently, only one US prospective multicenter randomized controlled trial is underway assessing the use of prehospital whole blood in trauma patients (NCT04684719), and until this trial is complete, the potential benefits of prehospital whole blood should not be viewed as definitive in nature. Despite these limitations, we believe that the potential for pushing blood products and more advanced surgical skills further forward should be strongly considered as an avenue to reduce potentially preventable deaths in the prehospital space (Table 1).

CONCLUSION

Although the trauma system developed within the combat theater does not mirror that of the current civilian system, the underlying principles focusing of decreasing the time to lifesaving interventions is exactly the same. The medical lessons learned from the US military's recent involvement in conflict surrounding prehospital blood products and earlier access to surgical intervention could pave the way forward to decreasing prehospital mortality and improving the physiology of critically ill trauma patients. Just as many military physicians throughout the years have been forced to develop creative solutions to exceedingly hard problem sets, novel solutions in the civilian prehospital space should be sought. Leaning on the military's experience may provide more insight into these challenges, especially with the renewed focus on military-civilian partnerships across the United States.

AUTHORSHIP

D.L., R.H., R.B., J.D., J.M., M.E., and J.B.H. contributed to study design. D.L., R.H., R.B., and J.D. performed the literature search. D.L., R.H., R.B., J.D., J.M., M.E., and J.B.H. critically interpreted the statistical results. D.L.,

R.H., R.B., J.D., and J.M. drafted the original manuscript. D.L., R.H., R.B., J.D., J.M., M.E., and J.B.H. critically revised the manuscript.

DISCLOSURE

Conflict of Interest: Author Disclosure forms for the authors have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/E570).

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